NOMENCLATURE OF SURFACE FORMS ON FAULTED STRUCTURES¹

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GEOLOGICAL AND PHYSIOGRAPHICAL NOMENCLATURE OF FAULTS

The geological nomenclature of faults is chiefly concerned with a geometrical treatment of local problems of underground structures, and gives little or no consideration to surface forms. The physiographic nomenclature of faults is concerned almost wholly with large topo-

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graphical problems of surface forms as determined by the action of erosional processes on faulted structures. The terminology here suggested for surface forms of this class is closely related to a systematic method of physiographic description which may be called the method of "structure, process, and stage," in that it recognizes, first, the underground structure—often called the geological structure—of the mass which exhibits physiographic forms in its upper surface; second, the process or processes which have worked on the structural mass so as to modify its initial surface forms; and, third, the stage reached by the action of process on structure in producing the actual forms under consideration, in view of the whole series of stages from the initiation of erosional work by the uplift of the structural mass to the completion of erosional work by the reduction of the mass to a featureless plain. Relief, or local inequality of altitude, and texture, or spacing of stream-lines, are also given explicit attention in the fully developed application of this systematic scheme, but they will not be closely considered here. As the proposed terminology for surface forms on faulted structures is thus related to a comprehensive plan of treatment for all sorts of forms on all sorts of structures, the terms can not be well understood from definitions alone. Their meaning can be better gathered from the following statement of the manner in which they are used.

THE CYCLE OF EROSION

It appears from the foregoing that an important feature of the scheme of "structure, process, and stage" is the recognition of the systematic sequence of surface forms that must be developed during the progress of erosional work on structural masses. Various essential terms in the scheme are related to the sequence in which surface forms are produced, and the chief of these will now be concisely stated. The time required for the completion of the whole series of erosional changes, between the initiating uplift of a land-mass and its ultimate reduction to a featureless lowland or to a submarine platform, is called by American physiographers a cycle of erosion; and all the members of the systematic sequence of forms produced during the normal progress of a cycle of erosion may therefore be called sequential forms—the three terms, initial, sequential, and ultimate, so appropriately related to one another in this scheme, having been first introduced by Dr. F. P. Gulliver in his study of "Shore-line Topography" ('99).

It has become to be habitual with many physiographers to speak of the early, intermediate, and late members of such a sequence as young,

mature, and old; and to speak of the early, intermediate, and late stages of a cycle as its youth, maturity, and old age—two of these biological terms having been employed in this connection nearly thirty years ago by Chamberlin and Salisbury in their description of the “Driftless Area of the Upper Mississippi Valley” (’85, 229), although what was there described as “old age” is here called “maturity.” Evidently a cycle of erosion thus conceived is not a definite measure of time, but simply such a duration as suffices for the accomplishment of the task initiated by uplift; just as the cycle of life for an organic form is not a definite number of days or years, but simply a time sufficient for passing through all the stages of growth in a completed life. Similarly when a certain sequential form is described as young or mature or old, no definite measure of time or number of years is to be understood, but only such a part of the total duration of the cycle concerned as corresponds to its earlier, middle, or later development. A young Sequoia might be older than a mature man, and a mature man much older than an old mushroom, because the terms young, mature, and old, even when indicative of age, are always considered in relation to the normal length of life of the individual under consideration; or, as Kant put it over a hundred years ago: “Wenn man wissen will, ob ein Ding alt, ob es sehr alt, oder noch jung zu nennen ist, muss man nicht nach der Anzahl der Jahre schätzen, die es gedauert hat, sondern nach dem Verhältnis, dass diese zu derjenigen Zeit gehabt haben, die es dauern sollte” (Sämmtliche Werke, I, 1867, 189).

INTERRUPTIONS OF THE CYCLE OF EROSION

The progress of changes through a cycle of erosion may be interrupted at any stage, if the land-mass is displaced so as to take a new position with respect to the controlling baselevel of erosion; the land-mass may be regarded as thereupon entering a new cycle of erosion, the young forms of the newly introduced cycle for a time combining with and then gradually replacing the previously developed forms of the interrupted cycle. Besides the many complications introduced by crustal movements which, following the terminology here employed, may “interrupt” one cycle and “introduce” another, there are other disturbing complications produced by volcanic eruptions or by climatic changes, which do not necessarily involve any change in the attitude of a land-mass with respect to baselevel. It is my personal habit to speak of these disturbances as “accidents,” and to reserve the word “interruptions” for crustal movements by which a land-mass is given a new attitude. With accidents we here have nothing more to do. With interruptions, which include up-

lifts, depressions, warpings, foldings, and deformations of any kind, we are further concerned, because one kind of deformation embraces faults, which involve differential movements of the two parts of a severed mass. The development of a systematic terminology, consistent with the rest of the terminology of the method of "structure, process, and stage," for forms developed on faulted structures is the object of this paper.

RELATION OF FAULTS TO THE CYCLE OF EROSION

It is manifest from what is known of many well studied examples of faulted structures that a fault may take place in any direction and with any displacement in a structural mass of any kind, at any stage in its physiographic development, under the action of any kind or kinds of erosional processes on its surface. It is also clear that, just as the fault may have any relation to the underground structures that it traverses, so its surface expression in a fault scarp may traverse indifferently all other kinds of surface forms. Further, it follows that on account of the new positions given to the two parts of the faulted mass with respect to base-level, the surface action of the erosional processes must be more or less changed as a consequence of faulting. The cycle of erosion previously current should, therefore, in accordance with the scheme above stated, be regarded as "interrupted" and the further work of erosion be treated as belonging to a new cycle "introduced" by the faulting; but, unless the displacement of the fault be large, so strict an application of the scheme of the cycle is not necessary; small disturbances may be treated as mere episodes of a single cycle. Nevertheless, if a long succession of small faults occur, the sum of their movements must suffice to interrupt the preceding cycle and to introduce a new one, and the work that the erosional processes were previously performing will thus in time come to be seriously modified and an altogether new series of sculptured forms will result therefrom.

In view of the object of that section of modern physiographic study which is concerned with the description of land forms, it is evident that the terminology of surface forms developed on faulted structures must have especial reference to existing surface features that are actually visible. This is hardly more than a truism, yet it deserves conscious recognition and emphasis, because it often happens that in the attempt to give explanatory description to land forms the complications of the past processes involved in the explanation distract the attention of the reader from their visible product in the features of the present landscape and direct it to the past action of inferred processes on invisible

structures. This is a real difficulty, which at present seriously embarrasses many physiographic studies; but it is not an insuperable difficulty. One of the readiest means of lessening it is not to neglect it but to attack it—that is, consciously to direct our attention toward the existing surface product of past processes on underground structures—and thus avoid entanglement in the maze of the past processes themselves. Our effort should constantly be turned to telling what a district looks like, whether we tell about it in the empirical terms of an earlier century or in the explanatory terms now more in fashion. The reasons which have led many to follow the explanatory method I have sufficiently set forth in an address of a year ago (*a*, '12, 104-112).

AN IDEAL SERIES OF FORMS ON FAULTED STRUCTURES

Two methods of procedure toward our present object are in use. One consists in gathering the accounts of various actual forms on faulted structures, arranging them in some suitable sequence, and giving them, one after the other, explanatory description in some fitting terminology; these actual examples then serve as types for the description of new examples. Another method begins like the first one with a collection of actual examples, but it goes much farther; it establishes the general principles that are exemplified in the collected cases, and then deduces from these general principles a systematic series of purely ideal examples, and describes them in a correspondingly systematic series of explanatory terms. The second method is here adopted, but only its deductive part is presented in this essay. In passing, it may be pointed out that in the possibility of greatly increasing the number of deduced ideal examples over the number of observed examples, and in the full understanding that is gained regarding the ideal forms, inside and out, in their past, present, and future conditions, lies the great advantage of a deductively developed explanatory terminology. Evidently the description of a new example will be much facilitated if the observer has previously made acquaintance with a large number of thoroughly understood types; and no method yet employed provides so large an outfit of well conceived types as the deductive method here adopted. But it should not be forgotten that the deductive part of this method of establishing a terminology can not be properly undertaken until after an earlier inductive and analytical study of many actual examples has made it possible safely to establish the general principles from which the deduced ideal examples are drawn.

Let us therefore begin the present study at the beginning, or initial stage, of an imagined new cycle of erosion, which is introduced by the

strong faulting of a land mass of any structure that has already reached any stage of erosional development in a preceding cycle. Be it noted, however, that the "strong faulting" is not to be understood as accomplished all at once, but by a succession of small faults, each of which alone would be, as already indicated, merely an episode, although all taken together suffice to interrupt the cycle previously current and to introduce the new one. We then follow the sequential changes as far forward through the new cycle and through later cycles as is profitable, and give appropriate names to the more important forms that are associated with the fault at successive stages during successive cycles in the work of erosion on it.

As long as our discussion is presented only in verbal form, its general values, indicated in such phrases as "a land mass of any structure in any stage of development" may be preserved; as soon as a diagram is added to give graphic illustration of verbal meaning the discussion is in danger of losing much of its generality, for a single diagram can show a land form of only one structure and usually of only one stage. Nevertheless, such are the advantages of graphic illustration that diagrams can not be dispensed with; their dangers may perhaps be lessened by using series of composite diagrams, as in figures 1 and 2, the two series having different structures and each series showing a number of successive stages. Figure 3 shows only a single mature stage of a mountainous district of massive structure crossed by recent faults. The variety of faulted structures is evidently endless, yet a comparatively simple scheme of treatment may be adapted to all of them. Step-faults may be best treated by giving separate account of each of their members. Renewed faults may involve several successive interruptions of cycles of erosion instead of a single interruption. Hence all that need be done here is to develop a scheme of treatment for a few simple examples; the scheme may afterward be modified as needed for complex examples.

INITIAL AND YOUNG FORMS ON FAULTED STRUCTURES

Imagine, then, a surface of any kind—for example, a young lava plain, A, figure 1, or a district of subdued or old crystalline hills, A, figure 2, or a mature, mountainous mass of deformed strata, figure 3. Let the surface be traversed by a fault of moderate displacement, producing a low fault scarp, B. For simplicity of introductory discussion, let the lower part of the faulted mass remain for the present in its former attitude with respect to baselevel, so that erosion is revived only in the up-lifted part.

In the initial stage of the new cycle thus introduced the physiographic account of a fault should always begin with the description of the surface previous to faulting; then proceed with a statement of the aspect, direction, length, and altitude of the fault scarp (or "vertical separation" of the two parts of the prefaulting surface), with special mention of significant local details—for example, the manner in which ridges and hills are divided, valleys displaced, and streams ponded or accelerated, as well as of local complications in the scarp caused by the doubling or splitting of

FIGURES 1 AND 2.—The Sequence of Forms developed on faulted Structures

the fissure—or, in brief, the account should state *the prefaulting surface and the effects of faulting*.

This procedure is in accord with a general principle of prime importance in the explanatory description of land forms, namely, whenever a movement of a land mass enters into its description—as in the case of a regional uplift, a fault, or a coastal subsidence—the thing that suffered the movement must be described as well as the movement of the thing; otherwise the visible landscape as affected by the movement can not be conceived; and the prefaulting forms should be described, by those who adopt the method of "structure, process, and stage," in terms of these three factors—that is, its general structure should be stated, the proc-

esses that have worked on it should be announced (except that if it has been worked on only by the ordinary or "normal" process of weather and water this may be understood without explicit announcement), and the stage reached by the action of process on structure should be indicated. Although the principle here involved is simple in essence and of evident value, it is very commonly neglected. An explorer may say that a coastal district has suffered submergence, and yet fail to tell what the form of the district was before submergence; thus he leaves his readers in the dark instead of enlightening them as to the present coastal forms. Another explorer may say that a district is traversed by a recent fault, and yet fail to tell what the form of the district was before the fault took place; his readers are then left too little informed and are unable to conceive the landscape that the explorer has traversed.

FIGURE 3.—*Young Faults in a Mountainous District*

If the surface of the lower mass is plain and gently inclined toward the fault, the longitudinal depression thus produced may be called a fault trough; a stream consequent on the faulting will then soon erode a fault valley. But if the faulted surface is hilly or mountainous, as in figures 2 and 3, no continuous fault trough will be formed by the faulting, and the irregular relief along the scarp base will cause any streams that may flow for a short distance along the fault line to depart from it sooner or later and perhaps to leave it altogether.

If the surface of the uplifted block is of small relief and is inclined by the faulting, new consequent streams may be formed on it; but this can only be the case when the pre-faulting slopes are weak and the faulting is rapid enough to extinguish the preexisting streams. New consequent streams might be expected on the inclined surface of the upfaulted lava plain, figure 1 B, but not on the rolling or mountainous surface of figures 2 and 3. In these two cases any new slant given to the upfaulted masses will, instead of developing new consequent streams, merely favor the headward erosion of those whose slope is increased and discourage it

in the others, as Campbell has pointed out in his discussion of "Drainage Modifications and their Interpretation" ('96).

The face of an initial scarp is rapidly changed into a young consequent scarp by the loss of waste, which slips, creeps, and washes down to the scarp base, there accumulating in landslides, talus slopes, and alluvial fans, which bury the fault line. Even if a stream is initially formed along the fault line, as in special cases above indicated, it is liable soon to be pushed away by the abundant down-wash of waste from the scarp; hence if such a stream afterward cuts a valley, the valley is not likely to follow closely along the fault line.

If faulting is soon renewed, the scarp will be refreshed and its base kept close to the fault line, as in figures 1 C and 2 C, although its earlier exposed upper slope will have retreated somewhat from its initial position. The details shown in figure 1 C are highly suggestive of a second uplift, which took place some time after the first, for here the face of the covering lava sheet is worn back to a slope, while the face of the underlying weaker strata is steep. During the retreat of a scarp it must take on details of form appropriate to its structure. Details of this kind may be called subconsequent if they do not depart greatly from the pattern of the initial scarp, or subsequent if they include altogether new features developed by the action of erosion on inclined structures of strongly different resistance. These details are, however, not limited to retreating fault scarps; they would be equally well developed on the two retreating walls of a young river-cut valley.

THE ESSENTIAL PRINCIPLE IN THE PHYSIOGRAPHIC DESCRIPTION OF FAULTS

It thus appears that a physiographic description of a fault in an early stage of the cycle that it has introduced should include an account of the pre-faulting surface and of the fault scarp, as before stated, and to these two headings a third should now be added, under which the features developed after faulting—that is, the youthful features of the new cycle—are described in their systematic modification of the pre-faulting features. Here again we find application of the same general principle of explanatory description that was mentioned above, but now extended so as to include three terms, namely, the post-movement features as well as the pre-movement features and those directly due to the movement itself.

Simple as this extension of the principle is and manifest as is its value, it is repeatedly overlooked. The explorer who describes a coastal district as having suffered submergence too commonly fails to tell what changes

have taken place since and on account of submergence, just as he fails to describe the landscape that existed before submergence; yet it is nearly always the case that along a certain line of the pre-submergence forms—namely, the new shoreline—certain post-submergence features in the form of bayhead deltas and headland cliffs have been more or less developed. Likewise, the explorer who describes a district as traversed by a fault usually fails to make explicit statement of the changes that have taken place since and on account of faulting, as well as of the prefaulting forms, in which the post-faulting changes have occurred. The establishment of some systematic method for the explanatory description of land forms will go far toward correcting these omissions; in my own experience the method of “structure, process, and stage,” here outlined in its relation to forms developed on faulted structures as well as on other structures, has repeatedly proved helpful in field work, and it is therefore the more confidently recommended to others.

EXAMPLES OF INITIAL AND YOUNG FAULT SCARPS

Various reports of the United States Geological Survey on the Great Basin province furnish us with the best described examples of initial and young fault scarps in this country, the initial scarps being in most or all cases the result of renewed movement on earlier faults. Several striking cases of earlier faults are described by Russell ('84) in southern Oregon, where the prefaulting mass was a broad plain of lava flows resting unconformably on a floor of more or less eroded crystalline rocks, and where a series of north-south faults has broken the mass into long blocks which have suffered strong differential displacement, the upraised block-edges being now more or less carved into mountainous ridges, while the relatively depressed areas are buried under plains of alluvium. Some of the scarps are “slightly scarred by erosion;” others are elaborately carved. The fault along the eastern base of one of the largest mountain blocks is about 100 miles in length, “with a displacement where the mountains are highest of not less than 5,000 or 6,000 feet;” and at one point “there has been a very recent movement along the old fault. The irregular scarp in alluvium formed by the recent displacement is fresh and unclothed with vegetation, and may be traced for several miles at the immediate base of the mountains, defining the boundary between swampy meadows [on the east] and solid rock [on the west]. The hade of the recent fault is to the eastward at a high angle, while the throw, as shown by the fresh scarp, is from 20 to 50 feet” (445). Another line of displacement “is marked by numerous hot springs and by

fresh fault scarps, from 20 to 50 feet high, that cross alluvial cones and cut embankments and terraces" (449). Some of the greater fault scarps, "forming the mountain faces, are in many instances nearly vertical walls, hundreds of feet in height, of such recent date that they have scarcely been notched by erosion, and have but small, if any, alluvial cones at their bases" (436). No details are given as to the special forms developed in the more elaborately dissected scarps. One of my own papers refers to part of the same district (*b*, '03, 164-). Koto ('93) has described and figured an extraordinary scarp in Japan produced by the earthquake of 1891. Tarr and Martin ('06) have done the same for scarps in Alaska produced by the earthquake of 1899.

MATURE FORMS ON FAULTED STRUCTURES

In the cases here figured the early post-faulting changes are, in figure 1 D, chiefly the retreat of the scarp by weathering and the incipient dissection of its face by short, wet-weather streams consequent on the faulting; or, in figure 2 D, by the much more rapid incision of the scarp face by the uplifted streams that flow down from it; in both these cases the burial of the scarp base under alluvium; or, in a later stage of figure 3, the concealment of parts of the scarp in the alluvial deposits of small lakes ponded by the rise of the uplifted mass across the valleys of pre-existent streams that flow toward the uplift. The later or mature post-faulting changes will include the further retreat of the scarp, and with this the development of various details in the scarp face by the subconsequent or subsequent modification of its initial form, as already mentioned; also the deeper incision of valleys in the uplifted mass either by new consequent streams or by revived pre-existent streams; but be it noted that the young or submature valleys here referred to must always be described as modifying the pre-faulting surface in which they are incised, as long as the remnants of the earlier surface constitute a significant part of the landscape. The pre-faulting surface must be explicitly included in the description of the faulted district as long as there are any manifest signs of it.

It is evident that as long as waste is abundantly washed down from the uplifted mass no continuous stream and valley are to be expected along the fault line, even in the more advanced stages of the new cycle, unless highly specialized initial conditions have favored their development; and as such specialized conditions must be rare, the occurrence of consequent streams and valleys along fault lines in a youthful or mature stage of the cycle introduced by the faulting must also be rare. Hence,

when a stream valley is found to follow a fault line, it probably has some other than a consequent origin.

In examples of faults of moderate slip that traverse uniform or massive structures at such a stage of the pre-faulting cycle as permits medium or strong relief, the post-faulting erosion may obliterate the fault scarp long before the relief is subdued or reduced to small measure; but where rocks of different kinds are brought together, the fault will long be marked by a change of form following the fault line long after the pre-faulting surface is worn away. If this change of form is a slope, more or less perfectly graded, descending to the relatively depressed side, it may be called a resequent scarp; if it descends toward the relatively uplifted side, as must be the case when weaker rocks occur on that side, it may be called an obsequent scarp, these terms being further explained below. If the fault has produced a belt of breccia, it may be followed by a subsequent ravine, which will often have a peculiar appearance from pitching obliquely down the slope that it dissects; this topic also will be further discussed below.

PHYSIOGRAPHIC EVIDENCE OF FAULTING

Let a special case now be considered, in which the lower side of a faulted mass suffers depression, while the upper mass suffers elevation. As a result the waste washed down from the uplifted mass will tend to accumulate heavily on the depressed mass; at first only near the base of the fault scarp; later on, advancing farther and farther from it and, if the relief of the depressed block be small, burying its surface more and more completely. In such cases the evidence of faulting will not be found in the relative displacement of corresponding structures on the two sides of the fault line, for all outcrops on the lower side will be buried, possibly for miles away. The existence of the fault at this early stage is inferred simply from the form of the scarp by geologists and geographers alike. As long as the scarp which limits the higher mass is strong and little dissected, the existence of a fault would probably be accepted on this evidence by geologists as well as by physiographers; but as dissection progresses and the continuity of the scarp is more maturely interrupted, the evidence of faulting is less immediately apparent; the occurrence of a fault may indeed then be doubted by geologists who give little attention to the evidence presented by land forms and who depend instead wholly on displaced structures; hence the physiographic features which demonstrate faulting in a dissected fault scarp that rises from a waste-covered lowland deserve special attention.

The incision of the initial scarp by ravines, which increase in depth as the scarp is increased in altitude by repeated faulting, will in time destroy its continuity, and when the total uplift has reached a thousand feet or more nearly all the face of the scarp will have been consumed between the slanting ravine walls; but so long as recent renewal of faulting holds the base of the scarp close to the fault line, the spurs into which the greater part of the scarp has been transformed must terminate in triangular facets. The slanting surface of the facets, not much worn back from the fault surface, must truncate the structure of the uplifted mass in such a way that the bases of all the facets stand along a single simple line.

As long as such facets are well defined, there need be no doubt about their marking a fault, even if no rock outcrops are seen on its lower side. The chain of evidence in such a case is indeed of the essentially same nature as that on which geologists usually rely for the demonstration of faulting, although composed of different links. The usual geological evidence of faulting is the occurrence of corresponding structures in discordant attitudes on the two sides of a line; the fault fracture is seldom seen, unless revealed by mining, and the movement implied in the term fault is never seen. In view of such an occurrence, a geologist would say: "Those two corresponding structures can not have been made independently; they must be two parts of an originally single mass, now fractured and displaced by a fault." And this inference of fracturing and displacement in the unobservable past is commonly spoken of in geological circles as if it possessed the same order of verity as the directly observable occurrence of the two discontinuous structures—that is, it is commonly treated as a "fact."

The physiographic evidence of faulting in the case here considered is the occurrence of a highly specialized group of forms, namely, the terminal facets of a series of spurs, peculiarly related to each other and to the structures that they truncate. In view of such an occurrence, a physiographer would say: "Those facets can not be the original termination of the structures that they now truncate; the action of the sea being excluded, no process of erosion can have worn back a former greater extension of the structural mass to so systematic a termination in triangular facets along a simple, non-structural line; hence the visible mass must be part of an originally greater mass, the other part of which has been relatively faulted down out of sight." This inference of fracturing and displacement is not today universally spoken of in geological circles as if it possessed a high degree of verity; but there was once a time

when even the orthodox geological evidence of faulting, based on displacement of corresponding structures, also failed to command general acceptance among geologists.

After faulting ceases the terminal facets of fault-scarp spurs will lose their sharpness of form; their edges will be rounded off, their faces will be worn back from the fault line, and although they may still for a time be arranged along a comparatively simple line indifferent to the structure, the unequal retreat of spurs of different resistance must eventually bring about an increasing irregularity in their ending. If the lowland forward from the irregularly retreating spurs is then still covered with transported waste, as frequently happens, the evidence of the fault will weaken, just as the usual geological evidence of a fault weakens when the outcrops by which it is ordinarily proved are covered by transported waste. But in either case, if the transported waste is removed and the rocks or their local soils are revealed, the evidence of faulting becomes manifest by the difference of soils on the two sides of a simple line, as in the cases already stated above.

EXAMPLES OF MATURELY DISSECTED FAULT SCARPS

The western face of the Wasatch range in Utah and the eastern face of the Sierra Nevada in California are regarded by various observers as fault scarps of great dimensions, more or less elaborately dissected. The latter example is largely composed of massive crystallines and, as far as it has been described, does not seem to present subsequent details due to erosion guided by exposed structures; the former example is largely composed of disordered stratified formations and is marked throughout by an abundance of subsequent details. Gilbert ('90, 340-) has briefly described the main scarp of the Wasatch, but has given more attention to the signs of recently renewed faulting along the scarp base. Huntington and Goldthwait ('04, 230) have studied the southern part of the Wasatch scarp; and in my own papers are some details regarding its middle part, which near Provo exhibit some well preserved terminal spur facets (*b*, '03, 152), and near Nephi some striking subsequent features oblique to the trend of the scarp ('05, 21); also some account of more maturely dissected scarps along the western sides of the Canyon and House ranges ('05, 29-, 46-). Diller has presented short statements regarding the repeated scarps of the northern Sierra Nevada ('86, 12), and Russell ('89, 279) regarding the great single scarp farther south, in the neighborhood of Mono lake. More recently Reid ('11, 114) has described strong scarps in the Lake Tahoe district. Lawson ('12) adds

details regarding fault facets and recent scarps in the same neighborhood. Louderback ('04,) has given a valuable account of the Humboldt Lake mountains, and Baker ('12, 130) has lately added a study of El Paso range, both of these being members of the Great Basin system and both possessing dissected fault scarps on one side.

McGee ('89, 616) some years ago described the submaturely dissected scarp along the inner border of the Atlantic coastal plain in Maryland. Twenhofel ('12, 20) has lately described a strong scarp on the north-western border of Newfoundland as due to faulting followed by a moderate amount of erosion; but his account does not exclude the explanation of this feature as a resequent fault-line scarp, here set forth in a later paragraph.

The broad valley, or graben, of the middle Rhine is inclosed by maturely dissected scarps. The one on the east, forming the western face of the Odenwald and Schwarzwald, is comparatively simple; the western side of the graben, where it forms the eastern slope of the Vosges, is a compound scarp, in the sense of being determined by several subparallel step faults. The southeastern scarp of the Erzgebirge is of similar origin. The physiographic description of these dissected scarps has not been carried so far as the study of their geological structure. A maturely dissected fault scarp, with a young scarp at its base, forms the eastern slope of the Lepini mountains south of Rome and is described in one of my own papers (1900). A number of submaturely or maturely dissected fault scarps are described by Süssmilch ('10? 344) as limiting the plateau blocks in the southern tableland of New South Wales. Bell ('09) and Cotton ('12, 309) describe a dissected fault scarp, with well defined terminal spur facets along the northwest side of Wellington harbor, New Zealand.

Nearly all these accounts of dissected fault scarps are wanting in details as to visible forms; hence if a scheme for the treatment of forms developed on faulted structures were based inductively on descriptions of actual examples now accessible in geographical and geological articles, it would be far from complete. On the other hand, the details as to dissected fault scarp forms already in hand suffice to warrant the establishment of certain general principles from which various consequences may be deduced, as above set forth; and an observer who has these expectable consequences in mind will be prepared to look keenly at the actual features of a faulted district, and to make explicit mention of their significant details in terms suggested by the deductive scheme that he has adopted. It need hardly be said that the scheme must never be allowed

to become rigid and controlling; it is simply a means to an end and must be modified and enlarged as experience demands.

OBSEQUENT RAVINE HEADS

In the special cases of small pre-faulting relief and a tilting of the uplifted block surface away from the fault, the initial crest of the fault scarp will form a new initial divide, as in figure 1 B, between the short, steep face of the scarp and the longer back slope of the tilted block, except where antecedent streams maintain their courses across the fault line. But the divide must soon shift away from its initial position by reason of the weathering and retreat of the fault face; the initial divide thus becomes a consequent divide, figure 1 C. The rapid headward erosion of a ravine in a retreating consequent scarp face of this kind will lengthen the ravine stream and correspondingly shorten the opposing back-slope stream; hence the headward part of such a retrogressive ravine, figure 1 D, is then of obsequent origin. Whether any observer cares to go as far as this in applying an explanatory terminology to forms thus developed is not known; but ravines of the kind here indicated are described in Abyssinia by Rathjens ('11, 71).

SUBSEQUENT FAULT-LINE VALLEYS

If an example be now considered in which regional uplift accompanies faulting, then the whole surface may be more deeply dissected by its streams and more worn down by weathering and washing than was possible in the cases thus far considered. In such an example the alluvium that at first tends to accumulate rapidly along the scarp base will be removed as the scarp slowly retreats, and the fault line may then be more easily traced, at least by difference of soils even if there is no difference of form. If the rocks on the two sides of the fault line are of similar resistance and the fault is a smooth and simple fissure, no valley need be developed along it even when it is thus laid bare by the removal of the alluvium that for a time covered it; but under other conditions two new features may be developed as follows:

First, let it be supposed that the fault is a complex fissure, along which the rocks are sheared and shattered; then a number of subsequent valleys will be gradually excavated along the sheared zone by the headward erosion of subsequent branches of transverse streams; in time an almost continuous depression may thus come to follow the fault line, and much of its length may by capture come to be drained by the subsequent branches of a few large transverse streams. These valleys are not due to

the faulting, and hence should not be called fault valleys; they are the work of headward erosion along the weak structures of the fault line, and hence should be called subsequent fault-line valleys.

Second, let it be supposed that the rocks that are brought together at the base of the fault scarp are of strikingly different resistance, and let those in the uplifted mass be the weaker, as might be the case in figure 1, if we suppose that the lava sheet which there formed the pre-faulting surface lies on weak horizontal strata, such as the sands or clays of a coastal plain or of an aggraded interior basin. As the fault scarp retreats, the weak strata beneath the capping lava sheet will be exposed along a belt, figure 1 E, between the fault-line boundary of the lava sheet in the less uplifted mass and the base of the talus below the retreating lava cliff in the more uplifted mass; a broad subsequent valley will be rapidly excavated along this belt in the manner above indicated for subsequent fault-line valleys. In all such cases the height of the retreating consequent scarp above the valley on the uplifted side will be now measured by the height of the fault *plus* the depth of the valley; and the lower scarp opposite to it, retreating slowly in figure 1 E because the weak strata are little or not at all exposed beneath the lava, will face the uplifted block. Thus two conditions, neither one very complicated, are deduced which must lead to the development of valleys along fault lines; but the valleys are in both cases not consequent but subsequent valleys.

OBSEQUENT FAULT-LINE SCARPS

In figure 1, after the retreat of the heightened consequent fault scarp in the uplifted block, accelerated by the sapping of the weak basal strata, has gone so far as to transform the subsequent fault-line valley into a wide-open lowland, the features of old age are soon locally developed because of the weakness of the rocks on which the erosive processes there work; the other scarp in the lower-lying block may still lie close to the fault line because its retreat is slow. As this scarp is produced by erosion along the fault line and not by the original faulting, and as it has an aspect opposite to that of the initial fault scarp, it may be called an obsequent fault-line scarp. Other examples showing variations on this type will be further considered below.

OLD FORMS ON FAULTED STRUCTURES

In the later stages of a cycle introduced by a fault all the forms of relief will be subdued to mild expression, and eventually an old lowland of erosion—a peneplain or plain, figures 1 F and 2 F—will stretch across

the whole district. If subsequent streams were developed along the fault line in the maturity of the cycle, they may now wander away from it in unrestrained meanders. The fault will then have lost all its topographic value, though it may still be visible in a difference of soils on its two sides. Hence the scarp of a physiographically "old" fault has not only retreated from the fault line, but has been topographically obliterated; yet the fault, geologically considered, still remains unchanged. Its slip, strike, hade, and other elements are not altered, although its physiographic expression has passed from its initial stage through all its sequential stages in the cycle of erosion introduced by the faulting to its ultimate disappearance. Evidently, then, the physiographic treatment of faults must be very different from their geological treatment.

During all the late stages of the cycle, after the pre-faulting forms have been destroyed, there is no longer any need or indeed any possibility of saying anything about them; they have vanished. Nor is the slip of the fault or the height of the initial scarp at this time of physiographic importance. Here and there some gentle fault-line slopes, maintained on resistant rocks, bordering or inclosing a broadly opened fault-line depression, may survive; but eventually only the location and direction of the fault line as a limit between unlike soils need be noted in a physiographic description.

Here we find a further application of the general principles of physiographic description, to which attention has already been drawn. At the beginning of a cycle introduced by faulting, the pre-faulting forms and the fault forms must be described; in the early and mature stages of the cycle the post-faulting forms must be added; now, in the late stages of the cycle, the two first elements may be passed in silence, for nothing is known of them; the post-faulting forms everywhere prevail and these alone need mention. The fault is topographically obliterated, and is of value physiographically only in delimiting different soil areas, yet it is geologically of the same value as when it was first produced.

TRANSVERSE FAULTS IN MONOCLINAL STRUCTURES

A case of special interest is furnished by monoclinical structures of alternating strong and weak strata, which before faulting have been reduced to rather small relief, so as to present a series of low, rectilinear, subsequent ridges and valleys. Assume that the monoclinical dip is 20° to the northwest, and that the district is then broken by a transverse fault, with vertical uplift on the northeast, as in figure 4 A. The initial position of the ridges and valleys in the uplifted block will be changed only in alti-

tude, but not in latitude or longitude. The linear continuity of the ridges and valleys will not at first be affected in plan; but as the new cycle advances, the ridges and valleys in the uplifted block will be shifted down the dip of their determining strata (except that under special conditions of small dip and moderate contrast of resistance a strong subsequent stream may cut down its new valley vertically, and thus come to be structurally superposed in a resistant stratum), and near the close of the cycle all the members on one side of the fault line will be laterally displaced, or "offset," from their fellows on the other side, as in figure 4 B, thus giving the effect of a fault of horizontal slip. Sometimes the offset may bring the halves of different ridges together; the fault line

FIGURE 4.—*Transverse Faults in a monoclinal Structure*

between them may then be marked by a mere notch or by a transverse valley. More frequently the offset will result in a haphazard opposition of a longitudinal valley to a truncated ridge. Special features will be determined by the angle between the strike of the monocline and of the fault line, which I have elsewhere treated ('89, '98).

SECOND-CYCLE FORMS ON FAULTED STRUCTURES

Now suppose another cycle of erosion to be introduced by a broad uplift of the whole region without renewal of faulting. This may happen at any stage of the interrupted cycle, but we will here consider only interruptions that occur near the end of the cycle that they interrupt. The streams of the region will be revived by the new uplift. The shattered rocks of any shear zone and the areas where weak rocks are exposed will waste away rapidly and will soon be reduced to new valleys and lowlands; the harder parts of the broadly uplifted area will for a time retain nearly the altitude of uplift except where cut down by streams. In other

words, the weak parts grow old rapidly, while the resistant parts pass through their cycle of development slowly; hence in a carefully stated description terms indicative of age must be separately applied to areas of different resistance. This is the converse of another principle, namely, that strong agents of erosion, like large rivers and strong sea waves, run through their cycle of form development rapidly, while weak agents, like weathering, advance slowly; hence the valleys of large rivers will reach late maturity or old age while the surface of neighboring interfluves are still young or submature.

If it happens that the rocks on one side of the fault are resistant and on the other side weak, a scarp will be developed along the fault line on the side where the resistant rocks retain young or submature forms, and this scarp will face the worn-down area, where the weak rocks are already subdued or old. The aspect of such a scarp is evidently independent of whether the resistant rocks are in the block of relative uplift or depression. If the newly developed scarp faces the originally uplifted mass, as in figure 1 G, it may be called an obsequent fault-line scarp, as already defined; if it faces the originally depressed mass it may be called a resequent fault-line scarp, because it again faces in the direction of the original scarp. Both kinds of fault-line scarps are drawn in figure 2 G. In the case of a faulted monocline, as drawn in figure 4 B, obsequent and resequent ridge-end scarps will alternate, right and left, along the fault line.

The distinction between fault scarps and fault-line scarps, in the manner here proposed, is not simply an academic question of systematic nomenclature. If a fault-line scarp is taken for a fault scarp, various erroneous inferences will follow; for example, the date of faulting will in such a case be inferred to be only long enough ago to permit the observed dissection of the scarp; while if properly interpreted the date of faulting would be at any period prior to the erosion of the preceding cycle, and hence possibly much more ancient than at first supposed. Further, the height of a young or submature fault scarp is a fair measure of the faulting, while the height of a fault-line scarp has no close relation to the faulting; it is dependent simply on the depth to which renewed erosion has brought about a different altitude on the two sides of the fault line; hence if a fault-line scarp is mistaken for a fault scarp, the height of the scarp may be mistaken for the vertical separation produced by faulting, thus giving incorrect measure of the original separation. In an early stage of the new cycle the fault-line scarp will be highest near the incised valleys of transverse streams, and it may remain for a time undeveloped on the interfluves; a variation of scarp height thus

systematically connected with surface streams must evidently be due to stream action and not to the original movement of the fault. Further, it should be noted that in an advanced stage of second-cycle erosion on a mass of complicated structure, newly developed fault-line scarps must be discontinuously developed, according to the opportunity that the weaker structures offer; they must always rise on the side of the more resistant rocks and overlook the area of weaker rocks; they must therefore here be of resequent, there of obsequent aspect, as in the cases of figures 2 G and 4 B, above referred to. Evidently so systematic a relation of scarp aspect to rock resistance must be the result of erosion, not of faulting; hence if a fault-line scarp were mistaken for a fault scarp, the uplift might be thought to be on the wrong side of the fault line.

In a second cycle, fault-line valleys will be developed by the action either of revived consequent streams or of subsequent streams working along the shattered zone of a fault bordered on both sides by rocks of significant resistance. Thus we see once more that, as far as valleys following fault lines are concerned, they may be developed either by revived or by new subsequent streams in a second cycle, succeeding any advanced stage of the cycle introduced by faulting. If the rare occurrence of consequent fault valleys as above set forth is now recalled, it will appear that most valleys associated with faults are likely to be of subsequent origin. They are not due directly to faulting alone, but to erosion working on a faulted structure. They are not initiated by the faulting movement, but first take the form of valleys long after the faulting has ceased. Hence they should be called by some special name, such as fault-line valleys, as here suggested, and the term fault valleys should be limited to valleys produced by erosion closely consequent on faulting.

Fault-line scarps in the early stages of a second cycle following an advanced stage of a previous cycle, and traversing a district of gently inclined strong and weak strata, will be associated with a peculiar and significant arrangement of ridges or of *cuestas* that deserves special mention. The advanced erosion of the first cycle will have resulted in producing offsets in corresponding ridges or *cuestas*, so that their ends will abut against the fault line some distance apart, as in figure 4 B. If old age be reached, the soil belts will be offset along the fault line. When renewed erosion of the weaker strata in the second cycle, introduced by uplift without renewed faulting, develops discontinuous fault-line scarps close along the fault line, their small retreat might be taken—especially by observers who are not critical in distinguishing fault-line scarps from fault scarps—to mean that the fault is of recent date; but the strong off-

sets of the corresponding ridges or *cuestas* will contradict this view and prove that the scarps are due to erosion after renewed uplift of a faulted and previously worn-down structure, and not directly to faulting. If the scarps were due to recent faulting, the corresponding *cuestas* ought still to stand nearly opposite each other on the two sides of the fault line. But this interpretation of the case has a geological flavor, in that it turns the attention chiefly to a succession of past events. A more geographical interpretation is reached when the mere mention of scarps in such a structure as fault-line scarps, either *resequent* or *obsequent*, at once awakens attention to the probable strong offset of corresponding reliefs on the opposite sides of the fault line.

As long as any significant traces of the forms developed in a first cycle are not obliterated by the erosion of a second cycle, they deserve explicit description in a physiographic discussion, following the general principle above stated; and their description should introduce, in any fitting order, a sufficient account of the faulted structure on which the forms of the previous cycle were developed, the processes that developed them, and the stage of development that they had reached when further progress was interrupted by uplift; then the effect or amount of the uplift should be stated, and finally the forms developed in the new cycle should be introduced in their proper relation to the surviving forms of the previous cycle. The omission of any one of these factors will leave the reader in doubt as to what the writer has seen.

With the advance of the new cycle even the hard-rock uplands will in time be maturely dissected, then subdued, and at last worn down to small relief in advancing old age; with these changes the newly developed scarps will retreat and take on details of form according to the structures revealed in them, after the fashion of retreating escarpments of whatever origin; thus the fault will again be topographically obliterated in the resulting lowland. The forms of earlier cycle thus lose their importance and do not need mention after the maturity of the new cycle. Eventually the uplands, hills, and scarps must all fade away, and a widespread lowland, figures 1 H and 2 H, will stretch across the region. Then or at any earlier stage uplift without faulting may again occur and the systematic series of changes will be begun over again; yet during all these physiographic transformations the fault is, geologically speaking, a constant quantity. Or renewed faulting and differential uplift may take place along the former fault line, and thus introduce more complex problems. Examples of this kind have been described by Huntington and Goldthwait ('04, 225) and by D. W. Johnson ('09, 154).

Most faulted structures are today probably in a later cycle of erosion than the one introduced by the faulting. Hence although the space here devoted to the forms developed in later cycles is less than that given to the forms of the cycle introduced by faulting, the use of the terms chiefly associated with later cycles, such as obsequent and resequent fault-line scarps and subsequent fault-line valleys, ought probably to be more frequent than that of terms associated with the cycle of faulting, such as fault valleys, consequent scarps, and so on.

EXAMPLES OF SECOND-CYCLE FORMS ON FAULTED STRUCTURES

An admirable example of a submaturely dissected resequent fault scarp is found where westward ascent is made from the broad plains of the Limagne to the crystalline highlands of Auvergne in central France. The scarp might well be taken, at first sight, to be consequent on faulting; but a study of the lava-flows that cross it and their relation to the lacustrine strata that once filled the Limagne graben will prove its resequent origin. An equally good example is found in the western part of the same crystalline highland, known as the Limousin, where it suddenly descends southwestward into the basin of Brives, that has been excavated on weak strata which were brought down against the crystallines by strong faulting, as described by Demangeon ('10). A third example, this time of a maturely dissected obsequent scarp, is found in the ascent on the northeast side of the excavated subsequent depression in northwest France, known as the Pays de Bray, of which the geological history has been studied out by Lapparent ('79, 113-). The renewed erosion in the second and third of these examples followed a late stage of an earlier cycle at the beginning of or before which the faulting took place.

A remarkable group of escarpments following a series of east-west faults occurs in central Sweden and is finely represented on the 1:100,000 map of that country, sheets 55, 56, 65, 66, 73, 74. These escarpments have been regarded as what are here called submature consequent fault scarps by Gunnar Anderson ('03, 27-49) and S. De Geer ('10, 34), but are to my view ('12, 169) better explained as submature resequent fault-line scarps developed in a second cycle, following the old age of a previous cycle; many subsequent fault-line valleys are associated with them. On the other hand, Brögger ('86) has described some mature scarps in the Christiania district which face the uplifted side of their fault-lines and which would therefore here be called obsequent. They are probably due to erosion in a later cycle of erosion than the one introduced by faulting.

In Scotland the abrupt southward descent from the crystalline highlands to the worn-down stratified rocks of the central lowlands is made by what seems to be a maturely dissected and strongly glaciated resequent fault-line scarp, developed in a second cycle by renewed erosion on a previously faulted and subdued mass. The long scarp on the northwest side of Newfoundland, above mentioned as thought by Twenhofel to be a fault-scarp, is possibly—or probably—a fault-line scarp.

Several submature resequent fault-line scarps with eastward aspect are crossed by the Mohawk valley in eastern New York, and have received general study from Darton ('95). The scarp at Little Falls has been described in detail by Cushing ('05, 71-); others of diverse aspect farther east near Saratoga by Miller ('11, 38-). A long and strong resequent scarp, with southeastward aspect, forms the border of the crystalline highlands toward the red sandstone lowlands in northern New Jersey; it is described by Kümmel ('98, 110) as a geological boundary rather than as a topographical feature. The eastern border of the Connecticut valley lowlands in Connecticut and Massachusetts is a west-facing scarp of the same nature, but more irregular in plan; it was worked out by Griswold and is described in my report on the Triassic formation of that district ('98, 122); the trap ridges of the same lowland in Connecticut are repeatedly terminated by oblique resequent or obsequent fault-line scarps, often too young to have their slopes completely graded, while in the already old, worn-down areas of weak sandstones the same faults are nearly or wholly obliterated ('89, 68; '98, 89). A remarkably good example of a maturely dissected obsequent scarp, now worn a mile or more back from its fault line, runs transverse to the dominating structural trends across the boundary between the Appalachian ridges and the Cumberland plateau in northern Tennessee; it is well represented on the Briceville folio of the United States Geological Survey. Several other obsequent fault-line scarps have lately been described by Paige for central Texas in the Llano-Burnet folio. Subsequent fault-line valleys and obliterated fault scarps are repeatedly illustrated in the Appalachians of Virginia and Tennessee.

The Hurricane ledge in the plateaus of northern Arizona north of the Colorado canyon is an exceptionally fine young, west-facing resequent fault-line scarp; it was described as a young fault scarp by Dutton ('85, 112-), but its resequent nature seems to be well established by a lava flow that I found in 1902 to lie across the line of the obliterated scarp of first faulting, protecting a local area of weak clays which have elsewhere been worn away on the west of the fault line, leaving the resistant limestones in bold relief on the east side (*a*, '03, 26-; '12, 171).

A neighboring fault, studied by D. W. Johnson ('09, 148) and myself ('01, 142), was found to be topographically obliterated for much of its length, but it appears locally in obsequent and resequent scarps transversely truncating several cuesta-like benches in the northward ascent from the Arizona plateaus to the High plateaus of Utah.

There can be little question that the recognition of the possible origin of scarps along fault lines by erosion (fault-line scarps) as well as of scarps by faulting (fault scarps) aids the determination of the class to which a scarp belongs. The possession of an elaborated mental equipment, including a good variety of type forms associated with faulted structures, facilitates the detection of corresponding actual forms in the field. The cases here considered, therefore, have a practical value as part of the mental outfit of every observant student of land forms.

AN IMAGINARY EXAMPLE

It is probably because of the unchanging constancy of the geological elements of a fault that many descriptions of faulted districts made by geological explorers are physiographically so unsatisfying. Indeed, one sometimes reads even in geographical journals and under headings that indicate the intention of the writer, whether he be a geologist or geographer, to produce a description of a landscape that he has traversed, such a statement as the following: An important fault, with a displacement of about a thousand feet, here brings Archean rocks and Triassic beds against late Cretaceous strata. The failure to mention the strike of the fault and the side of relative uplift is unsatisfactory even from a geological standpoint, although the introduction of such terms as Archean, Triassic, and Cretaceous may give a geological reader some consolation for other shortcomings. But the geographer is left entirely adrift by such a description, particularly if it is not accompanied by an appropriate map or diagram; he can form no definite mental picture of the landscape seen by the writer. The age of the faulted beds is of no use to him, although it is unfortunately becoming habitual, especially in Germany, to overload geographical descriptions with terms expressive of geological dates. Such terms are, of course, of value in themselves; they are useful in various scientific relations; they are essential in a geological history of a district; but, let it be repeated, they give no aid in forming a mental picture of surface forms; hence they are of no value in a purely geographical description. What a geographical reader does need to know as to the rocks, in such an instance as is here considered, is not the ancient date of their formation, but their present composition, atti-

tude, and relative resistance; and as to the fault, the stage of erosion that has been reached with respect to it in whatever cycles of erosion that have left visible traces; also whether the fault line is marked by scarps or valleys, and if so of what kind, and so on. A more satisfying physiographic description of the district here imagined might therefore be phrased as follows:

An important fault line, trending about northeast-southwest, separates a northwestern body of massive crystalline rocks, evenly covered by an alternating series of hard red sandstones and weak shales, dipping southwestward about 30° , from a southeastern body of younger,

FIGURE 5.—An imaginary Example of a resequent Fault-line Scarp

nearly horizontal, weak, gray sandstones and marls. The rolling uplands of crystalline rocks in the northwestern part of the district are irregularly dissected by rather close-spaced, early mature valleys, of which the larger ones, 250 or 300 feet in depth, trend southwestward as if eroded by superposed streams that were originally consequent on a former sandstone cover, while the smaller ones are for the most part of insequent habit. The red sandstone ridges rise 200 or 300 feet over the broad, late mature subsequent valleys that follow the intercalated shale belts; here the drainage is well adjusted to the structure. The gently rolling surface of the crystalline uplands and the even crestlines of the sandstone ridges, taken with the equable altitude of two east-west dikes, one of which crosses the fault line, suggest that, since the tilting and faulting, the whole district has been eroded to a peneplain, again broadly uplifted sev-

eral hundred feet without faulting, and thereupon again eroded; the northwestern district being now in early or late mature stages of the cycle thus introduced, while all the southeastern district of weaker sandstones has reached a late mature or almost old stage, as indicated by its low, subdued hills, separated by broad-floored, wide-spaced, shallow valleys of typically insequent pattern; and the fault boundary between the two districts being marked by a dissected resequent fault-line scarp along the border of the crystalline uplands and by a series of resequent fault-line scarps facing southeast and obliquely truncating the sandstone ridges; but the fault is topographically obliterated where the subsequent shale valleys open on the southeastern lowland. If such a description be accompanied by a diagram, like figure 5, the essential features of the district concerned may be easily conceived.

The essence of this imagined physiographic description is that it attempts to introduce everything that is relevant and nothing that is irrelevant to a clear comprehension of the surface features in the district concerned. The names of geological formations are intentionally omitted, because they do not aid in conceiving the visible landscape; but if the physiographical description were intended as an introduction to a geological report, geological formation names might, of course, be mentioned at the outset. The attitude of the strata, often regarded as a purely geological matter by geographers of the empirical school, is really a very serviceable physiographic factor, because it enables the reader easily to conceive certain systematically associated features which would otherwise have to be described one by one. The fault, the two cycles of erosion that have followed it, and the uplift without faulting that separated them are all manifestly of service in leading the reader to picture what the writer has seen; but these factors, like all others relating to past conditions and events, are not introduced with the object of narrating the history of the district—that would be pure geology—but with the object of setting forth its present form, and that is proper physiography.

FORMS PRODUCED ON FAULTED STRUCTURES BY OTHER THAN NORMAL PROCESSES

All the foregoing discussion has been under the postulated action of normal erosional processes—that is, weather and running water. The other chief processes—solvent action of water, waves and currents, glaciers, and wind—also deserve treatment in their proper place; but such treatment may for the present be postponed until more examples of faulted structures acted on by these various processes come to be known.

One might easily deduce, from what is already understood of the action of sea waves on coasts of different kinds, a series of ideal types dependent on faulted coastal structures—for example, the development of fault-line chasms by the attack of the sea on the weak breccia of a sheared fault; or the more rapid advance of the marine cycle on a body of weak rocks alongside of its less rapid advance on a neighboring body of hard rocks, the two rock masses having been brought together by a fault, reduced to subdued forms, and then submitted to marine action by depression. Similarly, a valley glacier, while actively overdeepening its trough, might develop a more or less abrupt step in the trough floor on passing across a fault from a resistant to a weak rock body; or a basin, on passing from a weak to a resistant rock body; likewise, the trough walls might be well smoothed or matured in less resistant rocks, while they still retained ragged or youthful features in more resistant rocks, as appears to me to be the case in certain glaciated troughs of the Snowdon district in Wales, although the juxtaposition of the two rock masses was not, as far as I know, in that case brought about by faulting. The fuller discussion of these and many other examples may wait till it is wanted.

In all these cases the object in view and the principles to be observed in reaching it remain the same. The object is the explanatory description of the visible landscape as directly as possible, with no more of past geological history than is helpful in attaining this object. The principles already illustrated regarding the description of the pre-faulting forms, of the direct effects of faulting, and of the post-faulting forms may be expanded so as to include the description of forms developed under the action of different processes, as has already been implied in the mention of coastal forms in earlier paragraphs. For example, when one process is replaced by another, the description of the resulting forms should include the forms reached under the first process at the time of change, then the change of process, and lastly the forms developed by the new process as modifications of the previous forms. In brief: here, as in all other cases, let the physiographer answer the question, "**What does it look like?**" in terms of the visible products of the work of processes on structures, and his work will be accomplished.

DEFINITIONS OF TERMS USED IN DESCRIBING FORMS ON FAULTED STRUCTURES

It may now be better understood than at the beginning of this paper why the nomenclature of surface forms produced by the erosion of faulted structures—that is, the physiographic nomenclature of faults—was not introduced by definitions of a geometrical kind. Such definitions might

be framed, but they would not meet the object desired, which is to describe the fault forms in their natural association with neighboring forms, all treated in relation to the stage of their development in one or more cycles of erosion, following some appropriate and systematic scheme of general application, the scheme here adopted being that of "structure, process, and stage." It is impossible to apprehend this manner of describing fault forms merely from definitions of terms; but after the manner of description has been learned, as from the foregoing discussion, it would be an easy matter to define all the terms regarding such forms in compact statements, which might be easily carried in mind after their useful meaning has been apprehended. Any one may make these definitions if he wishes to. I have refrained from so doing, even at the end of this essay, for fear that some readers might use the definitions as a short cut to a supposed understanding of the problems involved, and thus place the cart before the horse, the terms before their need and their meaning.

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