TRANSACTIONS

OF THE

SAN DIEGO SOCIETY OF NATURAL HISTORY

VOLUME VII, No. 20, pp. 211-258, plates 12-15, text figs. 1-34

GRANITIC DOMES OF THE MOHAVE DESERT, CALIFORNIA

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PUBLISHED WITH AID OF A GRANT FROM THE FUNDS
FOR PUBLICATION OF RESEARCH
OF THE NATIONAL ACADEMY OF SCIENCES

SAN DIEGO, CALIFORNIA
PRINTED FOR THE SOCIETY
MARCH 31, 1933

COMMITTEE ON PUBLICATION

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The Cima Dome, looking south. (Photo by Blackwelder)

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Summary

Several granitic areas in the Mohave Desert region of southeastern California have been degraded to smooth dome-like forms, to which Lawson has given the name, panfans. They have diameters of from 3 to 6 or 8 miles and heights of from 500 to 2,000 feet over the adjacent lower land. One of the best examples is shown in Plate 12. The well graded convexity of these masses, the steepest declivity of which seldom measures more than 4° or 5°, is flanked by the long, aggraded, concave slopes of their detritus. In some instances the domes are elongated into arches, 10 or 15 miles in length. Many other areas, granitic and non-granitic, less completely and less symmetrically degraded, exhibit bold or subdued residual forms surmounting their smoothly degraded flanks.

The most perfect domes or arches result from the undisturbed degradation of upheaved granitic masses which have been worked upon, according to their original form,[1] chiefly by one or the other of two somewhat unlike erosional processes, both of which are merely modifications of ordinary erosional processes appropriate to the dry climate where their action takes place.

One process involves mainly the back-wearing of the steep scarps of an upfaulted granitic lowland, previously degraded to low relief, the detritus shed from the retreating scarps being swept away by sheetfloods. Down-wearing of the upfaulted mass by streams is in this case relatively unimportant. The back-wearing takes place in a manner first analysed by Lawson (1915), but his analysis is here somewhat modified. Under this process the mountain faces are, as they retreat, completely—one might almost say, once for all—reduced to gentle slopes of sheetflood smoothness. The process is largely dependent on the habit of granitic rocks to weather both by surface exfoliation and by interior disintegration, so that when a large and angular joint-block is gradually reduced by exfoliation to a roundish core about a foot in diameter, it breaks down into fine granular detritus. Rocks other than granite, being less uniform in structure and weathering into angular blocks, scraps and grains, assume mountainous or hilly forms, unlike granitic domes.

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1 The phrase, original form, is here used in a somewhat special sense in contrast to initial form. The initial form of a land mass is the form that it had when deformation interrupted the cycle of erosion previously current and introduced a new cycle. The original or potential form is the form that it would have when the deformation is completed, provided no erosion took place during the deformation.

The second process of dome production, which involves mainly the down-wearing of broadly upwarped granitic masses of low relief by the excavation of ordinary valleys along innumerable, divaricating drainage lines, will be discussed in another essay, to be published in the Bulletin of the Geological Society of America under the title, Sheetfloods and Streamfloods.

Domes are best developed in areas of granitic rocks for two other reasons than their manner of weathering as specified above. No other resistant, mountain-making rocks commonly have a uniform structure over an area large enough for the production of good-sized domes; and no other mountain-making rocks waste away so rapidly as granites under arid weathering. Hence as a rule only these rocks have found the quiescent periods, which have been granted during the later geological ages to one or another part of the earth's crust in elsewhere uneasy Southern California, long enough for their reduction to completely graded, broadly convex forms. If these conclusions are correct, the original forms and altitudes of the upheaved granitic masses now represented by graded domes or arches may be in some cases roughly inferred from certain details of the present forms; that is, certain domes or arches may be regarded, even after all the residuals of the original form have vanished, as representing far-advanced stages in the arid degradation of fault-block Basin Ranges.

INTRODUCTION

The districts of southeastern California, in which the uncompleted and the completed granite[2] domes described in this essay occur, are located on the outline map, Fig. 6. They are all included in the vaguely limited arid region known as the Mohave Desert, of which an excellent description has been given by Thompson (1929). As shown by the many dotted lines, I have traversed various parts of the region at intervals in the past 6 years in company with Dr. L. F. Noble of the U. S. Geological Survey; Mr. Samuel Storrow, one of my students in the Harvard Class of 1887, now a retired engineer in Los Angeles; Mr. Myron Hunt, architect in Pasadena and lover of all out-doors; and several of my recent students in the California Institute of Technology at Pasadena. To all of these companionable associates I am much indebted for transportation and photographs, as well as for generous encouragement and assistance in my

[2] The old petrographic term, granite, is here used in a general physiographic sense, like that adopted for the old physiographic term, valley, by petrographers.

observations. To Professor Eliot Blackwelder of Stanford University I am gratefully indebted for his fine photograph of the Cima Dome.

The discussion which follows is limited chiefly to areas of granitic rocks because they, for reasons above stated, afford the best examples of smoothly convex domes and arches. Mountains of other kinds of rocks will be briefly treated in special sections.

PART I. THE THEORY OF DOME DEVELOPMENT

The Form of Graded Divides. Lawson's keenly analytical essay on the "Epigene Profiles of the Desert" has been an indispensable introduction to what here follows. He there discussed the processes of arid degradation with special reference to their action on upwarped or upfaulted masses "lithologically and structurally homogeneous" (1915, 25:3),[3] having highland surfaces of so low relief, in consequence of degradation in an earlier cycle of erosion, that their down-wearing degradation is slow except along occasional drainage lines, and having marginal slopes or scarps so bold that their back-wearing degradation is relatively rapid. He thus showed that where the original slope[4] of an upheaved rock mass is steeper than the slope of repose of its weathered detritus, "hard rocks present persistently steep slopes throughout the entire period of their degradation. The epigene rock slopes appear to be just as steep in old residual mountains, almost buried in alluvium, as in youthful mountains with but a small embankment of detritus at their base" (27:3). Hence, after the original slopes are weathered back to steep faces (or "subaerial fronts") of proper declivity, commonly about 35° for granitic rocks, they will retreat at a uniform rate parallel to themselves, somewhat as in Fig. 1, until each side of the upheaved mass is completely reduced to a systematically inclined rock floor (or "suballuvial bench") of hyperbolic profile, over-spread with a detrital cover (or "subaerial embankment"), which

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[3] In certain citations a digit following a colon after a page number represents the position of the cited statement on its page in ninths of the page height, counting down from the page top.

[4] See foot note p. 214. It may be noted that Lawson's analysis assumes the upfaulting of a mountain mass to be completed before its recessional degradation begins. Intermittent upfaulting would produce, for a time, a benched scarp; but as no such forms have been found they must, if ever occurring, have been destroyed by further retrogression. The extreme case of upfaulting so slow that it has been overcome by contemporaneous degradation need not be considered because all the mountain ranges of the region show that degradation has been far exceeded by upheaval.

thickens at a diminishing rate and which usually slants forward with gently concave profile to an aggrading playa.[5]

Lawson's analysis also showed that the detrital cover should ordinarily become thinner and thinner up-slope, so that it must be reduced to a feather-edge when the area of the rock floor on which it rests is sufficiently increased. This is because the essentially constant acclivity of the overlapping cover must be more and more nearly paralleled by the decreasing up-slope curvature of the underlying rock floor, just as a rectilinear asymptote is more and more nearly approached and paralleled by its arm

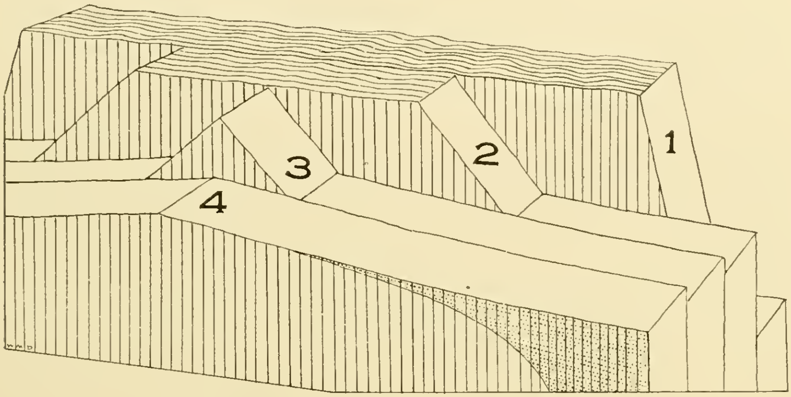

Fig. 1. Development of a blunt-angled rock floor.

of a hyperbola. It is therefore concluded that, if the retrogressive wasting of a mountain face be prolonged beyond the feather-edge of its detrital cover, as it may be in a late stage of the degradation of a large granitic mass, a "bare rock surface" will be developed; and that this surface will be extended "without appreciable change of slope" (38:2) until it extinguishes the surmounting rock residuals by meeting a similar rock surface ascending from the other side of the upheaved mass. There the intersection of the two surfaces will define a blunt-angled crest line, Block 4, Fig. 1, and the degraded mass will constitute, not a broadly convex arch

[5] Readers are warned not to regard this brief statement as representing in any adequate way Lawson's closely argued discussion of the problem of arid degradation, in which he begins with ideally simplified conditions and successively introduces a large variety of complications by which actual conditions are approached. Close study is needed to appreciate his thorough deductive analysis, which deserves to be ranked as a worthy supplement, for arid regions, to Gilbert's famous essay on Land Sculpture in his Report on the Henry Mountains; for that essay, although prepared after experience chiefly in an arid country, was mostly concerned with the degradational processes of humid regions.

or dome, but a "low rock ridge of symmetrical slopes" (31:7), and of essentially uniform declivity in its upper part.

In case the originally upheaved mass is of ovoid outline, so that, instead of a bilateral, a peripheral rock floor is developed around it, it would, under the above explanation, eventually assume the form of a blunt-angled cone. Johnson, following Lawson for the most part, brings out this result explicitly: "In the case of an originally circular mountain mass the end-result would be a far-spreading low rock cone blanketed in considerable part by overlapping alluvial deposits:" also, the general degradation of the central area would produce "a low conical rock pediment, relatively free from alluvium, the ultimate type form of the arid landscape" (1932, 390).

Each down-slope element of either a blunt-angled ridge or cone would be regarded by its sheetflood as having a slope for transportation only, down which the detritus from the retreating mountain face would be swept without erosional action. The sheetflood would therefore resemble a graded river in the sense that, however much detritus is washed along its slanting course, no erosion is there accomplished: for it is only under that condition of non-erosional transportation that the graded rock floor should have a hyperbolic profile. It is here that my explanation of the problem begins to differ from that of my predecessors.

The Development of Concave Profiles. The statement of our differences of view may be introduced by examining Lawson's special case of an upfaulted mass, the original upper surface of which, instead of being nearly level, increases in height toward its mid-line, as in Fig. 2, so that its

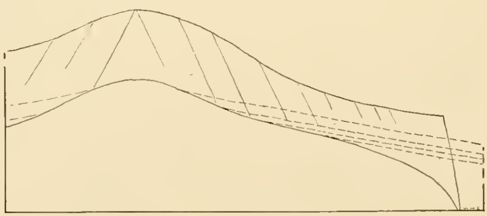

Fig. 2. Development of a concave rock floor.

mountain face grows higher and higher as it retreats, and it therefore sheds a greater and greater load of detritus to its base, to be swept away by the piedmont sheetfloods. Under such conditions the rock floor to which the upfaulted mass is retrogressively reduced must develop for a time, as Lawson shows, a concave profile of increasing steepness as its area increases.[6] This conclusion seems correct, although no actual examples of the kind have been recognized, perhaps because the growing edge of their rock floors would be covered right up to the base of the mountain face with a detrital cover of by no means feather-edge thinness.

The Development of Convex Profiles.[7] The case of an upheaved mass that does not increase in height toward its mid-line has not been so fully analysed. Lawson's brief statement is that the graded profile of such a mass will be, as compared to that of an originally convex mass, "flatter without changing the character of its [hyperbolic] curvature" (36:6); that is, without diminishing the tendency of the upper part of the profile to become rectilinear. This conclusion seems to me to be erroneous. To make my point clear let it be recalled that the essential condition for the development of a hyperbolic profile is that, while the mountain face retreats parallel to itself at a uniform rate (35:7), the detrital cover rises parallel to itself at a diminishing rate, chiefly because of the decreasing height of the face from which detritus is shed (35:5). This implies that all the detritus supplied to the cover comes from the steep mountain face, and hence that none comes from the degraded and gently sloping rock floor beneath the face. The grounds for an opposite inference are as follows.

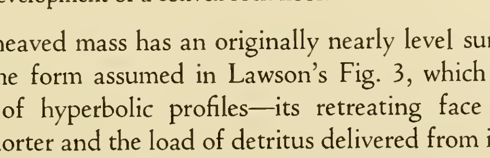

Fig. 3 Development of a convex rock floor.

If an upheaved mass has an originally nearly level surface, Fig. 3—and such is the form assumed in Lawson's Fig. 3, which illustrates the development of hyperbolic profiles—its retreating face must become shorter and shorter and the load of detritus delivered from it must become smaller and smaller as time goes on. A time must therefore come when the delivered detritus will not provide a sufficient load for the piedmont

6 This result would apparently be favored if the drainage of a mountain face led to a near-by playa of small area, which would therefore be rapidly aggraded.

7 The inferences stated in this section first took conscious form in my mind during the night of April 30, 1932, which was spent where the Cave Spring road passes near the base of a large rock knob on the dissected part of the rock-floor piedmont to the Granite Mountains, described on a later page.

sheetfloods and thereafter they will no longer act simply as transporting agencies. They must then begin to rob the cover of some of its detritus or the rock floor of some of its disintegrated grains, with which to satisfy their excess of energy; and thence-forward the conditions for the development of an increasingly rectilinear profile can no longer obtain.

Rock-floor Robbing by Sheetfloods. As soon as such rock-floor robbing sets in, the up-slope extension of the already thin detrital cover will cease, and the rock floor thereafter developed will be of less and less acclivity as it is retrogressively extended farther and farther toward its eventual summit. For after the robbing of the floor has once begun, it must go on at an increasing rate so long as the detritus delivered from the retreating mountain face continues to decrease; and in consequence of such increase of floor robbing the floor must acquire a convex profile instead of maintaining an essentially uniform acclivity to its head. This conclusion seems to me quite as correct as the one announced in the third-preceding paragraph; and it has the additional merit of being repeatedly exemplified in nature, as will be shown below.

The manner in which rock-floor robbing operates appears to be as follows: A cloudburst flood, rushing down a steep but short mountain face and spreading in a sheet on the graded slope of the piedmont rock floor and its detrital cover, may there find its total load of detritus insufficient to satisfy its capacity. It will thereupon at once increase its load by taking up some detritus from the rock floor. But the amount that it takes up will be less than its deficiency of load, because, by the very act of taking up some detritus, the gradient of the floor will be diminished, the flow of the sheetflood will be retarded and its capacity will be lessened. Hence the amount of detritus taken up must be such that, when added to the load previously acquired, it will make a total no greater than can be carried by the lessened carrying power. And all these changes must go on by infinitesimals, as if the sheetfloods were familiar with the differential calculus. This case is the opposite of that of a loaded river to which more load is added. Such a river will not lay down all the new load, but only so much of it as will, by increasing the stream gradient, increase also its velocity and its carrying power, so that it can then carry all its former load and the non-deposited part of the new load.

Let it be understood, however, that the surface here called a rock floor, as well as that called a "bare rock surface" by Lawson (1915, 38:2), does not show firm, bare rock, but only disintegrated rock in place, gradually passing into firm rock several feet underground. This is because, while the disintegration of a granitic mountain face causes its slow retreat, the disintegration of the floor at the mountain base slowly progresses downward; but while the steep mountain face is stripped of most of its finer waste, the floor is not. It appears to be with reference to the action of sheetfloods on this sheathing of disintegrated detritus that Lawson remarks: "Corrasion by running water is quite a subordinate part of the process by which desert mountains are degraded" (28:4); for corrasion is the process by which firm rock is worn away by water-borne detritus. It may be added that the surface of the disintegrated rock usually presents a much larger proportion of grains (or of angular scraps in non-granitic masses) than is found just below the surface, where fine sand and silt are plentiful; thus suggesting that they have been removed from the surface by the wind. A truly bare rock surface is found in rock domes only after active erosion, instigated by some change of conditions, removes the disintegrated rock.

It may be stated as a corollary to the above principle of rock-floor robbing that, even when the retreating remnant of a large and lofty mass of whatever form is eventually narrowed to a high, sharp-crested ridge, the detritus delivered from it will still satisfy the carrying power of the sheetfloods until the ridge is reduced to small height; only thereafter must the profile of the graded floor become convex. Inasmuch as the beginning of rock-floor convexity is here delayed until the originally large mass is reduced to a narrow ridge, the convexity will characterize only a small part of the completed profile. Such a mass will be, if elongated, a round-crested ridge instead of a broad arch; if ovoid, it will be a round-topped cone instead of a broad dome.

On the other hand, in the case of a broad and low mass, the retreating face will, at an early stage of its retreat, fail to shed detritus in sufficient quantity to satisfy its sheetfloods, and the convexity of the completed rock floor resulting from the back-wearing of such a mass will be early initiated. When such a mass is completely graded it will be, if elongated, a broadly convex arch; or if ovoid, a broadly convex dome. This, taken in reverse order, illustrates one of the ways in which rough inferences may be made as to the original form and altitude of an uplifted mass after all traces of the original form have vanished.

All these graded forms will be slowly reduced to less and less convexity as long as their region remains undisturbed. The manner in which such reduction takes place deserves brief consideration.

Degradation of Desert Domes. The most peculiar feature of dome degradation in an arid region which drains to aggrading playas is that the dome surface is most lowered at the top where it is flattest. It is less lowered on the flanks where it is steepest, and it is slightly built up on the basal slopes; but in a late stage of an arid cycle, when wind exportation of dust from the playas may gain the upper hand, the basal slopes also will be degraded. The agency by which the top of a dome is lowered fastest is chiefly sheetflood robbing of disintegrated rock, as above explained; and the manner in which the work goes forward seems to be very similar to that of rillsheet robbing on the round-topped hills of humid climates, as analysed by Lawson in a recent paper (1932) to which the reader will do well to refer. The leading contrast between the two cases seems to be that the slow degradation of the entire area, but still fastest at the convex crests, which may be theoretically expected in a late stage of an arid cycle, as above intimated, is continuously operative in a humid climate, because degradation there goes on with respect to slowly lowering stream courses; unless there also a temporary reversal of such lowering may take place near the streams in that stage of maturity when they spontaneously aggrade their courses slightly because their load increases after their slopes had become graded; but as old age is approached, such aggradation is followed by very slow and long continued degradation.

Terminology.[8] In spite of the risk of incurring censure, I propose, as may have been inferred from certain passages in the foregoing paragraphs, to replace the terminology hitherto in use for the kind of desert mountains here under discussion by a new one which seems to me in several respects more appropriate. Instead of using Lawson's term, "subaerial front" for the steep retreating slope of an upheaved mass, the ordinary term, mountain face or rock face, seems to be a sufficient designation. It may be noted that in granitic mountains, the face is craggy or bouldery; craggy where round-weathered ledges protrude; bouldery where detached blocks linger; finer detritus lies on it in protected nooks; also that a two-sided mountain mass retreating from its original fault scarps will, after first acquiring more or less indented and embayed margins and later narrowing to an irregular ridge with a serrate crest, be worn through in graded passes and

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8 The law of priority may well be followed in cases of mere nomenclature; but descriptive terms often need change when the theoretical explanation which they connote is modified; and even for non-explanatory description terms later proposed are sometimes better than earlier ones. Let the fittest survive under the law of competition.

thus eventually be subdivided into isolated mounts, knobs and nubbins, as in Fig. 4.

The worn-down and graded rock floor which takes the place of the retreating mountain face is called by Lawson the "suballuvial bench," although it is by no means always either bench-like or suballuvial. Bryan, Blackwelder, King and others call it by McGee's descriptive term, pedi-

Fig. 4. Reduction of a granitic mountain to mounts, knobs and nubbles.

ment (1897, 92:4), although when it arches over a fully degraded highland, it occupies no such subordinate position as pediment implies. This term should therefore be used only for young, relatively narrow, uncompleted rock floors. It is true that, when stripped of its detrital cover in consequence of erosion following crustal movement or climatic change, the outer part of a bared rock floor ascending with a steeply convex frontal slope may have something of a bench-like appearance, and I have described a discontinuous bench of this kind on the western side of the Santa Catalina Mountains in southeastern Arizona (1931); but after the degraded surface acquires greater breadth and especially after it extends completely over a dome summit, the term, bench, seems less acceptable than the more non-committal binominal, rock floor, because the word, floor, although commonly used for level surfaces, is also applied to uneven surfaces, such as the floor of the ocean.

Moreover, while the lower part of a degraded rock floor is, truly enough, in the earlier stages of its production, covered with detritus as fast as it is developed, its upper part may remain bare through the later stages of growth, except for transitory veneers of shifting waste; and "suballuvial" must then be replaced by "subaerial." So it is replaced by Lawson, although he gives, to my reading, too much emphasis to the persistently suballuvial condition of the bench in certain statements; for example, when it is said that until the last summit knobs are consumed "the suballuvial bench is, at all stages, buried" (34:4); again, as soon as "the rock crest [of unreduced knobs and nubbins] vanishes," the resulting surface "is, in its ideal completion, wholly one of aggradation, a vast alluvial fan" (33:4), as if the "suballuvial bench" were not visible at that stage of the cycle.

Fortunately an opposed statement is made on a later page. "In the late stages of the recession of the subaerial front, when its height is relatively small, and the embankment is relatively broad, the latter rises very slowly by increments that are nearly equal [all over its surface]; and the hyperbola [such being the theoretical profile of the rock floor] approaches very closely to a straight line and to tangency with the surface profile of the embankment. The profiles of both the bench and the embankment, though mathematically distinct, are then practically coincident. Under these conditions the horizontal [up-slope?] extension of the embankment does not keep pace with the recession of the subaerial front. Between the upper [feather-] edge of the embankment and the base of the front there is evolved a graded rock slope. The suballuvial bench becomes at this stage a subaerial bench, across which the detritus from the vanishing front is swept by sheetfloods in times of cloudburst, to be spread over the surface of the embankment below. This emergence of the bench and its persistence as a subaerial feature appears to be most characteristic of granite ranges" (37:8). Then follows the passage already quoted regarding the "bare rock surface extending.... without appreciable change of slope to... the crest" (38:2), which should therefore be, under Lawson's explanation, a "low rock ridge with symmetrical slopes" (31:7); but under my explanation, a low rock arch.

Embankment does not seem a fitting term for the long-sloping detrital cover which, either heading at the base of a moderately retreated mountain face or feathering out up-slope on a broadly developed rock floor, slants forward very gradually with a faintly concave profile to a playa basin or a river valley. Bahada[9] would be, as a relative of playa, a good name for this highly characteristic feature of the desert landscape; but unfortunately in its original Mexican use this term does not discriminate between the bare rock floor and its detrital cover. When the term is used

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9 An English form of spelling here replaces the Spanish, bajada, just as Mohave now replaces Mojave and canyon replaces cañon, in order to secure an approach to their Spanish pronunciation, and to avoid the unhappy loss of that pronunciation which has taken place in the fine word, mispronounced Cordíllera, due to its not having been respelled Cordilyéra.

Fig. 1

Fig. 2

Figs. 1, 2. Looking west and east across slightly dissected rock floor of Granite Mountains. (Photo by Storrow)

here it will, experimentally following Blackwelder, refer only to the detrital cover.

A singular feature of a bahada, when viewed from the level floor of the playa to which it commonly descends, is that the nearly level slope of its lower part seems to be followed at an angle by the apparently much steeper but in reality gently inclined slope of its upper part, as in Plate 14, Fig. 1. Yet no angular bend but only a very gradual increase of acclivity is found as the long concave slope is ascended.

Panfan or Dome. Following his interpretation of the problem, Lawson names the completely graded rock floor of a worn-down mass a "panfan," because, as already quoted, he takes its surface to be, "in its ideal completion, wholly one of aggradation, a vast alluvial fan" (33:4). But this is a partial statement of the case, applicable if at all only to degraded masses of small area and of questionable application even there, because in their penultimate stage, when the summit ridges are diminished to small size, the upper part of the rock floor, where it is slightly robbed, must become bare. The term is still less appropriate for larger masses, although in lack of another name I have used it for them in an earlier essay (1925); for in such cases, as Lawson himself recognizes, the upper part of the floor is, again as already quoted, a "bare rock surface" (38:3). Inasmuch as the bare surface cannot be a blunt-angled ridge or cone but must be more or less rounded off at the summit, the less specific term, dome—or arch for elongated masses—seems preferable to panfan because, while suggesting convexity of profile, it applies quite as well to a convex mass of smoothly degraded rock as to one in which the degraded rock is covered with alluvium. And since the term, dome, is here used for forms of undisturbed degradation on massive crystalline rocks, it should not be confused with salt domes of subterranean deformation, such as occur in Texas and elsewhere.

The occurrence of broadly convex domes is, however, fully recognized by Lawson, even though he calls the type example of such forms a "mountain ridge" (26:7); but the manner of their production is not clearly stated. Brief note is made to the effect that what is here called rock-floor robbing causes a modification of an already produced, blunt-angled panfan (44:5), and that this "modification would be manifest as a transfer of finer material from higher to lower levels;" also that this "process would of course be in operation long before the panfan stage, particularly when cloudbursts were local to the fan slope and did not affect the subaerial front" (44:5, 6). But the effect of the process in changing the nearly rectilinear profile of a graded surface to a broadly convex profile before the panfan stage is reached is not explicitly brought out.

It is, on the other hand, implied that the development of rock-floor convexity, which must be accomplished by the erosion of the rock floor, is postponed until after the mounts and knobs along the summit of the slope have vanished; but that seems, as already intimated, impossible, because the charge of sheetflood action from transportation alone to erosion and transportation together cannot be so long delayed. The change should have begun gradually as soon as the diminution of rock-face area causes the volume of detritus that it sheds to fall below the measure that the piedmont sheetfloods can transport. Hence a convex arch or dome and not a blunt-angled panfan is the normal form of a degraded granitic mountain in the desert. Such a convex form should be seen for a time before and enduringly after the sharp, ungraded ridges, mounts and knobs of the summit, with their bare rock faces, are all consumed.

But the graded dome is evidently not a final form. The very processes by which its convexity is initiated continue after its completion to degrade it to lower and lower convexity. I must therefore dissent in several respects from Lawson's statement concerning the "panfan stage of the geomorphic cycle of the desert," where he says: "The panfan may be regarded as an end stage in the process of geomorphic development in the same sense that the peneplain is an end stage of the general process of degradation in a humid climate. The peneplain closes the cycle of degradation and is a cut surface; the panfan closes a cycle of degradation and aggradation, is evolved by both cutting and filling, and is a built surface" (33: 5, 6).

On the contrary, a panfan when first developed is no more an ultimate form than a peneplain is. The degradational processes by which both forms are produced continue to operate, although the rate of their operation is retarded. I would therefore modify Lawson's statement, "with the disappearance of the rock crest the process of degradation changes from one of relative rapidity to one of extreme slowness" (32:7), by pointing out that, when rock-floor robbing is recognized, the degradation of the growing area where robbing operates was very slowly going on before the disappearance of the rock crest. Again, it is said that the vanishing of the rock crest marks "a stage of geomorphic development at which the processes of aggradation and degradation, in so far as they are due to the agency of water, both almost cease" (32:6); but it may be better said that those processes then still continue the slower and slower action, as far as the graded surface is concerned, that has long been slackening.

Furthermore, a fitting supplement to Lawson's analysis might carry its elaborations a little farther by considering the case of an upheaved granitic mass in a littoral desert, like that of southwest Africa which Kaiser has so well studied, and showing that the playas of interior deserts may be there represented by the unfillable ocean, so that an upheaved granitic mass might in such a region be degraded to a dome with respect to the standard baselevel or ocean surface, with negligible aggradation around its margin; and such a dome would correspond to a peneplain which is developed wholly by degradation. But the case of the peneplain might also be elaborated from its most elementary form in which all of an uplifted surface originally stands above baselevel, so as to include the more general case of an unevenly uplifted surface, part of which is occupied by low-level basins which must be aggraded up to a peneplain surface while the higher parts are worn down to it. In the first of these cases, the playa-less panfan is wholly a cut surface, like the elementary peneplain; in the second the peneplain is a cut-and-filled surface, like the ordinary panfan and its playas.

In view of these somewhat carping criticisms, it is a satisfaction to read on a later page of Lawson's essay a revision of his above quoted statements about peneplains, comparable to the other revision in which the existence of "bare rock floors" is recognized (37:7) after earlier insistence that rock floors are always covered with detritus (33:4, 34:4); namely, "the peneplain is, as the term implies, a penultimate rather than an ultimate stage of geomorphic development under persistence of uniform conditions. The final stage is a plain. . . . . . Similarly the panfan is a penultimate stage in the reduction of the relief of the desert under conditions of crustal stability" (44:1).

The Boulder-clad Mountain Face. The persistent steepness of the retreating, boulder-clad face of a desert granitic mountain has been fully explained in Lawson's essay and need not be further discussed here. The face may be regarded as roughly graded, as I have pointed out in an earlier article (1930, 147), in which its barren surface with scanty soil and practically no vegetation is compared with a graded and forested mountain side in a humid climate, the slopes of which are so well soil-cloaked that the sub-soil boulders of disintegration are completely concealed. In both cases the slopes have acquired such declivities that the local agencies of transportation are nicely adjusted to the work that they have to do. It may be added that in these steep mountain faces, just as on the sides of narrow gorges and canyons, in bold cirque heads, precipitous caldera walls and steep sea cliffs, the efficiency of joints in guiding the attack of the weather is manifest and unquestionable, however inefficient they are in giving supposed guidance to the course of graded streams in winding valleys.

The abrupt transition from the steep and roughly graded face of a desert granitic mountain to its gently sloping and well graded rock floor, whether covered with detritus or not, has been specially treated by Bryan, who shows that it is chiefly the result of the correspondingly abrupt transition from the large boulders which linger on the steep face to the granular detritus which, after being washed down from the face, has to be swept down the graded piedmont slope. The rarity of head-, fist- or nut-sized rock fragments on both the steep face and the graded floor is surprising, until it is understood that the disintegration of the smaller boulders reduces them directly into granular detritus. The small rock fragments that are occasionally found on granite slopes are usually angular scraps of quartz veins or of aplite intrusions. The same observer emphasizes the persistence of constant slopes in diminishing granitic mountains: "Solitary .... hills retain the same steep slope as the original mountains, but grow gradually smaller until the last remnants are masses of boulders or single rocks projecting above the general level" (1925, 96).

In mountains made of rocks which, unlike granite, weather into angular blocks, scraps and grains of all sizes, the transition from the steep upper slope of the retreating face to the gently sloping rock floor is, again as Bryan has shown, not made abruptly in a sharp bend of the profile, but is gradually accomplished in a sweeping curve. The contrast between such a curve and the abrupt change of slope in granite mountains, Fig. 10, is so striking that W. Penck's categorical denial of the occurrence of a basal angle (1924, 157:8) is hardly warranted; for it must of course be understood that, just as an angle in a road is of engineering quality, a mountain-base angle is of a geographical rather than of a geometrical quality.

Valleys in Arid Granitic Mountains. It is to be expected that, in spite of the prevalence of arid conditions, the highland surface of an upheaved land mass must be traversed by wet-weather streams along valleys of pre-upheaval erosion, or along new courses consequent on that surface as modified by deformation; also, that such streams must incise trenches in the upheaved surface and thus, in cooperation with the weathering of the trench walls, develop valleys which will in time consume all the original highland surface, in so far as it is not consumed by the back-wearing degradation of the original marginal scarps. This expectation is supported by the rarity with which any trace of the pre-upheaval surface can be detected in the present-day highlands of desert mountains because of their well-advanced dissection. Apart from a few Louderbacked ranges, the Paso Mountains,[10] recently uplifted along the Garlock fault, and the near-by Rand Mountains are the only ranges I have seen in the region in which the pre-uplift form is still easily recognizable.

The share taken by highland streams in the sculpturing of desert mountains is hardly discussed in Lawson's essay. It is briefly noted that "corrasion by running water is quite a subordinate part of the [degradational] process except in those ranges which are so high as to have a relatively abundant precipitation upon their summits" (28:4). "Acute indentation of the contour of the subaerial front" is said to "inhere chiefly in the heterogeneity of the mountain mass" (46:6); streams are not mentioned in that connection.

Bryan places a much higher value upon stream erosion. He writes: "The pediment is greatly increased in extent by the lateral migration of streams at and below the mouths of canyons. Extensions of the pediment into the mountains are common. These extensions consist of branching valleys, many of which are two miles or more in width and reach far into the interior of the mountain mass" (1925, 96, 97). He notes also that "residual hills are strung out [on the pediment] in lines between the original canyons. When the [inter-canyon] spurs become narrow they are cut through by slope recession on both sides, and hills are left standing as outliers on the pediment." Many of these hills are "prolongations of the inter-canyon ridges" (1925, 89, 94, 96), as is shown by his contour map of the Sacaton Mountains and their well developed peripheral rock floor in southeastern Arizona.[11]

Degradation of Non-Granitic Mountains. The forms assumed by non-granitic, mountain-making rocks differ from those of granitic moun-

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10 The name, El Paso, for these mountains is objectionable because it commonly results in their being called "The El Paso Mountains," which is absurdly redundant. The Spanish article is therefore omitted.

11 A question suggested by the above quotation, as to how far the canyon mouths are widened by the lateral erosion of migrating or swinging streams, will be discussed in my other paper, Sheetfloods and Streamfloods, referred to above.

tains because of their less homogeneous structure and of their different manner of disintegration. Instead of retreating from their original form in fairly simple faces, not deeply cut by valleys, they retreat irregularly and valleys are soon opened along their lines or belts of weakness. Instead of changing abruptly from a steep, craggy and bouldery face to a graded piedmont slope, as granitic mountains do, they change, as already told, from roughly graded but somewhat ledgy faces by a smooth concave curve to a graded piedmont slope, as Bryan has well shown. And instead of maintaining faces of essentially uniform declivity during their retreat, the faces tend to assume a gentler and gentler declivity as their cores of more resistant rock yield less and less coarse detritus in virtue of being more and more encroached upon by graded slopes.

The detrital fans formed at the valley mouths are much more prominent than the corresponding piedmont fans of granite mountains, because here the detritus in the fans is relatively coarse, and therefore their gradient is steep, their heads rise high above the base of the inter-fan mountain face, and their outspreading fronts advance far upon the elsewhere gentler gradient of the detrital slope.

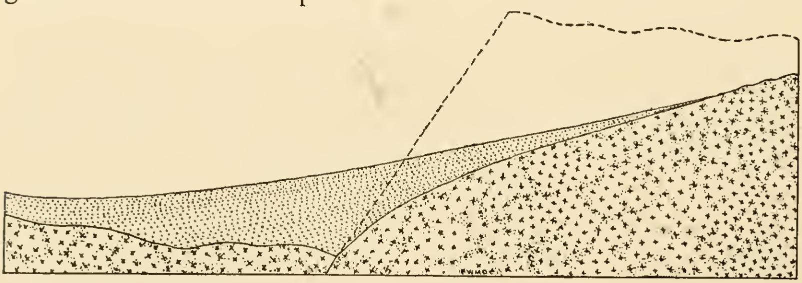

Fig. 5. Reduction of a non-granitic mountain to a group of mounds.

In their penultimate stage, Fig. 5, mountain masses of this kind are reduced to groups of low mounts or hills, each of the many members of a group having a somewhat ledgy crest where the resistant rock core which determines it feebly outcrops. It is to be inferred that the mount or hill having the most resistant core will dominate the other members of its group. The upper parts of these residual forms show little tendency to develop convex slopes, except just over their tops, presumably because the somewhat coarser detritus shed by the summit cores prevents the degradation of the upper slopes to a diminishing declivity. These mountains therefore show, in the penultimate stages, more ridge- or cone-like forms than granitic mountains do.

Part II. Examples of Unfinished and Finished Granitic Domes

Subdivisions of the Mohave Desert Region. The Mohave Desert region includes, in its extent of some 250 miles west-east and 150 miles north-south, a large number of irregularly spaced mountain masses or ranges, unlike in structure, area, pattern, height and stage of arid erosion. They alternate with correspondingly irregular intermont depressions or troughs, more or less heavily but always smoothly aggraded with waste from the mountains, which overlaps on their piedmont rock floors. The rock bottom of each trough, at depths of 1000 or 2000 feet below the present surface of its detrital filling, is probably as uneven as the originally upheaved rock tops of the bordering mountains, so that each depression then contained separate basins, just as the mountains originally exhibited separate summits. But while the original summits have been dissected into innumerable peaks, many of the original basins have been unified by aggradation in continuous trough floors, on which flat fans form low divides between shallow playas; thus anticipating the simplicity of the peneplains to which the mountains will be degraded when they show only low mounds between shallow swales. Unlike the more linear Basin Ranges farther northeast, which generally trend north-south, the mountains of the Mohave Desert have no systematic arrangement; and perhaps for that reason no agreement upon a subdivision of the region has been commonly reached. It is therefore here proposed to subdivide it somewhat arbitrarily into a number of districts, the names selected for which as well as those of the chief towns are given in Fig. 6. The reader will find it to his advantage, when looking over the following pages, to bear in mind the localities there named.

Examples selected for Description. The following account of several unfinished and finished granitic domes or arches is concerned particularly with the evidence that they furnish with regard to the occurrence of blunt-angled crests, according to Lawson's explanation, or of rounded crests, according to the modification of his explanation here presented. The examples selected for description probably differ from many others chiefly in the purely subjective quality of happening to lie so near highways or roads that they are easily reached. The mention of most of them therefore does not mean that they are objectively exceptional in giving better illustrations of the work of arid degradation than their neighbors, but only that they are the best examples of their several kinds that I have been able to visit. The origin of the ranges by faulting is not often directly

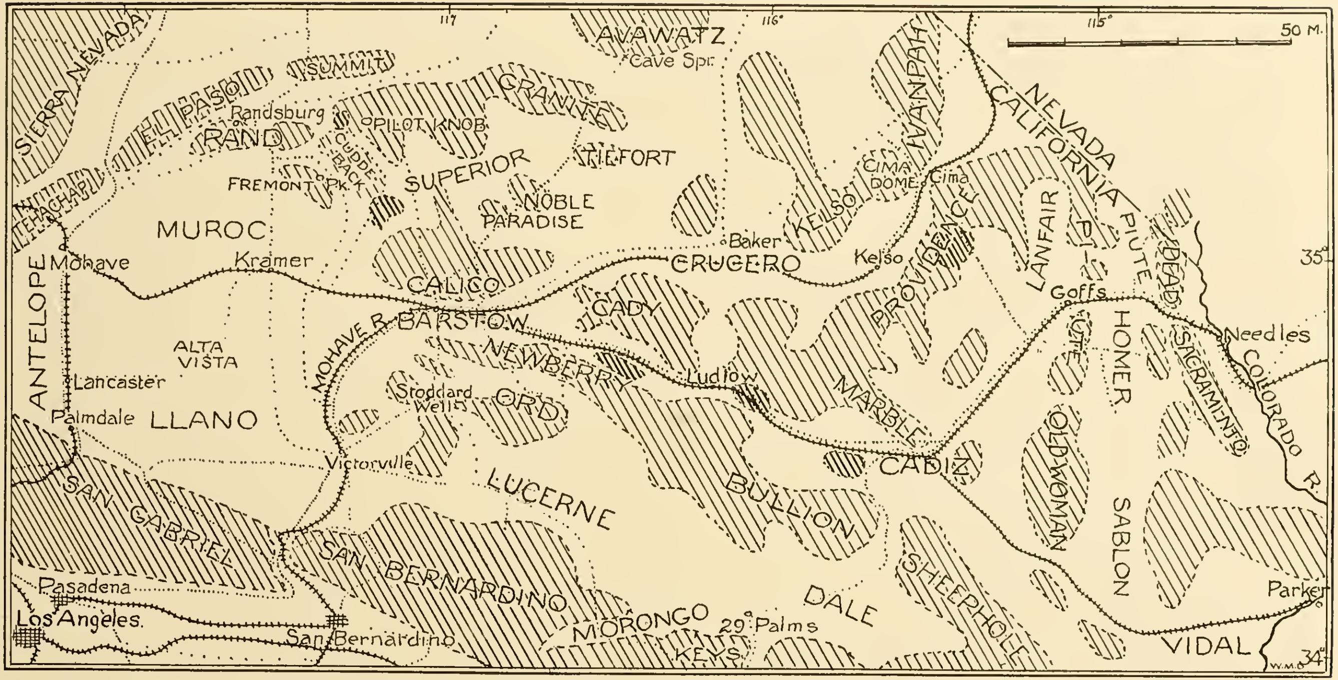

Fig. 6. Outline map of the Mohave Desert region. Its chief divisions may be named as follows: In the west a broad plain known as Antelope Valley. Next to east the Muroc-Llano district; at its mid-eastern salient lies Barstow, a center for locating other points. On the northeast is the Superior district, about 50 miles across; on the southeast is the extensive Lucerne-Dale trough. Between these, two long irregular troughs, united at Barstow, lead east-northeast and east-southeast. The first or Crucero-Ivanpah trough is followed by the Los Angeles-Salt Lake line of the Union Pacific Railroad; a branch trough turns from it to Death Valley. The other or Ludlow-Cadiz trough, followed by the Santa Fe Railroad and locally floored with recent lava flows, branches at the large Bristol playa, the Cadiz-Lanfair trough trending northeast, and the Cadiz-Vidal trough trending southeast. These branches are separated by the Old Woman and other mountains, beyond which the Homer-Sablon trough connects them; its northern part or Piute trough is crossed by the Santa Fe Railroad in its descent to the Colorado River near Needles.

provable; but the Marble Mountains, Fig. 7, north of Bristol playa, show a manifest discordance of baseline to monoclinal structure; and farther northeast the northern part of the Piute Range is thinly Louderbacked, as in Fig. 8, thus indicating that upfaulting has been concerned in the production of these two ranges at least; also that for the second example and therefore probably for many of its neighbors, the district had been reduced to low relief before upfaulting took place: in other words, the district was then a part of the vast "Powell surface."

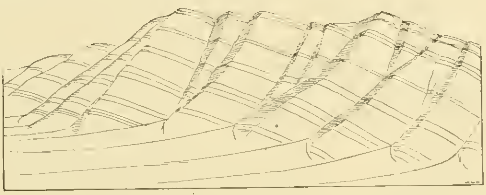

Fig. 7. Dissected fault scarp of Marble Mountain.

The occurrence of many rugged mountains interrupting the desert's broad expanse shows that their upheaval has been too recent to permit their reduction to completely graded, penultimate forms; but the long, smoothly graded slopes which flank many of the ranges, giving them fan-dented or fan-bayed patterns, show that since their uplift, a somewhat prolonged period of rest has permitted a good advance in their cycle of arid erosion. Some of the ranges still reach far down toward the flat axial

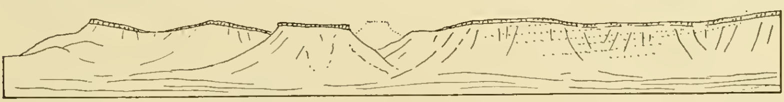

Fig. 8. Louderbacked scarp of the northern Piute Mountains, looking west.

floors of the aggraded intermont troughs, where they are wrapped around by floodsheets of detritus from their less salient parts; others have receded until they occupy only a minor part of the highland by which two intermont troughs are separated; and occasionally the floodsheets of detritus, doubtless concealing a graded rock floor at less and less depth for much of their ascent, rise towards a smooth skyline arch which, as in Fig. 9, replaces a degraded range. With the probable exception of those which ascend to or nearly to a crest line, these graded slopes exemplify the correctness of the Paige-Lawson principle that rock floors are covered with detritus as fast as they are produced. Most of the upper slopes are of astonishing rectilinearity, as shown in Fig. 10.

It should be noted that, as McGee pointed out (1897), the graded slopes are not drained along inbranching stream courses, such as prevail in the sharply dissected, residual mountains, but by broad sheetfloods, whose shallow and elaborately enmeshed lines of flow cover the surface with their intricate network. It is only where two sheetflood slopes converge obliquely that a true stream is formed along the line of their junction. True, some of the flow-lines of sheetfloods may continue here and there in stream-like form for several hundred feet or more, but they are sooner or later subdivided and distributed in enmeshed fashion. Even the

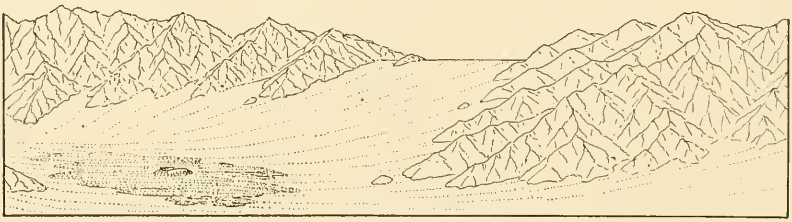

Fig. 9. Generalized features of the Mohave Desert.

trough floors, where it might be expected that streams would be formed by the union of sheetfloods from the two sides, are usually so flat that their drainage lines are of a braided habit, closely resembling the enmeshed pattern of sheetflood flow-lines. It is only when, for whatever reason, a graded surface is dissected that its enmeshad sheetflood drainage is converted into an inbranching drainage system, as will be shown in my other paper on Sheetfloods and Streamfloods.

Further exploration of the desert should surely bring to light many other good examples of the processes of arid degradation than those cited below; but it is felt that few if any will equal in smoothness of convex profile the beautiful Cima Dome, Plate 12, or the majestic Cuddeback Arch, Fig. 23.

The Granite Mountains. One of the best examples that I have seen of a graded but unfinished granitic rock floor below a bold mountain of back-wearing development flanks the Granite Mountains where they are crossed by the Cave Springs road, nearly 50 miles northeast of Barstow on the way to Death Valley. A rough sketch of the mountains and their graded piedmont slope, as seen from near Bicycle playa on the south, is given in Fig. 11. The road ascends the long slope a mile or more to the east of a south-stretching spur, in order to reach a narrow notch or pass in the range crest. The slope is largely covered with detritus, a true bahada, as it very slowly rises from the level playa surface and gradually steepens to an acclivity of 4° or 5° before reaching the rather sharply defined base of the craggy and bouldery mountain face; but the last half mile of the ascent shows many rock exposures, particularly for a part of that distance where, for an unknown reason, it has been slightly dissected after having been well graded, as in Plate 13, Figs. 1, 2.

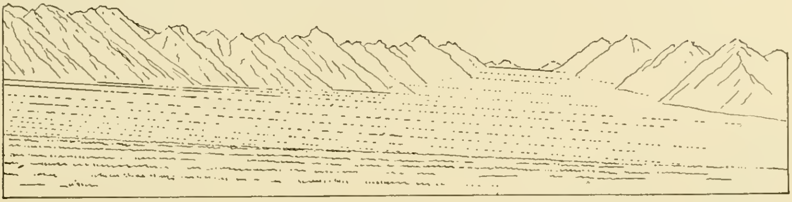

Fig. 10. Angular junction of craggy granitic mountain faces with rectilinear detrital slopes. Bullion Mountains, looking west.

The walls of the narrow pass are high, steep and rocky, like the mountain face to the east and west; and the steady acclivity of the rock floor continues into the pass and almost to its very summit, evidently because a good supply of waste is still shed there from the high walls. Yet the actual summit is not blunt-angled, but is arched over for a 100- or 200-foot distance; and this is taken to justify the inferences presented above in the fourth paragraph of the section on Rock-floor Robbing. Another inference here finds application; namely, that this much diminished mountain mass was originally a fault-block; for otherwise it could not have developed steep faces; but this inference finds no independent verification.

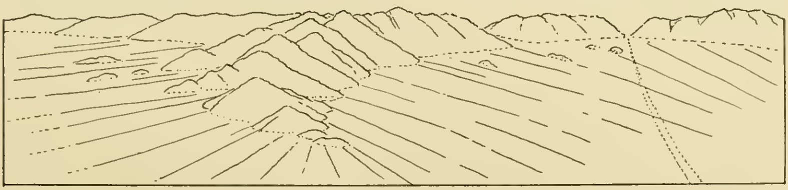

Fig. 11. The Granite Mountains, looking north.

The southward-advancing spur of the range, Fig. 11, has several rather well defined indentations, which are more probably explained by an increase in the number of joints than by a change in the nature of the rock; they mark a slightly less resistance of the mountain face under the attack of the weather, which is to be measured not by the amount of their recession back of a line connecting the adjoining salients, but by the small excess of their total recession over the slightly less recession of the salients from the original scarp of the mountain mass, which may have been several miles away. Some of these indentations, where the ridge crest sagged to less than its average height, have been worn through in open passes, the walls of which are lower as well as farther apart than those of the narrow summit pass followed by the road. One of the open passes was reached on foot by some of my students, who found it to be distinctly convex on a cross profile for about a quarter mile. This is taken to give further confirmation for the paragraph above referred to.

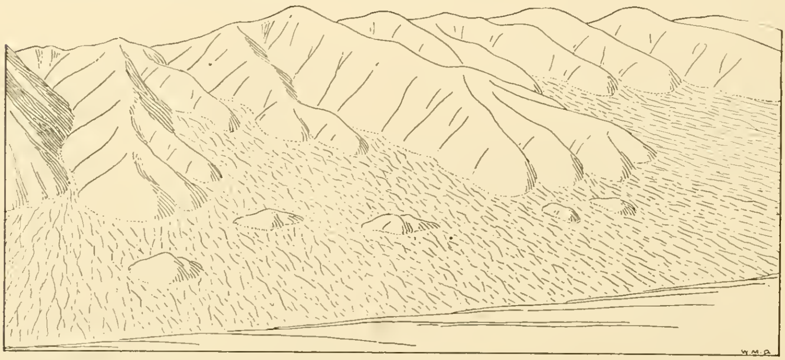

Fig. 12. The Paradise Mountains, looking southwest.

The northern face of the Paradise Mountains, half way between Barstow and the Granite Mountains, is outlined in Fig. 12, as seen from the Cave Spring road several miles to the northeast. It shows a fan-bayed stage of back-wearing degradation, of more irregular pattern than that of the Granite Mountains. Where its long bahada meets the bahada of the Noble Domes, next to the north, a stream course or "wash" is well defined.

Fig. 13. Pass between Bullion and Sheephole Mountains, looking southwest.

The Pass between Bullion and Sheephole Mountains. A pass, Fig. 13, about 4 miles wide, separating the granitic Bullion and Sheephole Mountains, is traversed by a desert road from Bristol playa in the Cadiz trough to the eastern part of the Lucerne-Dale trough. The broad crest of the pass is occupied by well developed rock floors sloping away from the bold terminal faces of the mountains toward a midline, along which clearly defined stream courses descend to the northeast and to the south; the latter being deflected from an expectable southwest course by a long and low spur of the Bullion Range. If sheetfloods had acted there only as transporting agencies the two slopes from the pass crest should be rectilinear and its cross-profile should be blunt-angled, as shown by the dotted line in Fig. 14. But as a matter of carefully observed fact the crest is broadly arched, as shown by the full line. Hence the sheetfloods must have acted there both as transporting and eroding agencies. It is, indeed, reasonable enough that they should have so acted near the crest, because before the pass was opened the originally continuous mountain mass must have been narrowed to a lowering ridge, the detritus from which could not have loaded the floods to capacity; moreover, the supply of detritus from such a ridge could not have been significantly increased by that from the retreating mountain faces on either side, because the slopes at their base would curve away from the pass toward the still lower slopes on either side of it.

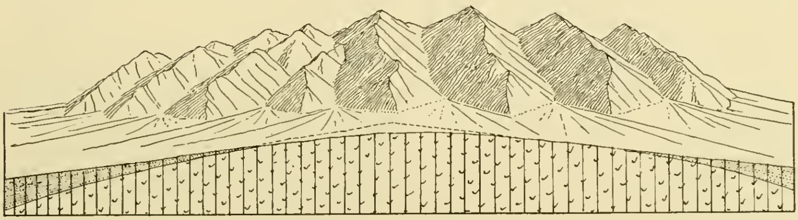

Fig. 14. Pass between Bullion and Sheephole Mountains, looking southeast.

For some unexplained reason the upper part of the northeast stream course has been rather sharply incised to a depth of about 20 feet, the detrital cover of the adjacent rock floors has been stripped off and the floors have been slightly dissected, as shown in Plate 14, Fig. 2; but the cover remains near the mountain scarps on both sides of the pass. The stripped floor here developed is one of the finest examples of its kind that I have seen.

The Unsymmetrical Storrow Dome. An uplifted granitic mass, from which the outwashed detritus has free discharge in nearly all directions, will develop piedmont slopes with convex contours on all sides. A partial illustration of this principle is seen in the divergent detrital slopes that sweep around the southern spur of the Granite Mountains, Fig. 11. But a contrasted condition may be imagined, in which the opposite sides of an upheaved mass drain into playas at different distances and different altitudes, so that one of the back-wearing flanks of the range will come to undercut the other, as in Block 2 of Fig. 15. Not until a later stage of retrogression will the rocky face that separates the two slopes be consumed, so that they can meet in a rounded crest, Block 3. An example of

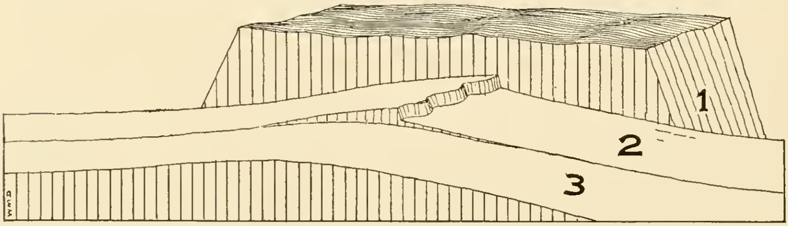

Fig. 15. Development of a scarped half-dome.

this kind occurs in the southern part of the Superior district, 13 miles north of Barstow: it is included in the southwest corner of the Avawatz sheet of the U. S. Topographic Map. A road that leads north from Barstow to the east side of the Cuddeback Arch, described below, crosses the western side of this dome, which I have called the Storrow Dome, after my companion on the two excursions which passed over its western side. Its half-domed surface, bearing scattered Joshua trees and so completely degraded that it shows no knobs or nubbins, slopes smoothly and gently northward from a convex, east-west crest which culminates at an altitude of 4100 feet; it drains to one of the playas, perhaps 10 miles from the crest,

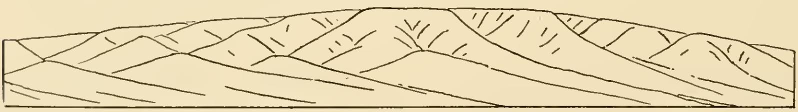

Fig. 16. South-facing scarp of the Storrow half-dome.

in the Superior district at an altitude of about 3500 feet. The south-facing scarp, Fig. 16, about 3 miles in length, has a height of from 300 to 600 feet and a slope of 30° or more, and is varied by alternating salients and entrants of moderate measure. A well graded detrital slope, beginning at the base of the scarp at an altitude of about 3500 feet, drains southeast to the Mohave River east of Barstow, 15 miles away, at an altitude of 2000 feet. The difference of altitude between the two local baselevels thus amounts to 1500 feet, and therefore suffices to account for the unsymmetrical form of the dome. Although granite boulders are seen here and there, the scarp is not craggy but smoothly graded and its basal profile is curved.

An Unsymmetrical Member of the Bullion Mountains. A less mature example of unsymmetrical degradation, differently conditioned from the Storrow Dome, is found in a branch of the Bullion Mountains which overlooks the broad Bristol playa of the Barstow-Cadiz trough from the southwest and which adjoins the above-described pass on the northwest. The northeast face of the branch-range, draining directly to the playa, rises boldly from the detrital deposits at its low base directly to the high crest, as in Fig. 17; but the southwest face, which consists of irregular

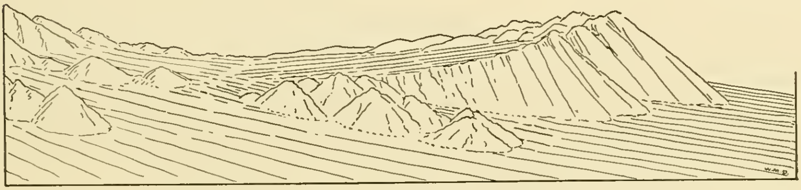

Fig. 17. Unsymmetrical degradation in the Bullion Mountains, looking northwest.

knobs of small relief, rises from an opposite detrital slope, the head of which has ascended to a considerable altitude because of the long course of its sheetfloods around the southeast end of the branch-range to the same playa. As the northeast face retreats farther and farther, it will consume more and more of the present crest and of the detrital cover behind it, until it undercuts the main range, 3 or 4 miles to the south. The desert probably contains other examples of this kind in earlier or later stages of degradation, but none that I have seen is so striking as this one.

The Kelso Mountains. An instructive group of back-wearing granitic mountains and unfinished domes is shown on the Ivanpah sheet of the U. S. Topographic Map on a scale of 1:250,000, with 100-foot contours. It rises along the northwest side of the Crucero-Cima trough, which is followed by the Union Pacific Railroad in a long upgrade. The largest mass of the mountain group occupies an area of about 5 by 6 miles and culminates in Kelso Peak with an altitude of 4746 feet. It is followed for 10 miles northeastward by other mountains of less size and height, the graded passes between them having altitudes of 3500 or 4000 feet. Still farther to the northeast is the finished Cima Dome, Plate 12. The fine highway that connects Los Angeles with Salt Lake City via Las Vegas, Nevada, passes 10 or 15 miles farther north; a good cross-road over the eastern side of Cima Dome connects the highway with the railroad.

The western part of this mountain group was seen only from a distance of several miles to the south. The irregular mountain faces advance in many points and retreat in as many bays, most of which have ragged or frayed-out patterns and therefore served me as types for the fan-bayed and fan-frayed stages of mountain retreat in an earlier paper (1925). As the ragged mountains are traced northeastward they diminish in size and height; then even the diminished residuals disappear and the graded slope, which farther west stopped in the bays, ascends to the crest and seems to arch over it. The crest, which has an undulating skyline, deserves to be examined more closely in order to measure the breadth of its convex profile; but I am persuaded that the convexity begins before the lowered rock residuals come to an end and then continues after they disappear. In view of the strong rock faces of these mountains, it would seem probable that they originated as upheaved fault-blocks, and therefore deserve to be classed with Gilbert's Basin Ranges.

The Cima Dome. One of the most profitable lessons of this district is found in the continuity of the undulating and apparently convex crest from the ragged Kelso Mountains northeastward to the perfect Cima Dome; for in the absence of a retreating rocky face on that dome, one might be uncertain, as long as it is considered alone, whether it had been produced by back-wearing or by down-wearing degradation. But the strong though ragged rocky faces in the Kelso Mountains make it clear that they are in process of back-wearing degradation, and their close relation to the Cima Dome, as well as their direct connection with it by what may be regarded as a series of closely confluent domes, leaves no doubt that it is a completed product of the same back-wearing process that they are passing through. Hence it, like them, probably began as a fault-block.

The convexity of the dome, Plate 12, is so perfect that it may be said to realize an ideal. My first sight of it was from the railroad, which passes close along its southeastern side, in 1925. It was visited in the spring of 1932 with Mr. Storrow, when several trails, not too rough to be followed by a strong and well driven car, led us up some of the slope lines toward the broad dome top. The name here given to the dome is Spanish for summit and is taken from that of a near-by railroad station in an open pass at the southern end of the Ivanpah range. The lower detrital slopes are, like those of the neighboring mountains, dotted over with creosote bush (*Covillea tridentata*), but while the neighboring mountains are relatively barren, the higher arch of the dome is occupied by a forest-like growth of that strange member of the lily family, the "maniacal Briaereus of the desert, frantic with meaningless gesticulations," known as the Joshua tree (*Yucca arborescens*), with which junipers, always spoken of as "cedars" in the arid west, are associated. The summit of the dome has an altitude of 5710 feet; its contours, Fig. 18, are roughly circular; the

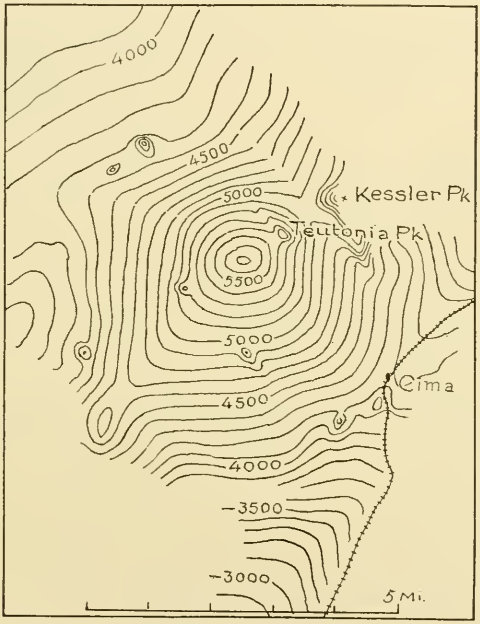

Fig. 18. The Cima Dome, from Ivanpah sheet, U. S. Topographic Map.

diameter of its circuit at the 4500-foot contour is a little over 4 miles. Teutonia Peak is a good-sized residual mount on its eastern side. Several smaller knobs and a multitude of bouldery nubbins, Fig. 19, are scattered like roc's eggs, over its crest and slopes; a few softly rounded residual mounds, Fig. 33, of aplite or other fine-textured rock are also seen here and there. The concave flanks of the dome are built up with detritus, but by far the greatest part of its convex surface is a smooth top of weathered rock. Kessler Peak, 6152 feet in altitude, the southernmost outpost of the Ivanpah range, rises near-by on the east. Three springs are mapped on the dome at altitudes of 5020, 5150 and 5350 feet. It seems probable that their emergence is guided by joints in the granite and that they therefore stand above the margin of the detrital cover. If so, the height of the dome summit above the cover margin would be 500 or 600 feet, and the dome diameter at the cover margin would be about 2 miles.

The slopes, which hardly exceed a 4° declivity at their steepest part around the circle of inflexion between the convex top and the concave lower slope, do not show true stream courses, but are faintly channeled by the innumerable enmeshed flow-lines of sheetfloods. These floods must,

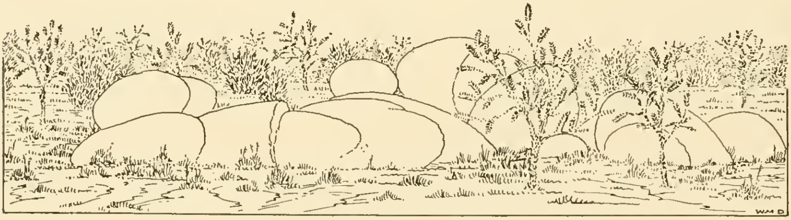

Fig. 19. Residual granite boulders near summit of the Cima Dome.

as a rule, spread to greater and greater width as they run down the diverging lines of slope, and the spreading must be most rapid near the dome top. But where the convex contours on the northern slope of the dome meet the contours on the northwestern slope piedmont to Kessler Peak in inturning angles, a true stream has excavated a well defined channel in the alluvium; for there, as is usual in such locations, sheetfloods from the two slopes must converge and join forces in a linear stream.

This beautiful dome is so broadly convex that its highest point is diffiicult to locate. It is very unlike a ridge, for there one identifies the upper edge, where ascent stops and descent begins, easily enough. On mounting to such an edge, one finds that it is at once a case of *ne plus ultra,* as far as altitude is concerned. But on so broad and perfect a convexity as that which the Cima Dome possesses, one wanders about uncertainly as the top is approached, because the direction of the final ascent there is more and more difficult to determine. While pushing on one repeatedly thinks the top must lie where the gentle convexity of the surface, as seen through the scattered trees, carries it out of sight a few hundred feet ahead; yet on reaching the line of its disappearance no summit is found, but only more convexity. The ascent of a dome is therefore almost a case of *semper plus ultra;* and for that reason I did not reach the summit.

An appreciative description of the dome has been written by Thompson in his account of the Mohave Desert region, as follows: "Northwest of Cima the land rises with a rather gentle uniform slope, like an alluvial slope, to a nearly dome-shaped summit. . . . Many outcrops show that [the upper part of] this dome is composed of granite and is not an alluvial slope, as it appears to be, but an erosional slope or mountain pediment beveled across the bed rock. It may have a thin veneer of alluvium on top of it, but at most this is only a few inches or a few feet thick. It is difficult to tell where the alluvial slope [which is hundreds of feet deep in the near-by valleys as shown by wells] ends and the erosional slope begins, for the decayed granite in place is much like the soil of the alluvial slope" (1929, 550, 551). Lawson's brief mention of the dome as a "mountain ridge . . . . almost completely buried in its own alluvial waste" (26:7) is therefore inadequate.

It has been suggested above that, in view of the neighborly relation of the finished Cima Dome to the Kelso Mountain group with their striking rock faces, the dome is a completely graded part of a Basin Range fault-block, which may very well have included the Kelso Mountains also. It may be added that the occurrence of a fault scarp buried under the detrital cover on one or the other side of the dome may perhaps be determined by the penetrating devices of modern geophysics; also that, in view of the broad convexity of the dome, its original highland surface, which may be regarded as an early uplifted part of what I have called the "Powell surface" of the Great Basin region (1925), was not much higher than its present summit; also that sheetflood erosion, from which all of its convex slopes have long been suffering, has somewhat degraded not only its rock floor but probably its detrital cover as well, so that the overlap of the cover is now less than it was formerly. These are extensions of the inferences based on the general principles developed above, in the section on Rock-floor Robbing.

Perfect as is the convexity of this beautiful dome, it does not completely demonstrate the truth of the principle that the production of a convex profile begins during the later stages of mountain degradation, when the residual ridges and knobs are reduced to so small a size that rock-floor robbing sets in; for it is conceivable that the present convexity of the dome might result from the slow degradation of a blunt-angled cone. Hence it is only because of the apparent truth of the principle of rock-floor robbing that the dome is believed never to have had a blunt-angled summit.

The Noble Domes. The Cave Spring road, between Barstow and the Granite Mountains, crosses several confluent granitic domes which, as they have no designation on the Avawatz sheet of the U. S. Topographic Map, where they are very imperfectly represented, I have named in my notes after Dr. L. F. Noble, who first guided me there several years ago. This group of domes has been visited three times since then, and a good part of the dome that is crossed by the road has been carefully examined. Much of its surface has thus been found to be delicately marked by an elaborate branchwork of shallow and minute stream courses, quite unlike the enmeshed lines of sheetflood flow which characterize the slopes of the

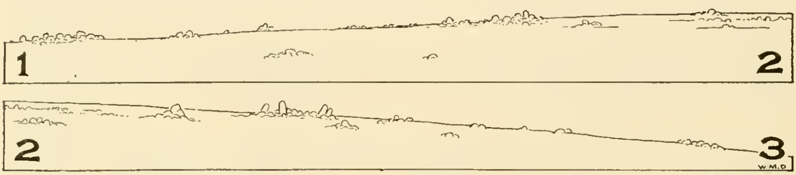

Fig. 20. Profile of the Noble Dome, looking east.

Cima Dome as well as the bahadas of the many less completely degraded mountains in the desert region. Hence, in spite of the nicely developed convexity of these domes, as shown in Fig. 20, they are regarded as the advanced work not of back-wearing but of down-wearing degradation, and their description is therefore postponed to my second paper, where it will be presented as a means of emphasizing the work of sheetfloods by the light of contrast.

Low-Grade Domes between Barstow and Lancaster. The western part of the Mohave Desert, between Barstow and Lancaster, contains a number of low-grade granitic domes of faint but remarkably regular convexity. Residual granitic boulders are sometimes seen on their slopes. Where the domes are confluent, as not infrequently happens, a forward

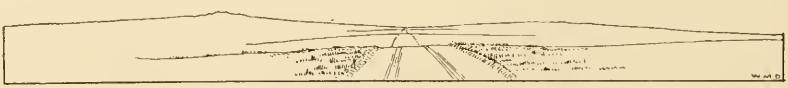

Fig. 21. Low-grade domes near High Vista, between Barstow and Lancaster.

view along a road which passes over them, sometimes on a land-office line, gives an indication of their gentle undulation, Fig. 21, and Plate 15, Fig. 1, which apart from their profiles is not clearly shown in their featureless surfaces. Some of them have been encroached upon by lateral erosion where the Mohave River north of Victorville has widened its flood plain at their expense; gulleys there incised in the steepened slopes as well as

Fig. 1. Deceptive appearance of angular change from lower to upper part of a bahada; Coxcomb Mountains, looking east. (Photo by Storrow)

Fig. 2. Slightly dissected rock floor in pass between Bullion and Sheephole Mountains, looking east. (Photo by Storrow)

occasional roadside cutcrops reveal deep weathered rock or caliche. Some of these domes are delicately carved by shallow, in-branching valley systems, as if they, like the Noble Domes, were the work of down-wearing degradation. However that may be, all of them are in a later stage of their evolution than the Cima Dome, and therefore like it they do not absolutely prove that, at the time when their last residual knobs were consumed, they already had a broadly convex instead of a blunt-angled summit. Further northwest, toward Mohave, broad expanses of the desert are reduced to the faint relief of a well advanced peneplain, except for well-spaced knobs, probably volcanic necks, as in Fig. 22. This area is one of the very few

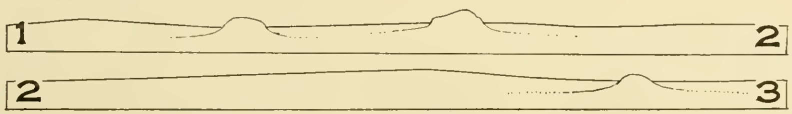

Fig. 22. Undisturbed peneplain in the Muroc-Llano district.

that I have seen in which an undisturbed peneplain is still suffering a continuation of its slow degradation.[12]

Singularly enough, the long repose of this greatly degraded district has not been disturbed by the strong upheaval of the mountain ranges on the north and south. A mile north of Victorville a highway cut shows the outwashed gravels from the southern or San Gabriel Mountains resting on the graded rock floor of an uncompleted dome, over which the granitic Silver Mountain, apparently a northwest-tilted fault-block, still survives; and as that uncompleted rock floor represents a much shorter period of undisturbed degradation than do the completed, low-grade domes to the northwest of it, they must have remained undisturbed since a somewhat remote geological date. It is for this reason that they may be regarded as resembling, if indeed they are not an undisturbed part of, the wide-spread "Powell surface" of advanced degradation, which occupied a vast area from Arizona and Utah across Nevada and well into California, before the upfaulting of the Basin Ranges and of their larger associates, the Wasatch Mountains on the east and the Sierra Nevada on the west.

The Cuddeback Arch. From 25 to 45 miles northwest of Barstow

[12] The advance sheets of the U. S. Topographic Map of Los Angeles County, on the scale of 1:24,000 with 5 foot contours, cover part of this district; the West Alpine, Lovejoy Springs, Llano and Black Butte sheets include several striking examples of residual mounts and graded piedmont slopes.

is a granitic arch of impressive dimensions, the finest example of its kind that I have seen. As it has no designation on the Searles Lake sheet of the U. S. Topographic Map, I have named it after the Cuddeback playa to which its southwestern slope drains. On two excursions, first with Mr. Hunt, later with Mr. Storrow, I have had the satisfaction of seeing this arch along both its sides and of crossing over it near the northern end. It is about 20 miles long, northwest-southeast, 2½ miles wide at the 3700-foot contour line, and 4000 feet or more in altitude along its remarkably even crest, or 1500 feet in height above the Cuddeback playa.

From the floor of the playa, the long double curve of ascent to the simple arch crest, 10 miles distant, is an extraordinary, a most impressive sight. Its perfection of smoothness, as seen from that distance, might seem monotonous and uninteresting to a searcher for more striking forms, but to a student of desert degradation it is wholly satisfying. The surface of the arch is, however, interrupted by several rather large residual mounts, as shown in Fig. 23. One near the northern end has a length of 2 or 3

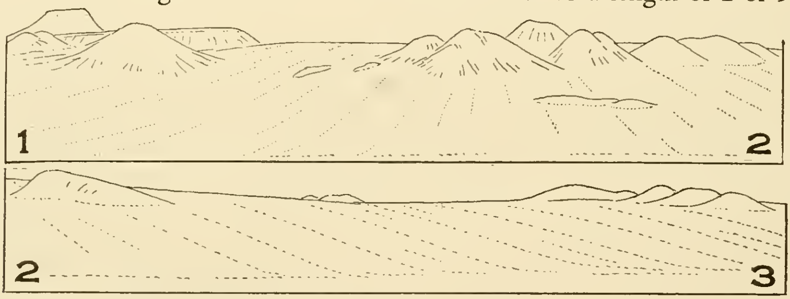

Fig. 23. The Cuddeback Arch, looking east; Pilot Knob in left background.

miles and an altitude of 4615 feet; it is the southernmost of three tabular, basalt-capped masses, which show that a considerable depth of degradation has taken place hereabouts in the production of the Cuddeback Arch, since a previously degraded surface of low relief was buried by the lava sheets and more or less upwarped. Pilot Knob, a famous landmark about 5 miles to the east, gives evidence of still greater degradation; it is capped with earlier volcanic beds on a higher granite floor, which probably marks an earlier surface of degradation than that on which the basalts were outspread.

Another residual rises on the mid-crest of the great arch to an altitude of 4682 feet, or to a height of some 500 feet over the arch; branches from it extend down both slopes. Several hills on the west slope of the arch near its southern end have altitudes of 3800 or 3900 feet. There can be no question as to the broad convexity of the arch crest, in view of Plate 15, Fig. 2, which shows it as seen from the summit of a transverse road, next south of the steep and talus-covered scarp of the northern basalt table. The eastern side of the arch is less regular than the western: a little to the north of its mid-length a somewhat lower arch, also with a broadly convex crest, branches out eastward and connects with an adjacent range of subdued summits, in which the now vanished "Copper City" was located. Taken as a whole this great arch stands as a willing witness for the process of rock-floor robbing by sheetfloods.

Two Granite Arches near Needles. Two examples of rock floors rising above the feather-edge of their lower detrital covers are described by Lawson from the eastern part of the Mohave Desert, as follows: "This emergence of the bench and its persistence as a subaerial feature appears to be most characteristic of granite ranges which disintegrate into fragments consisting chiefly of the individual mineral constituents, and therefore very uniform in size. The phenomena are exemplified in the group of mountains in southern California west of the Colorado River near the Needles. . . . Here broad alluvial embankments, from six to ten miles across, rise by a gentle slope to the summits of the ranges, where there are residual rock crests or 'nubbins,' and stretches where the crest has entirely vanished as a protuberance above the general slope. Within a mile or more of the summit one passes, without appreciable change of slope, from the alluvial detritus of the embankment on to a bare rock surface extending to the nubbins of the crest. The upper limit of the alluvium is a feather-edge" (37:9-38:3).

This description was not, however, based on Lawson's own observations. A foot note explains that it was supplied by two members of "the geological staff of the Southern Pacific Company," thus suggesting that the delicate difference between a blunt-angled ridge and a round crested arch, which is here under consideration, may not have been critically noted, for the two observers presumably had no such distinction in mind; and suggesting also that, in the absence of specific statement, Lawson's rephrasing of the observers' description as given above was brought into accord with his theoretical views as to the shape that degraded mountain masses should have, just as my expectation of the shape they should have was guided, before I saw either of the divides, by my theoretical views of their origin.

Half-tone plates of both examples are given in Lawson's essay, but they do not suffice to decide the question at issue. One is described on a fly-leaf opposite its plate as a "divide south of Sunrise Peak, 20 miles southwest of Needles. The upper feather-edge of the alluvial embankment fails to reach the base of the subaerial front, and a bare even rock surface one or two miles wide, having the same angle of declivity as the embankment, extends out from the 'nubbins' at the summit. Beyond this

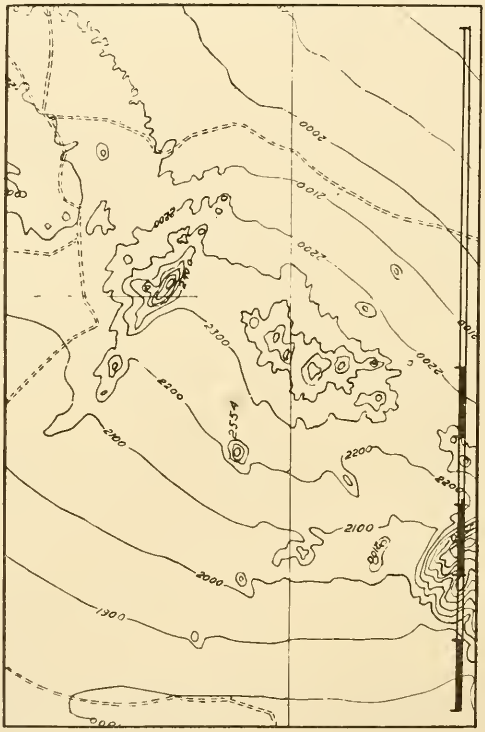

Fig. 24. Divide 20 miles southwest of Needles; from map by Southern California Metropolitan Water District.

the slope has a width of from 6 to 8 miles to the base of the alluvial embankment." The other is "Manchester Divide, near Needles," which is briefly described as having an "alluvial embankment extending up to base of 'nubbins' or residual crest of mountain range. An approximation to the panfan stage of the desert cycle. The subaerial front is small and the suballuvial bench and alluvial embankment both large, the latter being from 8 to 10 miles in width."

The Manchester Divide is included on the Camp Mohave sheet of the U. S. Topographic Map, but as that sheet, on a scale of 1:250,000 with contour intervals of 250 feet, was published in 1892 from still earlier surveys, the topography is very inadequately represented. The Needles sheet adjoining on the south does not extend far enough to the west to include the other divide; but both are fortunately shown on sheet 68 of the topographic map of recent survey for the Metropolitan Water District of Southern California, on a scale of one inch to 10,000 feet with 100-foot contours, in connection with the construction of the great aqueduct from the Colorado River to Los Angeles. The first, Fig. 24, is at its

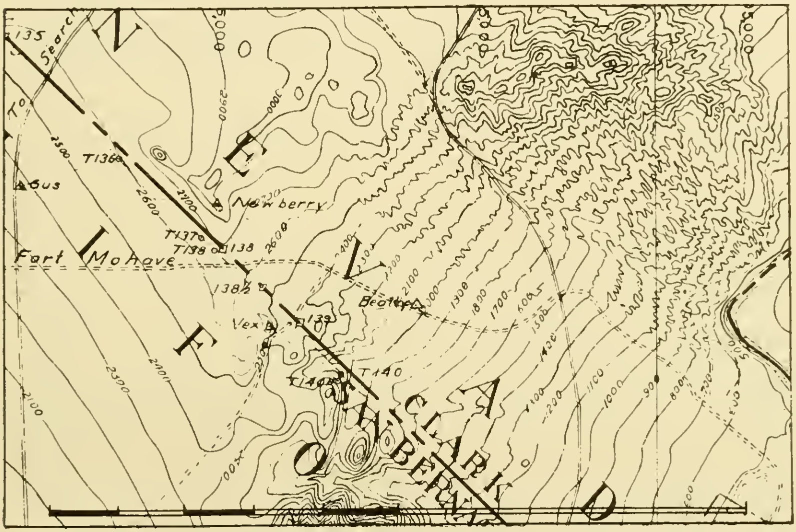

Fig. 25. Manchester divide, 24 miles northwest of Needles; from map by Southern California Metropolitan Water District.

designated distance southwest of Needles; the second, Fig. 25, is 24 miles north-northwest of Needles.

When the attempt was made with Mr. Storrow to reach the first divide, the mapped road leading southward to it from the highway (U. S. 66) along the east side of the Homer-Sablon trough proved to be undiscoverable on the ground and unknown to workmen on the highway who were familiar with other roads thereabouts. So the best that could be done was to take another mapped but execrable road, never graded, rarely used and wholly uncared for, on the west side of the trough, to a point about 10 miles west of our goal. The divide, as then seen across the trough, is outlined in Fig. 26. Its highest summits on the left and right have altitudes of 2800 feet, the lower summits near the middle of the view rise to 2600 feet; the two smooth stretches of the crest are, in the north, between 2300 and 2400 feet, and in the south, between 2200 and 2300 feet. The axial line of the trough west of the divide lies at 1800 feet on the left and at 1700 on the right. Close scrutiny with a good field glass showed an apparent increase in the density of vegetation toward the smooth stretches of the crest, and that I interpreted to mean that the crest is broadly convex. Mr. Storrow's opinion as to the cross profile was: "It would be difficult to know when you reach the summit." I greatly regret our inability to visit this interesting locality.

Fortunately, the Manchester divide, which occupies a space over 5 miles wide in the southernmost angle of Nevada between the Newberry

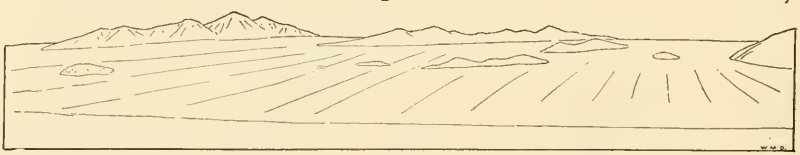

Fig. 26. Divide 20 miles southwest of Needles, looking east.

Mountains on the north and the Dead Mountains on the south, proved to be easily accessible by several rough but practicable roads that lead eastward from the highway which follows up the Piute trough to connect Needles and the Searchlight mining district in Nevada.[13] The altitude of the pass varies from 3000 feet in the north to 2400 feet in the south. Near its middle is a narrow rocky ridge, about a mile long, with knobs 200 or 300 feet high, its southern end being shown in Plate 15, Fig. 3; it is almost coincident with the oblique boundary between California and Nevada. Several smaller ridges and knobs survive near the Dead Mountains. The crest line is bowed to the west, presumably because of faster degradation on the steeper, eastern slope, where a southeastward descent is made at the rate of 300 feet in a mile to a westward curve of the Colorado River, 7 miles distant; while on the gentler western slope a southwestward descent is made into the Piute trough at the rate of 160 feet in a mile. It must be because of the unlikeness of these two slopes that the

[13] One of the cross-roads is of historic interest, as it marks the route followed in the early days between Fort Mohave on the Colorado River and Fort Tejon, 240 miles to the west in Grapevine Canyon in the curved mountain range that limits the Great Valley of California on the south. It ascends by a somewhat winding course from the river, but after crossing the divide it pursues a due west course for 12 miles across the Piute trough to a notch in the lava-capped Piute Range, through which a distant, flat-topped butte, shown in Fig. 8, serves as an excellent landmark.

eastern one now undercuts the western at the crest by 20 or 30 feet, as is shown in some detail for the southern part of the divide in Fig. 27, and in a more general view for the northern half in Fig. 28. It is apparently because of a recent westward shift of the river that much of the eastern slope has been rather sharply dissected by many close-set little valleys, after having been previously more smoothly graded.

As the crest is approached from the western side the slope gradually decreases; and for half a mile before reaching the crest the surface is almost

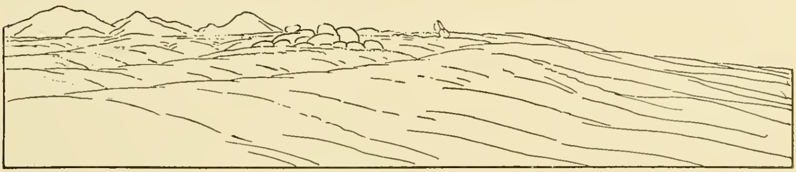

Fig. 27. Unsymmetrical crest of Manchester divide, southern part, looking northeast.

level, as shown in Plate 15, Fig. 3. When one looks down either slope from a point near the crest, the lower part slowly steepens out of sight: hence there can be no question whatever as to the convexity of the divide. The western surface is slightly dissected near the crest by inbranching valleys, 5 or 10 feet deep, and whatever detrital cover it formerly had is removed. Rock exposures are therefore abundant. Farther west the valleys disappear and the detrital cover is well developed in a mile or so; the re-

Fig. 28. Unsymmetrical crest of Manchester divide, northern part, looking north.

mainder of the descent into the Piute trough is of sheetflood smoothness without rock exposures. The cause of the upper dissection here was not discovered. To the east, the valleys continue according to the map all the way to the river in the northern part of the slope; but in the southern part of the slope no valleys are shown. As far as this slope was examined it now has little detrital cover. The fact that the cross profile of each slope is convex, in spite of the presence of several residual ridges and knobs near its crest, is significant.

Other Desert Arches. During traverses of the desert region several even, intermont skylines were noted, which could not be reached as no road led over them but which appeared to have arched or convex crests, like those above described. One of them, Fig. 29, lies next south of the

Fig. 29. Even crest line in the Piute Mountains, looking west.

lava-capped part of the Piute Range, Fig. 8, between Lanfair and Piute troughs. Another, Fig. 30, lies north of the eastern part of the Sheephole Mountains, toward the Cadiz-Vidal trough. A third lies from 20 to 40 miles northwest of the Cima Dome; it is crossed at a sag by the highway from Los Angeles to Salt Lake City. Various other examples will doubtless be found, and it is expected that their arched crests will be covered only with weathered rock in place.

Desert Granitic Domes on the Sierra Nevada. Before the Sierra Nevada was upfaulted to its present altitude, which in its highest eastern margin amounts to over 10,000 feet, most of its area appears to have belonged to an extensive, submountainous or lowland region of advanced degradation, which I have called, as already intimated, the "Powell sur-

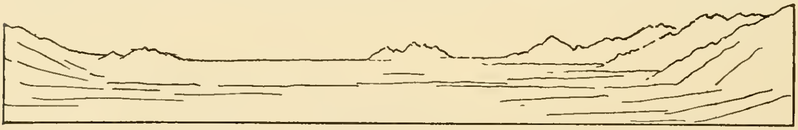

Fig. 30. Even crest line north of Sheephole Mountains, looking east.

face" (1925). The climate of its southern part must then have been much more arid than it is now and its senescent or senile forms may therefore have resembled those seen today in other parts of the same region not yet disturbed; for example, in the Muroc-Llano district of the Mohave Desert, where, as has been told above, something very like what the Powell surface is believed to have been is still to be seen. Hence, in the granitic areas of the Powell surface, more or less completely graded domes should then have been present.

The southern Sierran highlands today exhibit broad plateau-like surfaces, which are presumably the slightly modified lowlands of that earlier area; and these highlands are surmounted by residual summits of dome-like form, except that great cirques have been excavated in their flanks by Pleistocene glaciers. Lawson was the first to give good account of these mountain forms, just as he was the first to give thorough explanatory treatment to the epigene profiles of the desert; but here as there I wish to modify his explanation. He described the Sierran summits as follows:—"Several of the culminating portions of the summit divide are either flat topped, or have slopes which are so gently inclined as to be in sharp contrast to the more precipitous slopes [of glacial excavation] which abound in the region" (1903, 307). Evidently, therefore, the Sierran domes were better developed in Preglacial times than they are now; but they still rise over "a splendid plateau" (308); that is, over a part of the uplifted desert peneplain now trenched by deep valleys of later erosion. The same observer suggests that the Sierran domes represent granite batholiths, stripped of their former cover; that is, the height which they retained over the surrounding lower land before upheaval of the Sierran block took place, was the result of structural control, independent of gradation with respect to the baselevel of the time. Furthermore, while recognizing that the erosion of the lower land also might have been similarly controlled, he prefers to interpret it as "a broad valley bottom nearly at baselevel" (315).

With this latter explanation I am fully in accord, but for the former an alternative explanation is here offered, in view of the belief that the Sierran highland was, before its upheaval, a somewhat diversified desert lowland. The alternative explanation is that the granitic domes as well as the plateau which they surmount are all parts of a region of advanced arid degradation, now uplifted and much modified by ordinary and by glacial erosion. This view is preferred on several grounds: First, it is reasonably associated with the probable history of the region before the great Sierran block was upheaved. Second, the gradual slopes by which the preserved parts of the domes now descend to the plateau are strongly suggestive of their having been graded with respect to the baselevel of their time, although they were not worn down so completely as the lowland areas were; but it should be understood that the lowlands themselves may have then stood hundreds of feet above baselevel, in view of their situation at a good distance inland from the ocean shore, and in view of the relatively strong gradients of graded desert sheetfloods. But third and more significant still is the fact that the batholithic granites are less resistant to desert weathering than are the schists into which they were intruded; hence, as far as structural control was effective, the residual summits of that time should not have been granite domes but peaked and steep-margined schists over retreating slopes of the weaker underlying granites. Some such forms appear to occur in the High Sierra of today; but they are exceptional compared to the prevailing granitic domes. The domes of the High Sierra therefore seem best explained as the domes of today are.

The same explanation may, perhaps, apply to the rounded summits of the Front Range of the Rocky Mountains in Colorado, where the uplifted peneplain of the highlands—so first recognized by Powell over 60 years ago—are surmounted by well preserved domes at lesser elevations and by glacially modified domes at greater elevations, as I had opportunity of seeing during a summer field course in 1910 (1911); for before the elevation of that region, its climate must have been significantly drier than now; so much so that, following Blackwelder, we may suppose the Colorado river was then not much larger than its little tributary, the Gila, is today.

Another lesson of importance in the analysis of High Sierran forms may be learned from the desert; namely, the considerable differences of

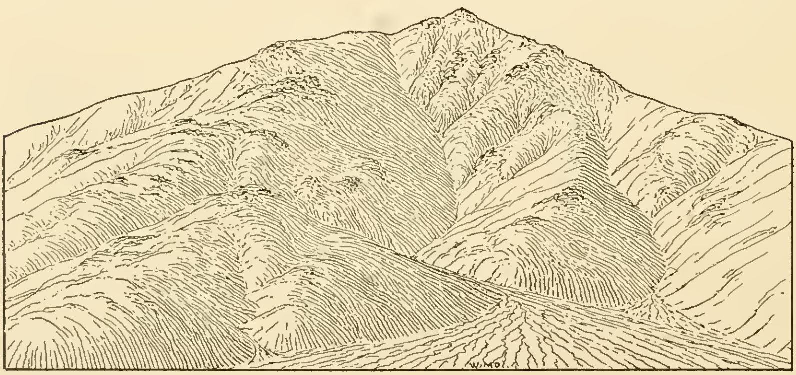

Fig. 31. Fremont Peak, looking west.

altitude between the rock floors and their domes in different parts of a worn-down arid region. For example, the crest of the northern half of the Manchester divide, described above, stands at an altitude of 3000 feet; it is connected by the continuously graded detrital floor of the Piute trough with a relatively narrow, sub-detrital, contemporaneous rock floor marginal to the south end of the Dead Mountains, 20 miles to the south, which stands at an altitude of only 1600 feet. Similarly, the rock floors on the west side of the northern Piute Mountains near the head of Lanfair trough have an altitude of 3600 feet; while contemporaneous rock floors at the base of the Ship Mountains, where the prolongation of the Lanfair trough joins the Cadiz trough, have an altitude of only 1000 feet. Evidently, therefore, desert rock floors now uplifted in the High Sierra should not be expected to have uniform height.

Examples of Non-Granitic Desert Mountains. Three good illustrations of the irregular degradation of non-granitic mountains may be selected from many others. Fremont Peak, Fig. 31, northwest of Barstow and next south of Cuddeback playa, illustrates the irregular alternation of outcropping ledges and steep-graded slopes which results from the non-homogeneous structure of these masses; also, the deep penetration of a valley into the heart of the mass, and the persistently concave basal slopes, as determined by the disintegration of their rocks into blocks, scraps and

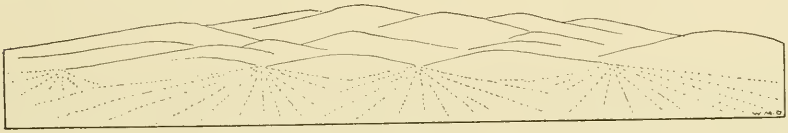

Fig. 32. Group of non-granitic residual mounts, south of Barstow.

grains of all sizes, by which the mountain passes gradually into its detritus-covered rock floor. Tiefort Mountain, next south of the Granite Mountains, like the two Ord Mountains north of the Lucerne trough, is of somewhat more massive form; but otherwise it systematically repeats the features of Fremont Peak with merely individual variations.

The best illustrations of the senescent forms of similar masses that I have seen are crossed by a road between Barstow and Stoddard Well. Quite unlike the granitic residuals which retain their steep faces until, after being reduced to mere heaps of boulders, they vanish, these non-granitic residuals have faint, smoothly graded slopes, Fig. 32, hardly distinguishable from the detrital cover of the rock floor into which they merge imperceptibly; and instead of being reduced to simple domes or arches of large but low-curved convexity, they survive as groups or belts of low mounts at the summit of long detrital slopes, Fig. 5. It would thus appear that it is not only by pattern and color of outcrops that the geological structure of a desert area may be roughly mapped from a commanding point of view, but that even where outcrops are scanty, reconnaissance work may be guided by form, at least to the extent of differentiating areas of granitic from non-granitic rocks.

Mounts of Resistant Rock on Granitic Domes. The occurrence of mounts of more resistant rock on granitic domes is not infrequent. They are often composed of aplite and then presumably represent centers of minor intrusion into the granite. They differ from surviving knobs of granite in having, by reason of their habit of weathering into blocks, scraps and grains, concave basal slopes which grade delicately into the larger detritus-covered granitic area. An excellent example of this kind

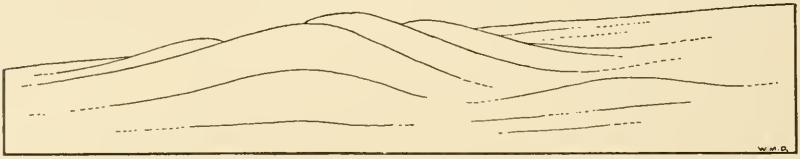

Fig. 33. Subdued aplite mounts, southeast slope of Cima Dome.

may be seen on the southeastern slope of the Cima Dome, Fig. 33; another is found on the lower part of the long bahada which slants southward from the Granite Mountains to Bicycle playa, Fig. 34. In their later stages these residuals are reduced to less and less convexity and eventually become, as Lawson says, "mere patches of bed rock obscured by the residual unmoved products of disintegration, nearly but not quite flush with the general slope" (1915, 32:3). The desert offers various beautiful

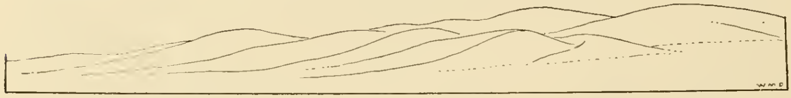

Fig. 34. Subdued non-granitic hills, at southern base of Granite Mountains.

examples of such vanishing mounds. The most delicate one that I have seen is not far east of Stoddard Well on the road that leads toward Ord Mountain, about 8 miles south of Barstow.

Concluding Remarks. It will have been noticed, especially by petrographers if any are included among my readers, that the mountain-making rocks of the desert are here classed simply as granitic and non-granitic. This is because it has been impossible for me to attempt a better classification. It is therefore to be expected that, when a better classification is made, various new details as to mountain forms will be discovered. In the meantime I hope that the distinctions here recognized between the two classes of rocks, by reason of their different habits of disintegrating and their resulting differences of form, may hold good and prove to be of serviceable interest to students of desert landscapes.

Fig. 1. Low-grade domes near High Vista, between Barstow and Lancaster.
(Photo by Hunt)

Fig. 2. Broadly convex crest of the Cuddeback Arch, looking south.
(Photo by Storrow)

Fig. 3. Level crest of Manchester Divide, southern part, looking southeast.
(Photo by Storrow)

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