QUATERNARY FAULT STRUCTURE
OF THE
BISHOP REGION, EAST-CENTRAL CALIFORNIA

Thesis by George F. Taylor

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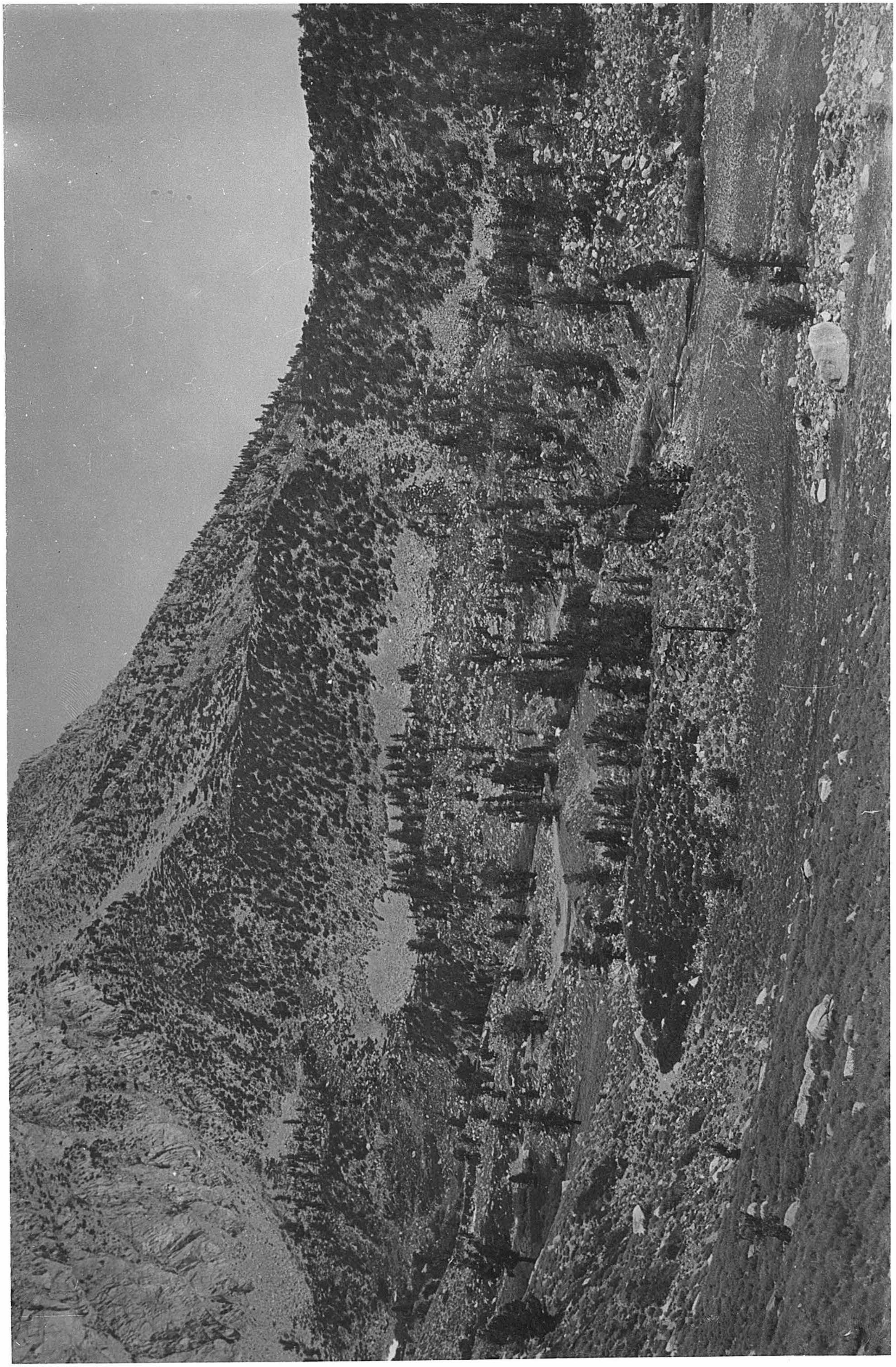
Plate 2

Recent scarplet crossing McGee Creek. This fault feature cuts the prominent lateral moraine in the middle distance a short distance to the right of the middle of the photograph and continues south across the stream bed as a sharply defined scarp. See page 72.



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SUMMARY

This paper presents the results of an investigation carried on during 1932 of the Quaternary geologic structure and stratigraphy of the Bishop Region, eastern California. Close relationship of structural and stratigraphic data has resulted in the formulation of a rather complete outline of the later geologic history of the region.

Contributions to the stratigraphy of the area include the establishing of the Zurich formation to embrace Pleistocne "lake beds" and fanglomerate. Both the tuff-breccia and pumiceous breccia of the Volcanic Tableland are grouped as the "Bishop formation". The Zurich formation is shown to be at least partly contemporaneous with the Bishop formation.

The piedmont faults of the region have been accurately located by numerous recently formed scarplets. A very noticeable offset in the Sierran base southwest of Bishop is described and termed the Bishop Offset. The type of sloping surface lying between two faults which diminish their throws in opposite directions, as present in the Bishop Offset, is described as a newly recognized geomorphic form and named a "Scarpramp".

The Sierra Nevada is believed to have been uplifted a considerable amount since the Inyo-White Mountain Range attained approximately its present elevation. The effect of this recent uplift on the climate of Owens Valley is discussed.

Deep Spring Valley and Cowhorn Valley are shown to be similar fault outlined features, each the result of the dropping down of a lozenge shaped block in the interior of the range along normal faults. The east wall of Deep Spring Valley was formed considerably more recently than the west side.

The Sierran piedmont fault zone is generally narrow but becomes distributive at some localities.

INTRODUCTION

The area described in this paper lies in northern Inyo County, California, about 225 miles north of Los Angeles, and includes portions of the Sierra Nevada, Owens Valley, the White Mountains, the Inyo Mountains, and Deep Spring Valley. Although this region has long been recognized as being of exceptional interest to the geologist, it has been the subject of but little detailed investigation. As early as 1872, J.D. Whitney, geologist in charge of the second California State Geological Survey, visited Owens Valley to investigate the results of the disasterous 1872 earthquake and apparently recognized at that time the tectonic origin of the valley, although he does not appear to have realized the recency of the faulting along its margins. (1, p. 290) Clarence King had passed through the territory somewhat earlier but he published very little bearing on its structure.

Charles D Walcott visited Owens Valley several times about the turn of the century and published papers concerning the Cambrian faunas of the Inyo Range and an article describing the Waucoba embayment (10). A most excellent reconnaissance report of the Owens Valley region by Adolph Knopf and Edwin Kirk appeared in 1918 but the limitations of time imposed on these workers apparently made a delineation of the structure a practical impossibility. As a result, their work, although rather complete in its stratigraphic information, contains very little structural data (2). It seemed, therefore, that this region should present exceptional opportunities for a detailed study of its recent structure. With the elucidation of this general subject in mind the author carried on field work during the Spring, Summer and Fall of 1932. The problem originally undertaken, a study of the Quaternary structure, has grown in scope somewhat as the field work has progressed, but the aim throughout has been to treat this problem and closely related ones to the exclusion of other interesting subjects. The old meta-sedimentary series of the White Mountains, for instance, offers an exceptionally attractive field of study to the structural geologist, but this problem is obviously unrelated to the recent structure and so was not considered during the field work.

ACKNOWLEDGMENTS

The writer wishes to express his thanks to Professor John.P. Buwalda of the California Institute of Technology who supervised this problem. Dr. Buwalda suggested it originally, offered numerous valuable suggestions throughout the course of the field work and in many ways made the carrying out of the project a pleasant as well as an interesting task. The work in the Waucoba embayment, east of Big Pine, was carried on jointly by Dr. Buwalda and the writer, and is incorporated in the present thesis by Dr. Buwalda's kind permission. The writer, however, assumes responsibility for all conclusions reached in this paper.

Especial thanks are due to my brother, Mr. W. T. Taylor whose financial assistance has made possible in large measure the present investigation.

A conscientious effort has been made throughout this

paper to differentiate carefully between proved facts acceptable to anyone and hypotheses of the author, some perhaps acceptable to no one. Geology, particularly physiographic geology, is largely inferential, and it is inevitable that differences of opinion will arise in the interpretation of field data. The less data the greater the variety of interpretations. It has been the author's constant aim to present all sides of contentious questions -- whether he has been successful is extremely doubtful, but if he has been able, on the whole, to refrain from dogmatism to conceal his own uncertainties, he will feel that his efforts have not been entirely in vain.

GEOGRAPHY

The Sierra Nevada (Spanish, "Snowy range"), a portion of which was investigated during the preparation of this paper, extends in a practically unbroken line from Tehachepi Pass on the south, to the vicinity of Mount Lassen on the north, a distance of over 400 miles. (It is suggested that the Sierran unit be delimited by the Garlock and San Andreas faults on the south, and by the Lassen lava field on the north.) The general form of this great range varies somewhat but essentially it is a tilted block, bounded on the east by a steep scarp which rises to its summit within a few miles of its eastern base; from the summit its rather gentle slope extends westward until it merges with the Sacramento and San Joaquin valleys some 30 to 60 miles distant. The northern portion of the range has been affected by relatively recent faulting at several places a considerable distance west of its crest (7, p.42). The southern part has been faulted along and near its western margin between Bakersfield and Merced (3).

The gentle western slope is well watered by winds from the Pacific Ocean -- rainfall varies greatly with latitude and altitude but generally exceeds 30 inches. As these winds rise higher and higher in crossing the mountains, they drop more and more of their moisture until they reach the crest, as they pass down the precipitous eastern slope they contribute comparatively little rainfall to this side of the range. As a result of this desiccating effect of the Sierra Nevada, Owens Valley is relatively very arid, the average rainfall at Bishop (at an elevation of 4147 feet) being less than 7 inches per year. The farther east we travel, away from the ocean, the smaller is the amount of rainfall. Death Valley, partly below sea level and in the lee of several great mountain ranges receives the minimum of the southwest region.

The differences in rainfall are well shown by the changes in vegetation that occur from west to east across the Sierras and the region to the east. The sagebrush-covered floor of San Joaquin Valley (except where it has been irrigated) yields to the manzanita slopes of the foothills which in turn merge into the lower coniferous zones of the mountains. Conifers are present continuously from an elevation of 3000 to 4000 feet to the timber line at about 11,000 feet. The eastern slope of the Sierra shows approximately the same succession of vegetation although the much smaller rainfall is indicated by the relative thinness of growth. The floor of Owens Valley, receiving only 5 to 7 inches of rainfall a year, exhibits the sparse plant cover typical of the arid regions of the southwest. To the east of Owens Valley, pines occur only at elevations above 9000 feet -- below them a scraggly belt of junipers.

Extreme dryness thus characterizes the region east of the Sierra, although this very feature which seems to retard erosive processes has made of it an ideal place in which to study recent geologic activity.

An unfortunate confusion has arisen in connection with the name of the range of mountains which forms the east wall of Owens Valley, the northern half has been called the White Mountains and the southern half the Inyo Mountains. Since the entire range is a distinct, unbroken, orographic unit, the use of two names is undesireable but both of them have become established firmly by local usage and cannot very well be discontinued. The southern portion extending from the Coso Range south of Owens Lake north to the Waucoba embayment east of Big Pine has been called the "Inyo Mountains", and the northern part, extending from the Waucoba embayment to Montgomery Pass has been called the "White Mountains". This usage will be continued in the present paper. When the entire range is referred to, it will be called the "Inyo-White Mountain Range".

The range is bounded on the east, from south to north, by Saline Valley, Eureka Valley and Fish Lake Valley and contains as an integral part Deep Spring Valley. All of these valleys are closed desert basins containing no perennial streams and thus are not "valleys", sensu stricto, but it seems futile to call them by any other name when the word valley has such a tenacious claim both by usage and priority. If we are to redefine old, long-established words such as this one, we are attempting to establish lexicographic leadership that hardly seems justified. Defining carefully both as to meaning and place of application any new term that an author intends to introduce to an already sated literature is commendable but to attempt to restrict narrowly the meaning of old, well-known words seems to be an unwarranted exhibition of missionary zeal.

Owens Valley and its climatic conditions are peculiarly the concern of Los Angeles, since the southern city at the present time obtains most of its domestic water supply from that region. Development of the Colorado River aqueduct will eventually make Southern California more or less independant of Owens Valley, but at the present time the precipitation in the Inyo-Mono area is of the greatest importance to Los Angeles residents. Further, the geologic structure of Owens Valley is of very great concern to the people of Los Angeles, since the safety of the Owens River aqueduct is intimately related to possible movement on the fault system of the valley. The region discussed in the present paper does not cover those parts of the valley traversed by the aqueduct but the recent geologic structure of the entire valley is much alike.

A few words concerning the water supply of Owens Valley may not be amiss if they present some understanding of the long controversy between the residents of the valley and the City of Los Angeles. When it became evident some 25 years ago that water sufficient to meet the needs of Los Angeles could not be satisfactorily developed in Southern California, the city made arrangements to buy certain water rights in Owens Valley and to construct an aqueduct to lead the water south. Since Owens Valley before the construction of the aqueduct was a fairly successful farming community and because Los Angeles now uses practically all of the water in the valley it was inevitable that agriculture in the Owens Valley region should cease. This has caused a great exodus from the valley and the arising of a feeling of rancour in the hearts of the people who have stayed to see once prosperous farms return to sagebrush. Such resentment is entirely expectable under the circumstances, even though the city has in the main been more than generous in its business dealings with the land owners.

The highest claim on any water supply -- domestic use-- has supplanted use for irrigation in this case as it has in many others, and as it will undoubtedly continue to do in the future.

MAP

As a base on which to plot the structure, U. S. Geological Survey topographic maps have been used. The Bishop quadrangle and portions of the Mt. Goddard, Mt. Morrison, White Mountain and Lida quadrangles were employed. All but the latter are on a scale of 1:125,000; the Lida sheet was enlarged from a scale of 1:250,000 to 1;125,000 for this work. The contour interval of all of the maps is 100 feet.

Faults were drawn according to the legend on Plate 1, which will be briefly explained here. At the outset of the field work it was believed to be desireable to differentiate between various degrees of certainty in fault mapping, both as to existence and location of the fault trace. Further, the date of latest activity, when it could be determined, was believed to warrent notice on the map. At Dr. Buwalda's suggestion, therefore, I undertook the preparation of a legend to show as much as possible of this information.

The only attempt, so far as I know, to do this was made in the preparation of the California Fault Map. Here, "active" and "dead" faults are distinguished (according to different standards with the two authors, however) and the certainty of location of the fault trace is indicated as has been customary, by solid, dashed and dotted lines. Nowhere, though, have I seen any attempt to differentiate faults according to the certainty of their existence. We have been led to believe that authors were either positive of the existence of the faults they mapped or did not map them! As a matter of fact we realize that the personal judgment of what constitutes certainty varies widely so the actual fault maps of a particular territory prepared by several workers often differ considerably. In order to make possible the mapping of features of whose interpretation as faults I was not certain, I devised the portion of the legend in which faults are classified as "Certain", "Probable" and "Possible".

The reader of the map can thus tell at a glance how diagnostic the field evidence is with respect to any particular fault feature. He can also tell at once the clarity of expression of the fault by noting whether its location is "Certain", "Approximate" or "Concealed". In order to make as little change as possible from existing means of showing faults, I have employed without change the usual convention of solid, dashed and dotted lines to represent certain faults whose locations are respectively certain, approximate and concealed. The other patterns of lines are simple -- two dashes with one, two and three dots to represent probable faults and one dash with one, two and three dots to represent possible faults.

Interpretation of the terms certain, probable and possible are sure to vary a great deal. My own use of the various classifications is about as follows:

Certain -- no contradictory evidence, a large amount of confirmatory evidence.

Probable -- little or no contradictory evidence, a fair amount of confirmatory evidence.

Possible -- a small amount or no contradictory evidence, little confirmatory evidence.

The use of different colors to represent the date of latest activity is not new, as has been mentioned, although the assigning of definite ages to the most recent activity has apparently not been done previously. On Plate 1, I have distinguished faults that have been active during Recent time, those active during the Quaternary (Pleistocene and Recent) and those whose date of most recent activity is not known.

GEOLOGY

STRATIGRAPHY

Although the present paper deals primarily with the recent structure and geologic history of the Bishop Region, a discussion of the stratigraphy obviously is necessary, for not only is the physiography greatly influenced by the types of rocks, but the later geologic history has been deciphered largely through a recognition of the relative ages of the many Quaternary deposits, glacial, volcanic and continental. A generalized columnar section of the region, partly after Knopf (2) is shown in Plate 3, from which it will be seen that a fairly complete geologic section from pre-Cambrian through

Plate 3

COLUMNAR SECTION

- Cenozoic
  - Quaternary
    - Recent
      - Valley fill
      - Basalt
      - Younger alluvial cones
    - Pleistocene
      - Tioga glacial stage
      - Basalt
      - Tahoe glacial stage
      - Sherwin glacial stage
      - McGee glacial stage
      - Zurich formation –– Bishop formation
  - Tertiary
    - Older volcanics
- Mesozoic
  - Triassic
    - Shales, limestones, sandstones, volcanics
- Paleozoic
  - Permian
    - Owenyo limestone
  - Pennsylvanian
    - Reward conglomerate
    - Later Pennsylvanian limestone and shale
    - Diamond Peak quartzite
    - Basal Pennsylvanian limestone
  - Mississippian
    - White Pine shale
  - Devonian
    - Middle Devonian limestone
  - Ordovician
    - Shale of Normanskill age
    - Limestone of Chazy age
    - Limestone of Beekmantown age
    - Sandstone
  - Cambrian
    - Arenaceous limestone and shale
    - Calcareous sandstone and limestone
    - Silver Peak group
    - Campito sandstone
- Pre-Cambrian
  - Deep Spring formation
  - Reed dolomite
  - Oldest sandstones and dolomites

Triassic, with the exception of Silurian, is present.

Older Rocks

The pre-Tertiary rocks consist of a great series of meta-sedimentaries intruded by a composite batholith of probable Jurassic age (2, p. 11). The meta-sedimentary rocks are confined almost exclusively to the Inyo-White Mountain Range (see Plates 5, 6 and 7), with a few small, scattered occurrences in the Sierra. The batholithic rocks are present both in the Sierra, where they form the major portion of the range, and in the Inyo-White Mountain Range where they constitute about half of the rocks exposed at the surface. Several papers concerning the pre-Tertiary rocks have been published, and the reader is referred to them for detailed information (2,9).

From the time of the great batholithic intrusions, probably during the Jurassic, until the latter part of Cenozoic time (late Pliocene of early Pleistocene) when the rhyolite tuff breccia series north of Bishop and the Zurich formation of the White Mountains were deposited, no rocks are recorded in the region covered by this report. Beginning with the above volcanic and fanglomeratic formations, however, an unusually complete stratigraphic record is available.

Quaternary Rocks

Earliest of the Quaternary deposits is the rhyolite tuff breccia series, north of Bishop, which is at least in part contemporaneous with Knopf's "Older talus cones of the Inyo Range" (2, p. 54). This latter group of beds, which

Plate 4

Tightly compressed syncline in Cambrian metamorphic rocks near Devil's Gate in Waucoba Canyon, Inyo Mountains. The difference in type of folding of competent and incompetent beds is well shown.

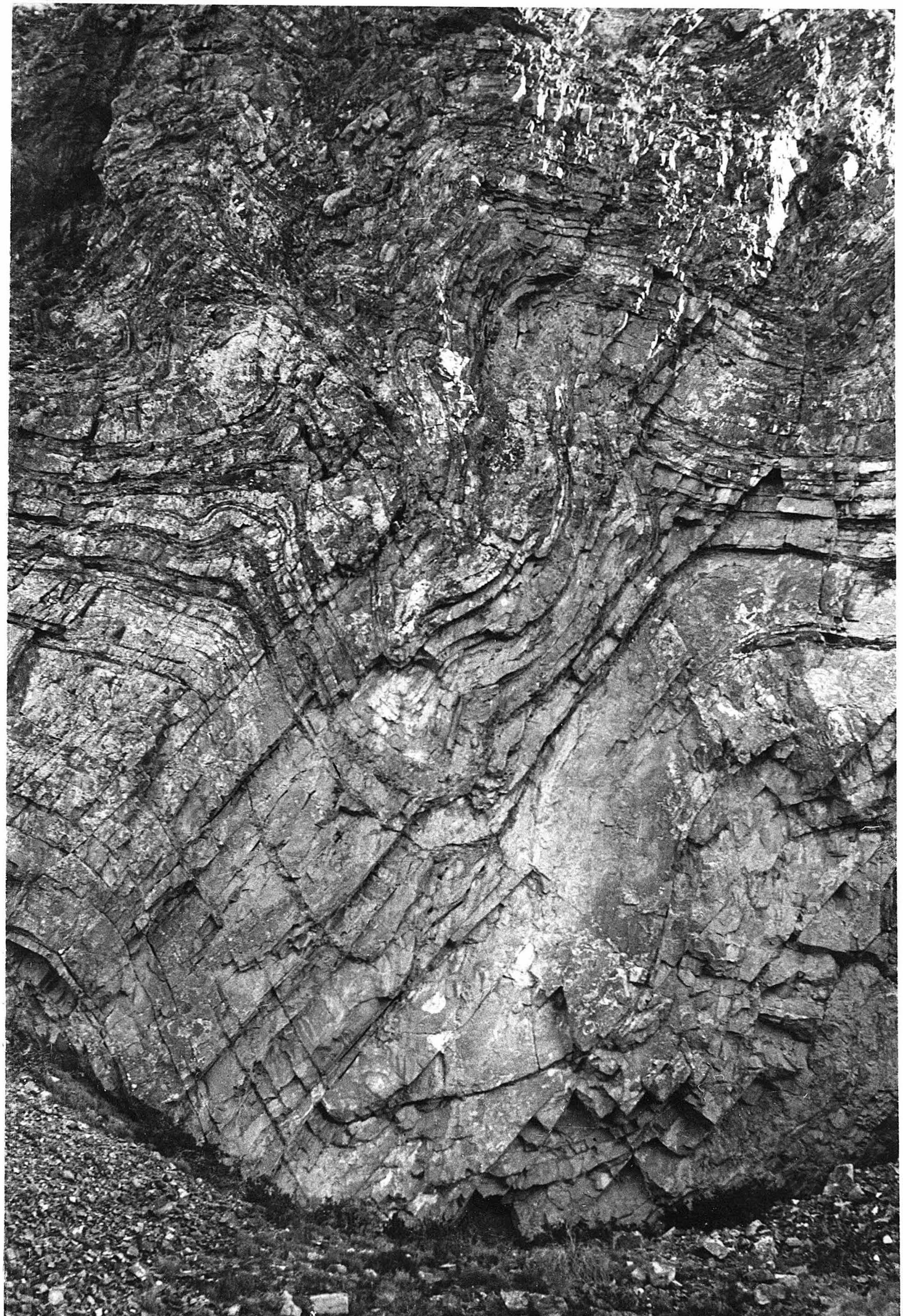


Plate 5

A. Fault along course of upper Black Canyon, White Mountains, cutting Paleozoic metamorphics. The view was taken looking north at the fault plane which dips 65 degrees to the west.

B. Detail of fracture cleavage as developed in Silver Peak group (Cambrian) near Black Canyon spring, White Mountains. The hammer lies on a cleavage ;lane. The bedding planes are shown by the alternate dark and light lines.

Plate 6

A. Detail of Campito sandstone (Cambrian) in Black Canyon, White Mountains.

B. Unconformity between Reed dolomite (pre-Cambrian ?) and Campito sandstone (Cambrian) above, near Black Canyon Mine.

have moreover proved to be largely contemporaneous with Knopf's "Tertiary lake bed series" (2, p. 48) as exposed in the Waucoba embayment, east of Big Pine, has been studied in some detail by Dr. Buwalda and the writer.

The glacial history of the Sierra Nevada, recently treated in an important paper by Blackwelder (5) has been correlated in many important respects with the older depositional history of the region as a result of the present investigation. There is some doubt about the relative ages of the oldest glacial epoch, the McGee (5, p. 902), and the Zurich formation, but the other glacial deposits are all younger than the tuff breccia series, which is believed to be largely contemporaneous with the Zurich. The two later glacial stages, the Tahoe and the Tioga, are both younger than the main body of recent cone material flanking the Sierra, while at least part of the great basalt series of the valley is intermediate between these last two glacial epochs. (2, p. 98) Lake beds in Deep Spring Valley are of late Pleistocene age. Recent wind-blown dust, stream channel filling, and superficial alluvial fan material are the most recent deposits of the region.

Zurich Formation

East of the town of Big Pine, on the western flank of the Inyo-White Mountain Range, occurs a series of sandstones and fanglomerates that indicate an interesting depositional history for this part of Owens Valley. These beds, previously noted and described by Walcott (10) and Knopf (2, p. 48) were studied by Dr. Buwalda and me during the progress of the present investigation with a view to discovering evidence for recent faulting that seemed to be indicated by certain topographic forms. During the course of the structural study certain facts concerning the stratigraphy of these beds appeared that are somewhat at variance with the conclusions reached by earlier investigators.

This series of sandstones and fanglomerates was considered by Walcott to represent a group of "lake beds" overlain by recent alluvial breccia (10) and by Knopf to represent three distinct units, a "lake bed" series and two overlying alluvial breccias of different ages (2, p. 48 et seq.). As a result of the joint work by Dr. Buwalda and me in the Waucoba region, as well as my own work farther north along the White Mountain Range, I believe that two depositional units of Cenozoic age are represented in the Waucoba embayment. Further, the "lake bed" series of Knopf is now believed to be largely contemporaneous with his "older alluvial cones of the Inyo Range". It is thought desireable to redefine the boundaries of these units.

The younger of the fanglomerates is an unconsolidated alluvial breccia, largely composed of material derived from the older fanglomerate, and it is being deposited at the present time in the canyons and along the range front. Older than this coarse alluvial breccia is a series of sandstones and fanglomerates, partly cemented, which has been previously referred to as a "lake bed series overlain unconformably by alluvial breccias" (2, p. 49). Knopf, in fact, points out localities where this unconformity may be observed (2, p. 49). I believe, however, that the series of beds lying beneath the

Plate 7

A. View in canyon to the north of Silver Canyon in the White Mountains east of Laws showing Recent fanglomerate, poorly stratified and lithified, below, somewhat incised by present stream. Above is the fanglomerate of the Zurich formation, fairly well stratified and lithified and dipping about 20 degrees to the west. Cambrian bedrock outlier against which the Zurich formation abuts is to be seen to the extreme upper right.

B. Pumice breccia stratum of the Zurich formation as exposed in the mouth of Poleta Canyon southeast of Bishop. Here the bed dips about 6 degrees to the west. Note small fault to right center with left side (west) down about 10 feet. See page

most recent cones constitutes a single depositional unit, representing various phases of one formation for which the name Zurich formation is proposed.

Since it is important in a consideration of the general relations of the Zurich formation, to establish its essential contemporaneity throughout, the field evidence adduced to substantiate this view will be presented at the outset. One of the most striking localities to show the interbedding and lateral gradation of typical "lake beds" into typical "fanglomerate" is in a small canyon about an eighth of a mile northeast of Devil's Gate. Here individual beds may be followed for nearly a half mile along their strike in a direction normal to the shore line (i.e., their contact with the ancient Paleozoic metamorphosed sediments). A complete and gradual gradation from angular, fanglomeratic material to well-rounded, relatively fine-grained "lake bed" deposits may be observed here. Overlap of the finer material on the coarser, angular breccia may be seen to excellent advantage at a locality about an eighth of a mile northwest of Devil's Gate. On the north side of the Saline Valley road at an elevation of 5500 feet, the interbedding of these coarse and fine materials may be well observed. (See Plate 8)

It seems probable that Knopf was misled by various minor local unconformities, or diastems, in his determination that the alluvial breccias overlie the "lake beds" with a "readily apparent unconformity" (2, p. 49). These local breaks in the stratigraphic sequence are observable at many places, although Plate 9, taken about a half mile east of

Plate 8

A. View showing intertongueing of "lacustral" type of deposits and coarse alluvial breccia of the Zurich formation. The breccia material lies below the "lacustral material" at this point. Photograph taken along Waucoba Canyon at an elevation of 5550 feet. See page 19.

B. Closer view of same relations shown above. The close association of coarse and fine material is well brought out in these views which emphasize the variety of deposits comprising the Zurich formation. See page 19.

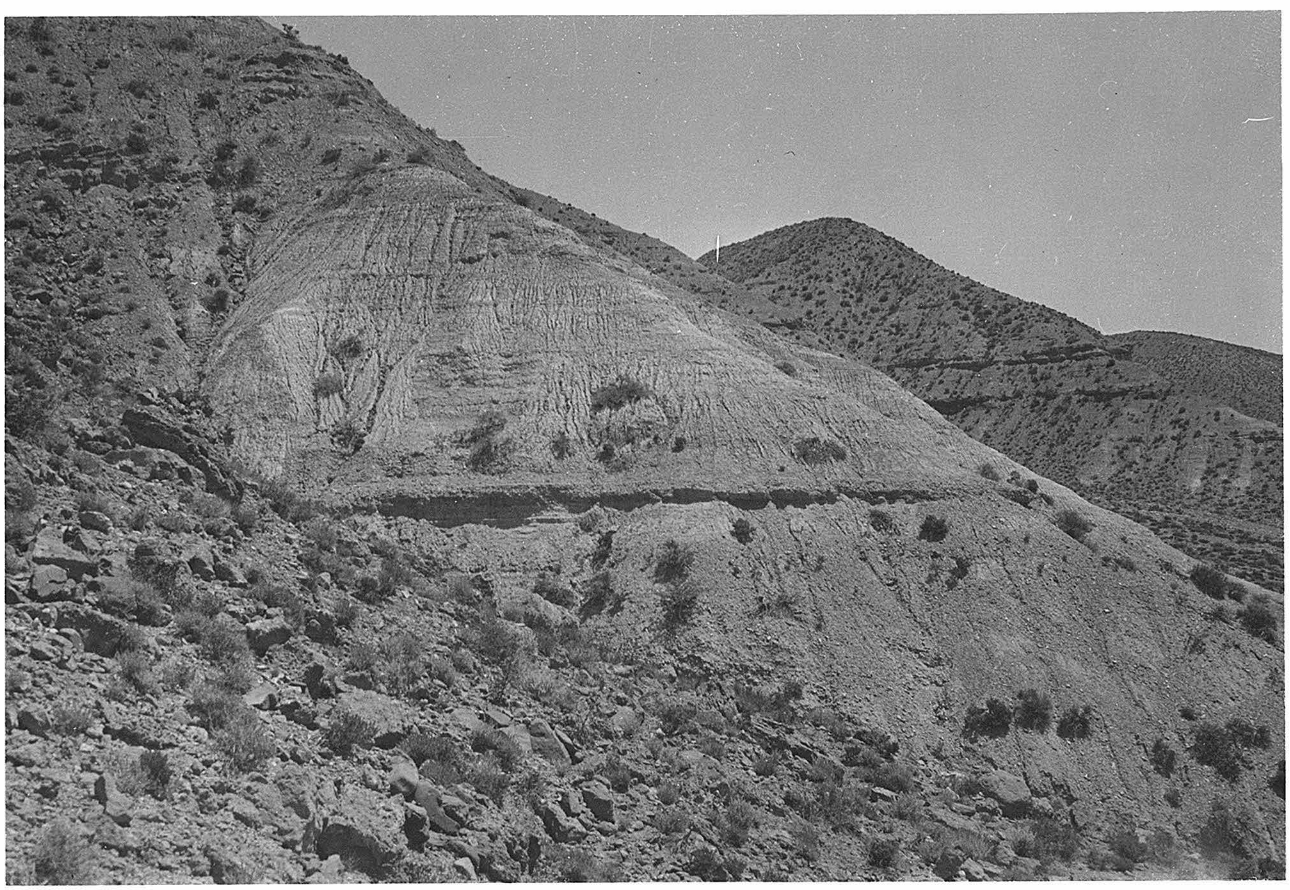
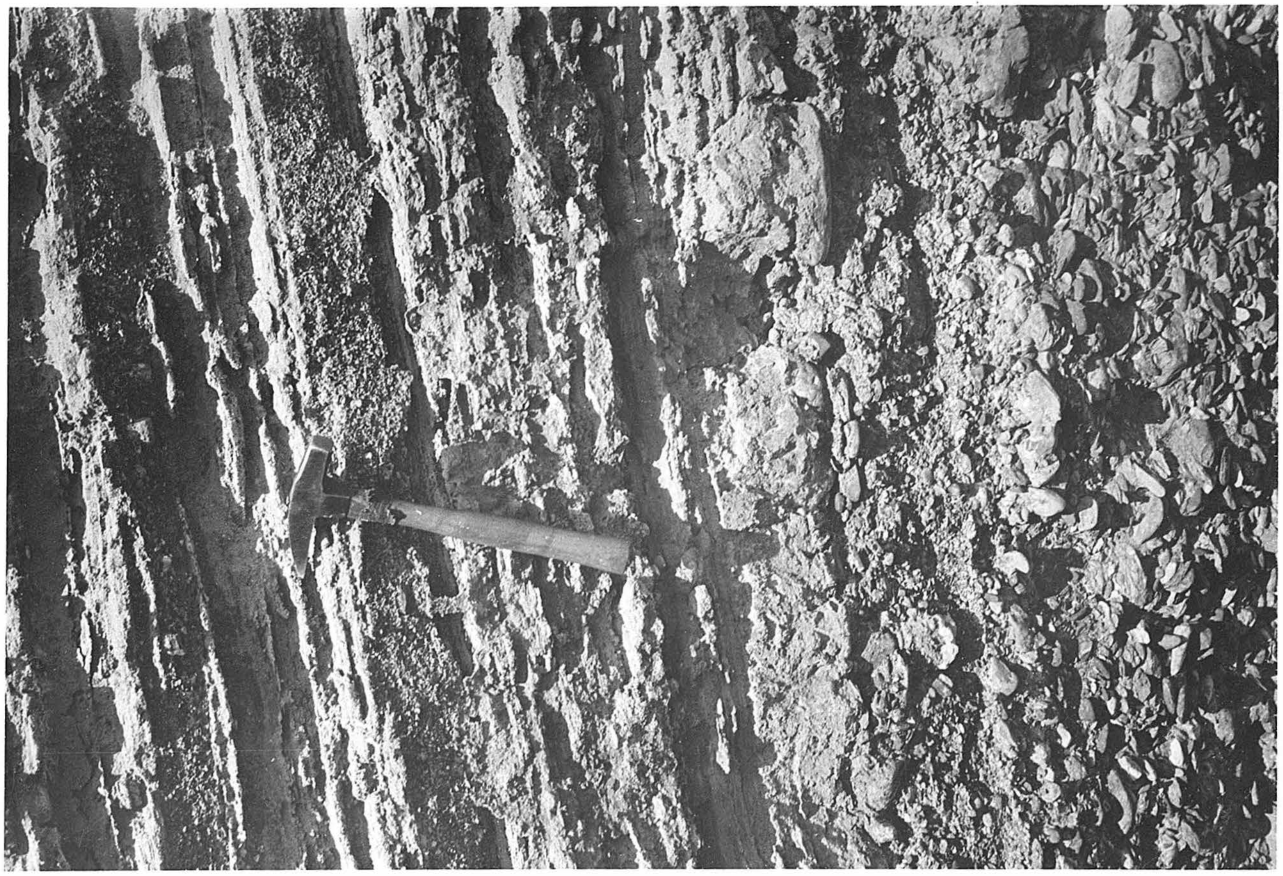


Plate 9

A. Detail of Zurich formation near Southern Belle mine northeast of Laws. Note the varied character of the formation in this very small section of it, as well as the fine "lacustral" beds overlying the coarse fanglomerate below. See page 19.

B. View taken at same locality as above showing a more general view of the formation. Several diastems are observable in this view. The rapid stratigraphic variations in lithology are well displayed. See page 19.



Knopf's Plate X,a, is particularly notable. It will be seen that the same kind of phenomenon is exhibited in both views, yet the one figured in the present report is stratigraphically considerably below the one that Knopf noted, and is about a half mile nearer the source of the detritus, here the Cambrian quartzites at the front of the Inyo Range. This type of local unconformity is to be seen at many places in the Zurich formation and is interpreted by the writer as representing nothing more than a diastem. Such a feature would be highly expectable in a shallow basin, exposed alternately to lacustral and sub-aerial conditions such as are postulated for the Waucoba embayment in which the Zurich formation was deposited .

One of the interesting features observed in the Zurich formation is the presence of highly angular, talus breccia material intimately associated with well rounded, water worn sand and pebbles. This type of deposit is found near the margins of the basin and was probably caused by material derived directly from the mountain face being mixed with detritus which had been brought a considerable distance along the range front. Such an occurrence emphasizes the intimate relationship which exists between fanglomeratic and lacustral sediments in this region.

The thickness of the Zurich formation can not be determined accurately, first, because of the lack of recognizable beds, and second, because of the rapid lithologic changes which take place toward the margin of the basin of deposition. Several hundred feet may be taken as a very rough estimate of the maximum thickness exposed at any one locality.

It is similarly impossible to assign a type section to the Zurich formation that will have any practical value, because of the pronounced lithologic changes that occur within relatively very short distances. In general, however, the formation shows characters that range from those of typical alluvial fan deposits to those of playa lakes, with every gradation between the two extremes. A recognition of the latter fact -- that the Zurich formation as a whole includes many different facies -- is the chief point of difference between the present interpretation of the series and interpretations of earlier investigators, who all regarded the "lake bed series" as a unit distinct from the fanglomeratic deposits of the region.

The distribution of the Zurich formation presents some interesting features and provides information of great value concerning the later structural history of the Inyo-White Mountain Range. Its greatest development is in the Waucoba embayment where one may examine practically all of its facies -- alluvial fan, littoral, and lacustral. The Zurich formation is well developed also in the lower courses of some of the large canyons which drain the western slope of the mountains, such as Black Canyon, Poleta Canyon, Silver Canyon and others. Most striking is the fact that it does not appear at any distance away from the mountain front. This fact, coupled with its extensive development in the larger canyons, suggests strongly at once that rather extensive faulting has occurred along the range front since its deposition. Between the large canyons, the Zurich is displayed as a thin veneer extending a comparatively short distance up the scarp face -- a much shorter distance than would be expected from its position in the large canyons -- a further fact favoring recent uplift of the range and stripping of the Zurich from its face.

The detritus that constitutes this formation shows a very wide variation in degree of rounding of the particles and in size of grains, and a smaller variation in type of material, which is largely debris from the meta-sedimentaries of the Inyo-White Mountain mass. At other localities along the range front not visited during the progress of the field work the equivalents of the Zurich formation, if any exist, will naturally contain debris which reflects the composition of the neighboring country rock.

In the region studied for this paper, extending from south of Waucoba Canyon to Coldwater Canyon on the north, varying amounts of volcanic ash were found in the Zurich formation at various points, and, very important for its value in correlation, a stratum of white pumice breccia several feet thick was traced along most of the range front that was examined. This pumice breccia stratum varies considerably in composition, but the gradual variations are apparently related to distance from the source of the volcanic material. Thus, to the north, opposite the Volcanic Tableland, the pumice forms practically pure beds in the alluvial breccia of the Zurich formation; many of these occurrence to the north are so pure that they have been located as sources of pumice and worked on a small scale.

Plate 10

A. View looking east at the Zurich formation along the mountain face just north of Black Canyon, southeast of Bishop. The bedrock against which the Quaternary Zurich formation abuts is highly folded Cambrian metamorphic rock.

B. Pumicious breccia stratum of the Zurich formation cropping out in the small canyon just north of Black Canyon, southeast of Bishop. See page.27.

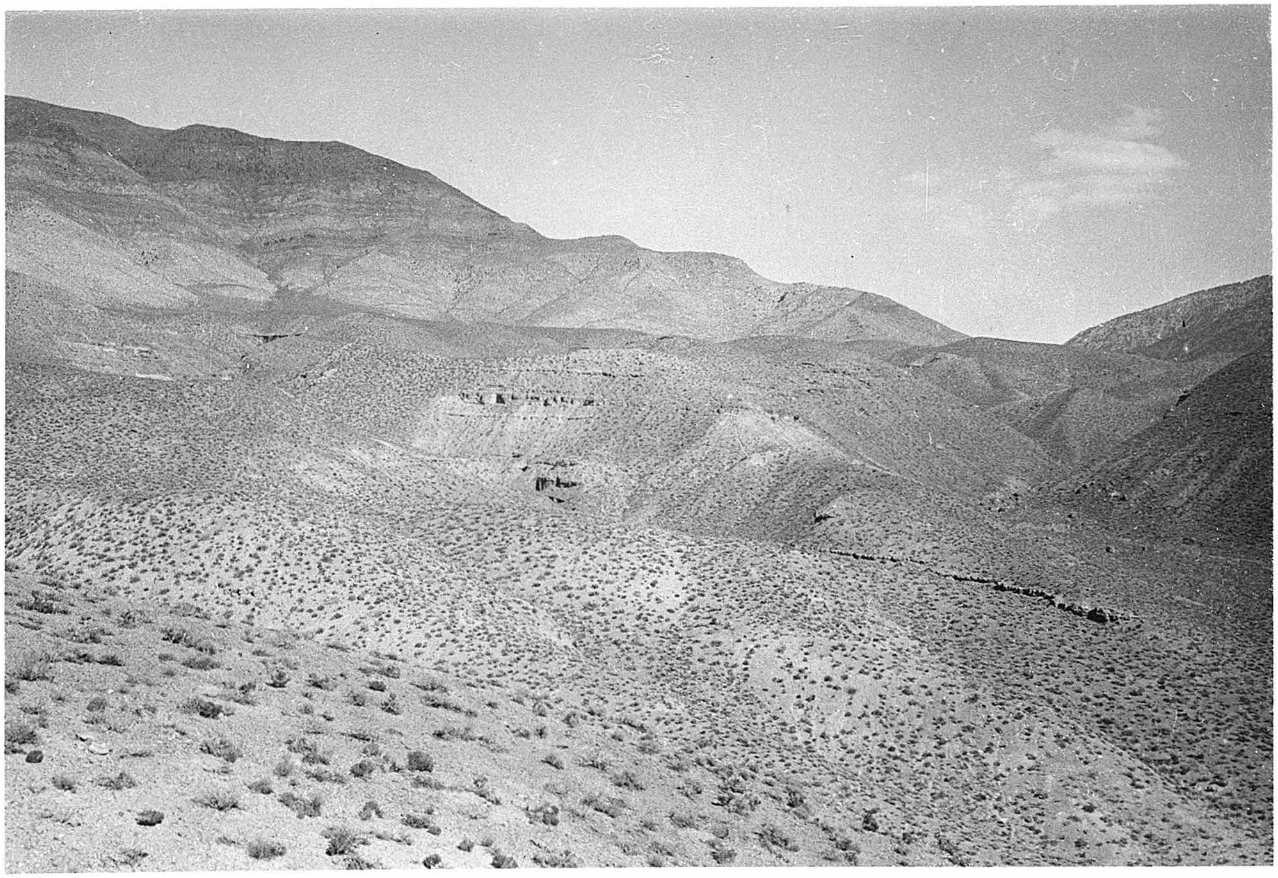
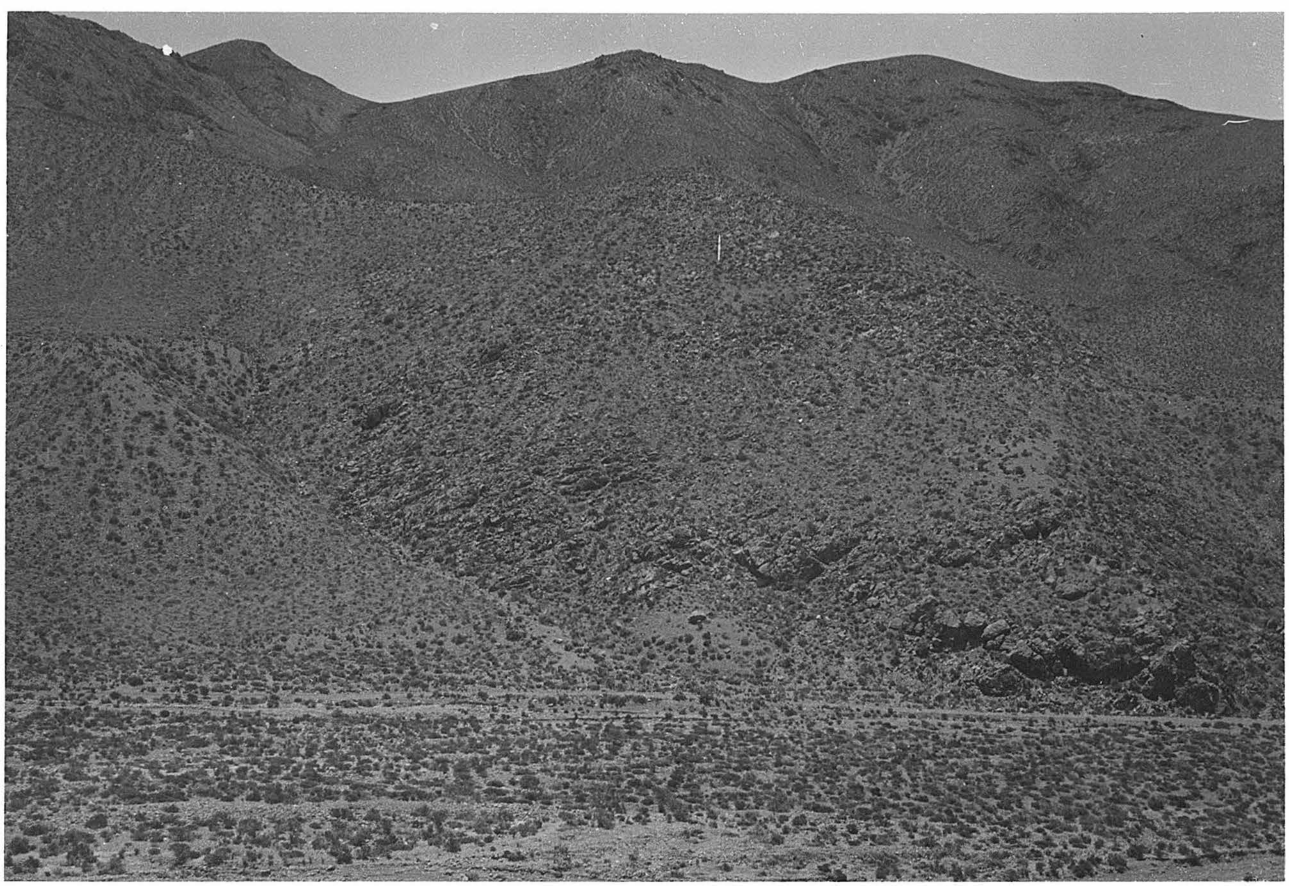


Plate 11

A. Steep depositional surface between fanglomeratic facies of the Zurich formation to right and Campito sandstone (Cambrian), here standing nearly perpendicular, to left. Overlap of Zurich onto steep pre-Zurich surface is very well marked here along the west flank of Black Mountain.

B. View showing flat upper surface of Zurich formation in Waucoba Canyon interrupted by pre-Zurich bedrock mass.



A partial section of this pumice stratum made at T 104 north of Silver Canyon is given below:

Top -- Poorly sorted, slightly stratified talus breccia
30" -- Medium grey pumice breccia (particles 2-5 mm. in size)
37" -- Light grey pumice breccia do
2" -- Brownish grey pumice breccia (somewhat finer)
5"+ Light grey pumice breccia (particles 2 mm. in size)
No base exposed

At T 63 the pumice forms an uneroded remnant in the midst of younger alluvial cone material. It varies in composition from practically pure pumice to pumiceous alluvial breccia. Somewhat over a mile to the north, at T 94, about 50-60 feet of pumice and pumiceous breccia occur, again intercalated in the Zurich formation. This last locality is directly opposite the Volcanic Tableland with its thick deposit of very pure pumice.

The trace of the pumice zone is indicated on the map wherever it could be followed. South of T 104 it is traceable continuously to Poleta Canyon where it may be seen in the north wall of the canyon at an elevation of 4500 feet, as a sandy pumice stratum 30 inches thick in a zone of pumiceous breccia several feet wide. (See Plate 7B) This locality was noted by Knopf (2, p. 55). Black Canyon, several miles to the south, displays the same sandy pumice bed in its walls. Here it is 30 inches thick, the lowest few inches fairly pure, but the upper portion very impure from admixture of sand and gravel. In the Waucoba embayment, the zone appears at several places, all of them apparently at approximately the same horizon.

We thus have a pumice zone, purest and thickest toward the north, which is traceable continuously along the range front from Coldwater Canyon or beyond on the north to Waucoba embayment on the south. From the variations in thickness and character of this zone it seems that there can be no reasonable doubt that its source was to the north. It further seems almost certain that the pumice zone of the Zurich formation should be correlated with the pumiceous portion of the rhyolite tuff breccia series north of Bishop.

The age of the Zurich formation has been provisionally determined to be Pleistocene as a result of evidence afforded by both vertebrate and invertebrate fossils. Walcott collected fresh water invertebrates which were examined by Dr. W. H. Dall, who reported on them as follows, "Any of them might by Recent or Pliocene; my impression from the mass is that they are Pleistocene" (10, p. 342). A few years ago a party including Dr. Buwalda and Dr. Chester Stock spent several days searching for vertebrate material and was successful in discovering horse remains in the Waucoba embayment. Professor Stock has stated that the material is too scanty to afford an accurate age determination for the beds but that a Pleistocene age seems most probable (Oral communication).

Bishop Formation

The rock constituting the cap of the Volcanic Tableland is a pinkish brown tuff breccia, apparently rhyolitic in composition (See plate 12B). It contains numerous obsidian fragments and many fairly large quartz grains. Flow structure is seen in some of the included felsite fragments but not

Plate 12

A. Meanders in Owens River along the ~~edge~~ margin of the Volcanic Tableland north of Bishop. View taken looking southeast. See page 132.

B. View looking up Owens River gorge in the Volcanic Tableland about 13 miles northwest of Bishop. Both the pumiceous and the tuff breccia members of the Bishop formation are exposed in the gorge at this point. See page 28.

in the breccia itself. Thickness measurements of the capping stratum average between 20 and 30 feet. The rock is very porous on weathered surfaces whereas that from fresh quarry faces is grayish in color and apparently much less porous. The breccia has been quarried rather extensively for use as an ornamental building stone.

Underlying the rhyolite tuff breccia bed is a series of incoherent, rather massively bedded pumice and sandy pumice strata with some admixture of pinkish breccia in places. This material is very pure white pumice at some places and has been mined to a considerable extent for use in manufacturing acoustic plaster. It forms white bluffs beneath the brown cap rock that are highly distinctive. One locality in particular, along the Owens River, northwest of Bishop, is called Chalk Bluffs in reference to the striking whiteness of the outcrop. The thickness of the volcanic was not determined at any one place, but it seems to be at least 300 feet, judging from outcrops along the Owens River and along Fish Slough. The base is not exposed anywhere. No fossils were found in the series and so far as known none has been reported.

It is proposed to call the tuff-breccia cap rock of the Volcanic Tableland together with the underlying pumice strata the "Bishop formation". The cap rock will be referred to as the "tuff-breccia member" of the Bishop formation and the underlying strata will be termed the "pumiceous member". Since the lava flows immediately surrounding Casa Diablo Mountain are probably of the same period of volcanic activity as the breccia and pumice of the Volcanic Tableland, I believe that these lava flows should properly be included in the

Bishop formation. They were not studied, however, during the field work so this suggestion is only tentative.

STRUCTURE

Introduction

Structure of the northern Inyo territory may be grouped in two major divisions, one of them including features of a much more recent date of formation than the other. The region is still in the grip of the later period of tectonic activity manifested not only by land forms obviously of recent diastrophic origin but also by seismic activity in historical time. The later period of activity has been in progress more or less continuously during Cenozoic time and its action during the Pliocene and Quaternary has blocked out the major land forms of the present landscape. The structural history of the region prior to the later period of diastrophism is not treated in this paper. It should be emphasized, however, that the older structure is highly complex, and that the time chronicled by it was most eventful, but it does not fall within the scope of this investigation.

General Features

Normal faulting has determined the general outlines of most of the present topography of the Bishop region. Pleistocene glaciers have altered considerably the high mountains, great alluvial fans have encroached on the valleys, volcanoes have poured out lava and cinders, yet the effect of these various agencies in shaping the land forms of the area has been dwarfed into insignificance by the profound influence of block faulting.

Owens Valley is a great fault trough bounded on both the east and west sides by normal faults of great recent displacement. Deep Spring is bounded on the east side by a fault scarp of the greatest recency. Cowhorn Valley is the result of faulting along both of its sides. The Sierra Nevada is a westward tilted fault block, the Inyo-White Mountain Range is a complexly faulted and tilted mass. In short, all of the major topographic lineaments of the region owe their form to normal faulting.

Bishop Offest

A striking feature of the plan of the Sierran base in the Bishop region is the offset that occurs just southwest of the town of Bishop. Here, the rectilinear base that continues unbroken from the vicinity of Olancha to a point north of Big Pine is interrupted and the northern segment is offset to the west about 10 miles. South of this offset the eastern face of the Sierra is less bold than at most places along its extent, while north of the offset the Round Valley scarp presents one of the boldest fault scarps of large magnitude to be seen in North America. Both the offset and the notable difference in boldness demand explanation on structural grounds, since the rocks of the two sections are essentially identical. The offset will be called the "Bishop Offset" in this paper.

A multiple working hypothesis for the origin of the offset is presented below, discussed, and the most probable explanation is presented.

a. A major cross fault might have displaced the north-south fault zone through a horizontal distance of 10 miles.

b. The offset might represent two fault zones, diverging northward from a point southwest of Big Pine, the western zone continuing as the Round Valley fault, the eastern one terminating southwest of Bishop.

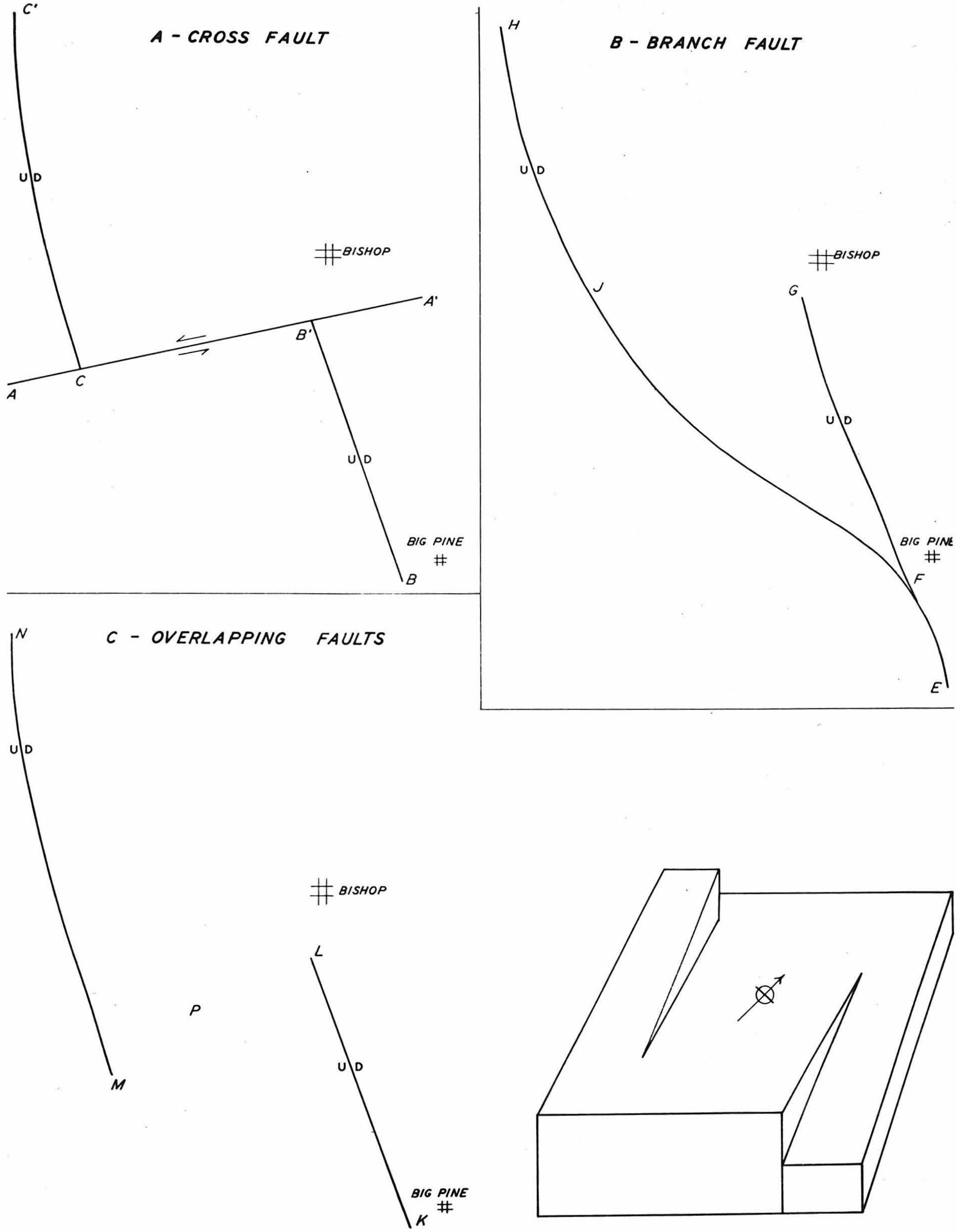
c. The offset might represent a slice between two essentially parallel and overlapping fault zones, the eastern zone dying out to the north and the western one dying out to the south.

Plate 14,A represents diagramatically the cross-fault hypothesis for the offset. Here, the dip-slip zone BB' which has produced the major Sierran uplift in the Big-Pine-Bishop region is shown cut by the strike-slip fault AA' and displaced to CC'. In this situation we should very certainly find evidence of the strike-slip fault in the regions east and west of the points B' and C since it is not conceivable that a fault of this very considerable magnitude should terminate in less than several miles. Field evidence, however, is directly contradictory to this corollary for there is no evidence of faulting along AA' east of B' or west of C. Furthermore, while displacement along the line AA' has undoubtedly occurred to some extent, it has been entirely of a dip-slip nature.

Referring now to Plate 14,B we have a major zone of faulting EFH which bifurcates at F with a branch FG terminating at G. In this case we should find positive evidence of faulting

Plate 13

Alternative hypotheses for Bishop Offset


A - CROSS FAULT
C'
U D
BISHOP
A'
B'
A
C
U D
BIG PINE
B
B - BRANCH FAULT
H
U D
J
BISHOP
G
U D
BIG PINE
F
E
C - OVERLAPPING FAULTS
N
U D
BISHOP
L
P
M
U D
BIG PINE
K

from F to J along the main line of faulting. Further, the type of faulting on this line should be similar to that from J to H. That is, if the faulting along HJ is essentially dip-slip in character, it would be highly unexpectable to encounter predominantly strike-slip movement along JF and dip-slip movement again from F to E. Careful investigation in the field, however, has failed to reveal any important faulting along the line JF. There is some topographic suggestion that a fault may follow the course of the south fork of Bishop Creek because of the rather pronounced rectilinear trend of that valley. It is sinuous in detail, however; sufficiently so that a fault following its general trend must be exposed at a number of places along its course. No fault is present.

The possibility that the valley may represent a zone of rifting thus seems to be eliminated. Knopf, in addition, points out the fact that the middle fork of Bishop Creek, flowing nearly normal to the south fork, is fully as deep, so that valley-depth alone is no criterion for faulting (2, pp. 79, 104). Further, accordance of levels on the two sides of the south fork points strongly against dip-slip faulting along this line. Physiographic evidence at other points along the line JF is unfavorable to the possible existence of an important dip-slip fault for the line crosses several old erosion surfaces without notable hypsometric discordance on the two sides. Although the region along the line JF was examined critically in the field, no structural evidence of important faulting was found.

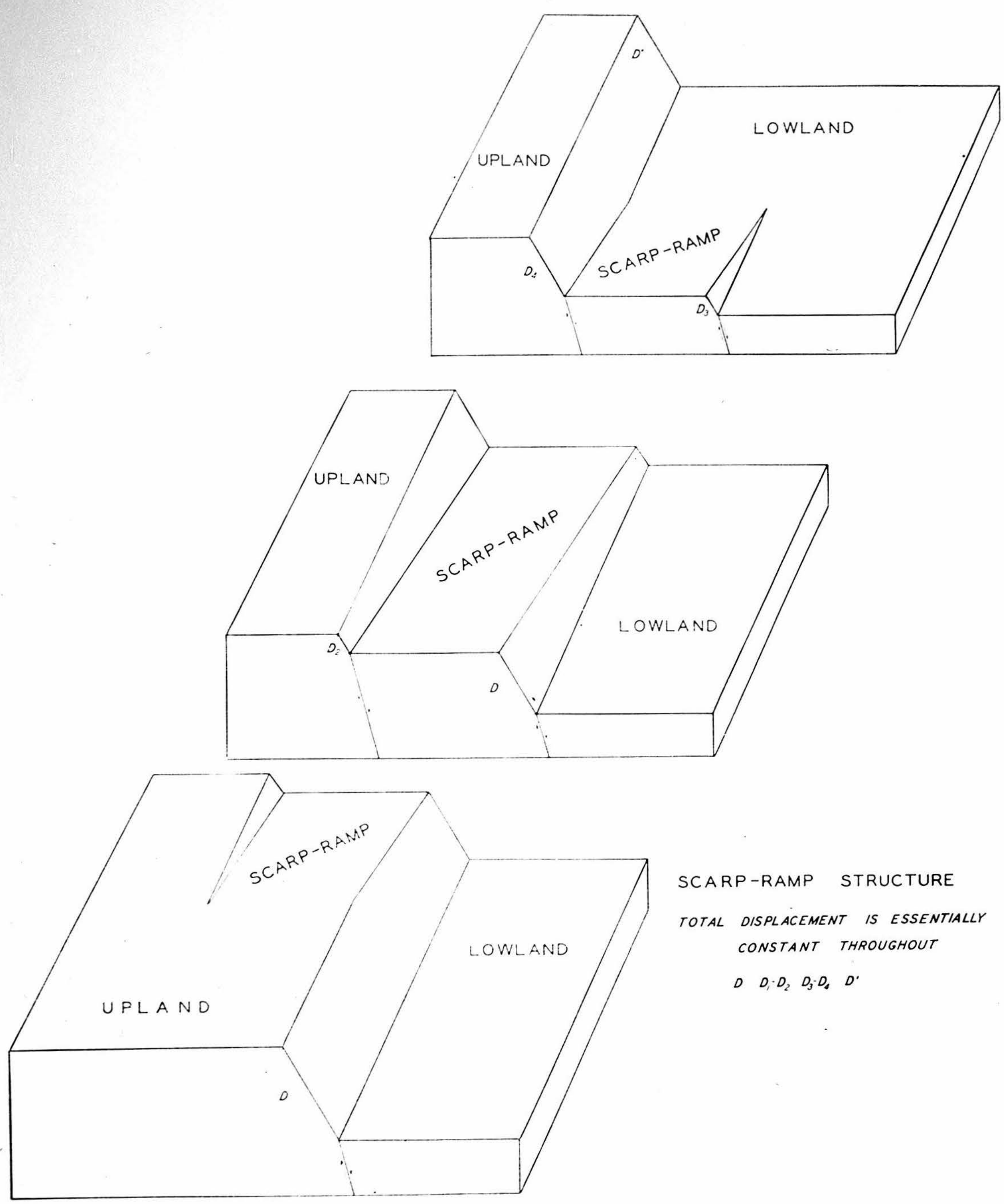
Turning now to Plate 14,C we see that the main fault zone KL which bounds the east face of the Sierra for many miles ends to the north at L. The Sierran scarp is then continued along another major zone MN which dies out to the south at M. According to this conception, the zone between the overlapping ends of the main fault zones, near P, should be a warped surface sloping to the north.

Field evidence strongly supports this conception of the structure of the region. First, the zone of faulting KL shows no visible displacement north of the point L except that in the Volcanic Tableland, north of Bishop, a zone of minor dip-slip faulting occurs with opposite displacement (east side up). This may represent an extension of the general zone of faulting KL, but it does not invalidate the general statement that the zone of major faulting essentially ends at L, since the slight displacement north of Bishop is in the opposite direction and is of very minor importance. That the Round Valley fault zone continues south nearly to Bishop Creek, near M, is shown conclusively by the presence of a very distinct recent scarplet crossing McGee Creek (See Plates 1 and 2). The Round Valley scarp also clearly continues south almost to Bishop Creek near which point it ends.

Scarpramp

The physiography of the area involved in the Bishop Offset should give valuable indications of the manner in which the offset has been effected. We see at once a marked bowing down to the north of the land surface lying southwest of Bishop, in which Coyote Flat, an old surface of erosion (see page 123) lying at an elevation of 10,000 feet in the

Plate 14



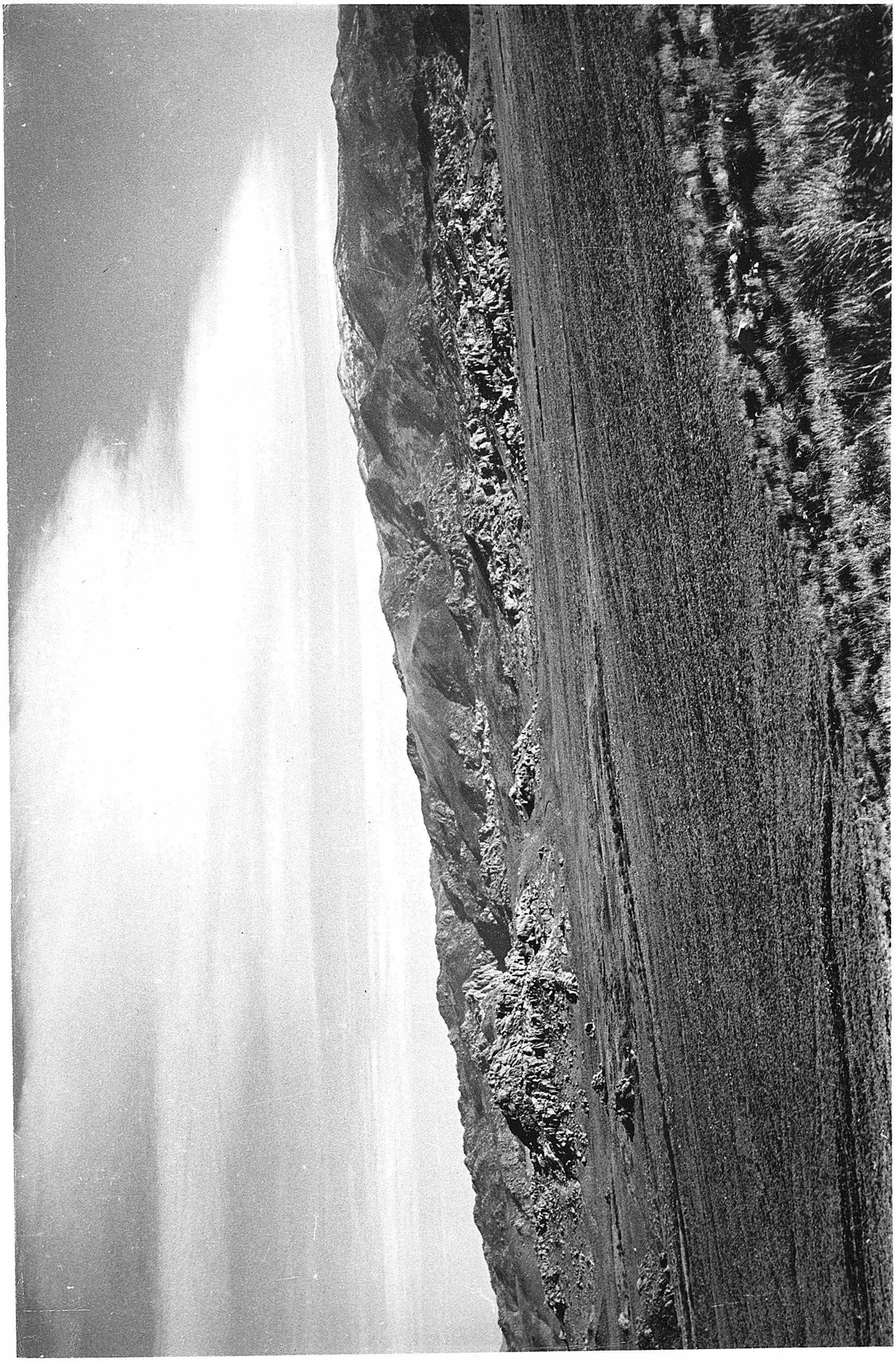
SCARP-RAMP STRUCTURE

TOTAL DISPLACEMENT IS ESSENTIALLY CONSTANT THROUGHOUT

$D \quad D_1 - D_2 \quad D_3 - D_4 \quad D'$

Plate 15

View looking Southeast across the scarpramp of the Bishop Offset showing the old land surface of Coyote Flat clearly flexed down to the north (left).



Bishop-Big Pine segment of the Sierra Nevada shows a marked slope to the north near the northern end of the segment. Other physiographic features of more recent age of formation likewise show a northerly slope in the same territory.

This physiography cannot be explained by ordinary erosional processes since the old age surface of Coyote Flat is itself bowed down to the north. Structurally this flexure may be explained as the result of an epoch of folding. This is highly unlikely, however, since forces of a type to cause folding have not been active elsewhere in the region since the beginning of the Sierran uplift.

As a corollary of the structural pattern outlined in Plate 14,C the bowing down to the north is very well explained. It will be seen that in general the surface lying between two parallel, overlapping faults with displacements in the same direction, one dying out in one direction and the other in the other direction will slope in the direction in which the outermost fault decreases its throw. Since this type of surface is unique to this structure I believe it desireable to name it. It is essentially a ramp, connecting two surfaces on different levels, and its position is determined by scarps on its two sides.

The term <u>Scarpramp</u> is proposed for this type of bowed surface lying between two essentially parallel faults one diminishing its throw in one direction and the other in the opposite direction, and sloping in the direction in which the outermost fault decreases its throw. The sum of the displacements of the faults where they overlap is approximately constant and equal to the displacements of the single fault beyond the offset. More than two faults may overlap to form a series of scarpramps.

Apparently the first person to point out this particular type of geomorphic form in this region was W. H. Hobbs who described the earthquake features of the Owens Valley which had resulted from the shock of 1872. He says,"This overlapping of parallel faults, ... is a very characteristic feature of the scarps of the valley. Whenever a number of such overlapping faults occur together, the effect is a retreating (or advancing) series en echelon like the wings in a theater. The terrace height is maintained through the displacement on the one fault being diminished in the same measure that upon the other is increased. The land lying within the overlapping portion of the two faults is thus made to tilt or dip in the direction in which the outermost fault from the terrace diminishes its throw." (11, p. 380)

The northern edge of the scarpramp of the Bishop Offset is broken to some extent by minor dip-slip faults trending in an east-west direction. These were evidently formed when the warping became too steep for the granitic rocks, which then deformed by faulting. They are of relatively minor displacement, apparently not over a few hundred feet at any place. In all cases, as indicated physiographically, the southern side has risen with respect to the northern, and there has been no apparent horizontal movement. The region near the mouth of Bishop Creek is so heavily covered with glacial till that it is not possible to obtain information there about these minor faults, none of them apparently having been active since deposition of the till. They seem to terminate gradually, hinge-like, to the east, as they approach the main zone of faulting along the Big Pine-Bishop segment.

Physiographic evidence for the existence of these features is very clear to an observer standing about 5 miles WNW of Bishop -- scarp faces, truncated upland surfaces, and the rectilinear base lines of the scarps. No offsetting of streams and no scarplets were seen, and from this it is concluded that the faulting along this line is relatively older than faulting along the main Sierran scarp.

Round Valley Syncline

A syncline, trending east-west, approximately normal to the Round Valley scarp at Pine Creek, and which involves the interfault surface of the Tungsten Hills on its south limb, is intimately associated with the Bishop Offset. The folding involved in this structure has been relatively slight and is the result of non-uniform displacement along the Sierran fault system rather than folding in the sense of compressional forces. The region on the north limb slopes south with an inclination of less than a degree and the Tungsten Hills area slopes gently north. The rocks involved in this broad fold are granitic and volcanic. They have been warped so slightly that only a few tension faults have developed parallel to the fold's axis.

The net displacement along the Round Valley scarp varies from a maximum near Pine Creek at the synclinal axis to zero a few miles to the south and to a minimum a few miles to the north. Complete information concerning the fault zone was not obtained north of Sherwin Hill.

Waucoba Embayment

The Waucoba embayment located east of the town of Big Pine presents an example of a complication in the piedmont faulting that occurs at several places along the scarps of both the Inyo-White Mountain and the Sierra ranges, namely the distribution of frontal faulting along a rather wide belt in certain areas. Ordinarily the faulting is confined to a narrow zone along the base of the range. In the case of the Waucoba embayment, the Inyo Range frontal faulting has become so widely distributive that the steep scarps to the north and south have given way to a gently sloping surface in the form of a basin -- the Waucoba embayment. Plate 16 presents diagrammatically a generalized plan of the faulting that created the basin.

It can be seen that the erosion of such a fault system to a condition of gentle relief may result in the production of a westward sloping basin. Such a means of formation for the Waucoba embayment is thus postulated. Owing to the fact that the basin has been filled with sediments since it has has had its general form outlined by faulting and subsequent erosion, and because these sediments have effectively concealed the fault system in the bedrock for the most part, the general structure of the basin has been determined largely through a study of the recent scarplets that traverse it at the surface.

Big Pine Salient

A marked zone of distribution in the Sierran fault system occurs just west of the town of Big Pine. The frontal faulting which is concentrated in a relatively narrow zone to the north and south here becomes widely distributive and attains a width of several miles. The topographic feature resulting from this fault system will be termed the "Big Pine Salient". Plate 16 shows in a very general way the manner in which this phenomenon has occurred. Because of the fact that glacial and alluvial material near the mouth of Big Pine Creek has covered a large area of considerable importance in deciphering the regional structure a complete and accurate picture of the fault system in this region cannot be reconstructed, although a general scheme may be formulated that is fairly certain to be correct in its broad aspects.

Before proceeding further, it might be well to call attention to the peculiar fact that the two most important zones of distributive faulting in the region, the Big Pine Salient and the Waucoba Embayment, are located almost directly opposite one another, the former bending out from the general line of the range front and the latter bending into the range. Since little is known about the factors that tend to cause distributive faulting, little may properly be inferred from the coincidence of the two zones here. It seems, however, that more than mere coincidence has operated in determining the position of these similar structures. It is noteworthy that the width of the area affected by the distribution of faulting, both in the Waucoba embayment and in the Big Pine

Plate 16

All of the faults in the Waucoba embayment have the same relative direction of displacement with the east side having risen with respect to the west side.

The faults of the Big Pine Salient show movements in both directions, although the net displacement is up to the west.

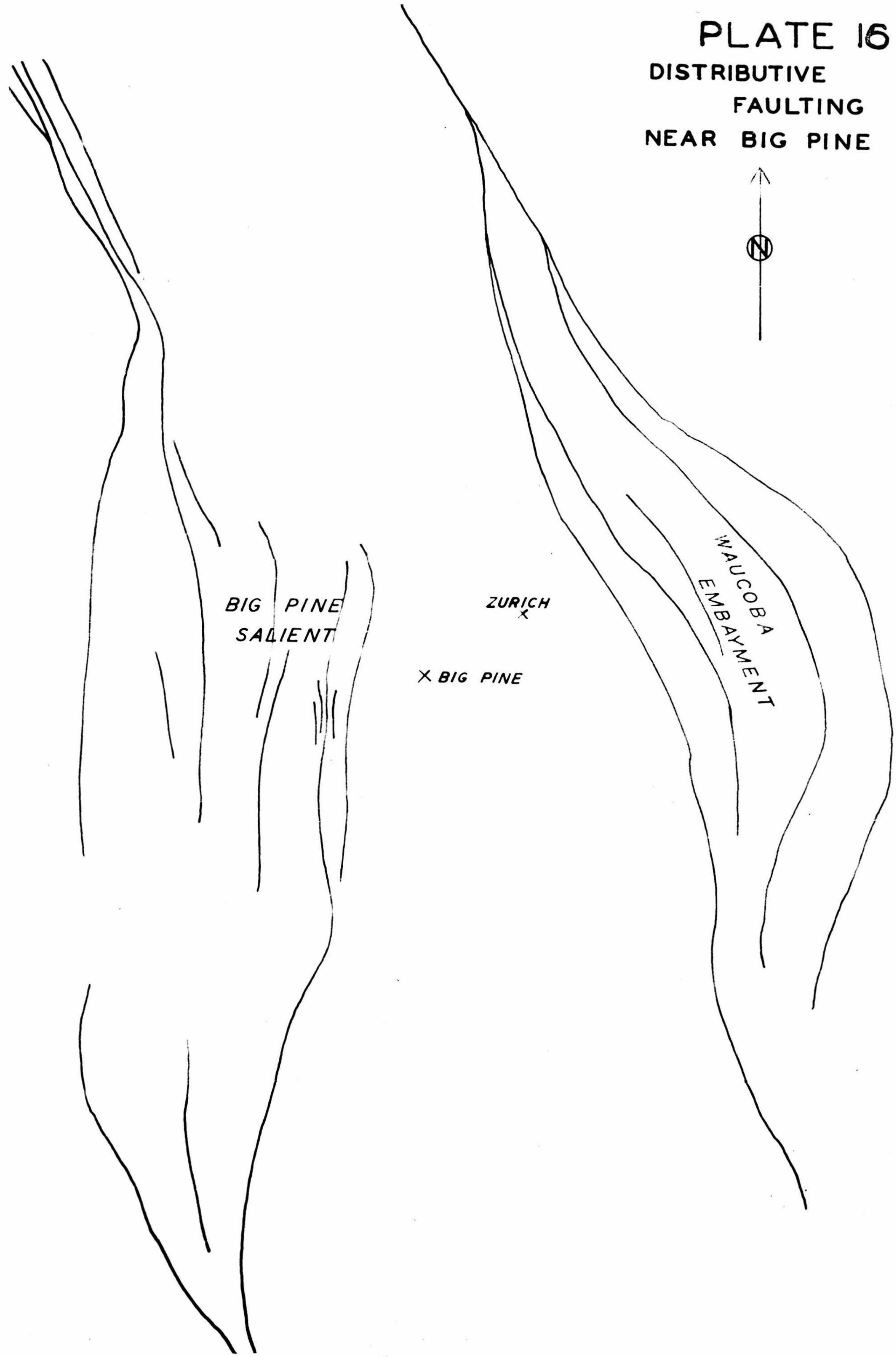
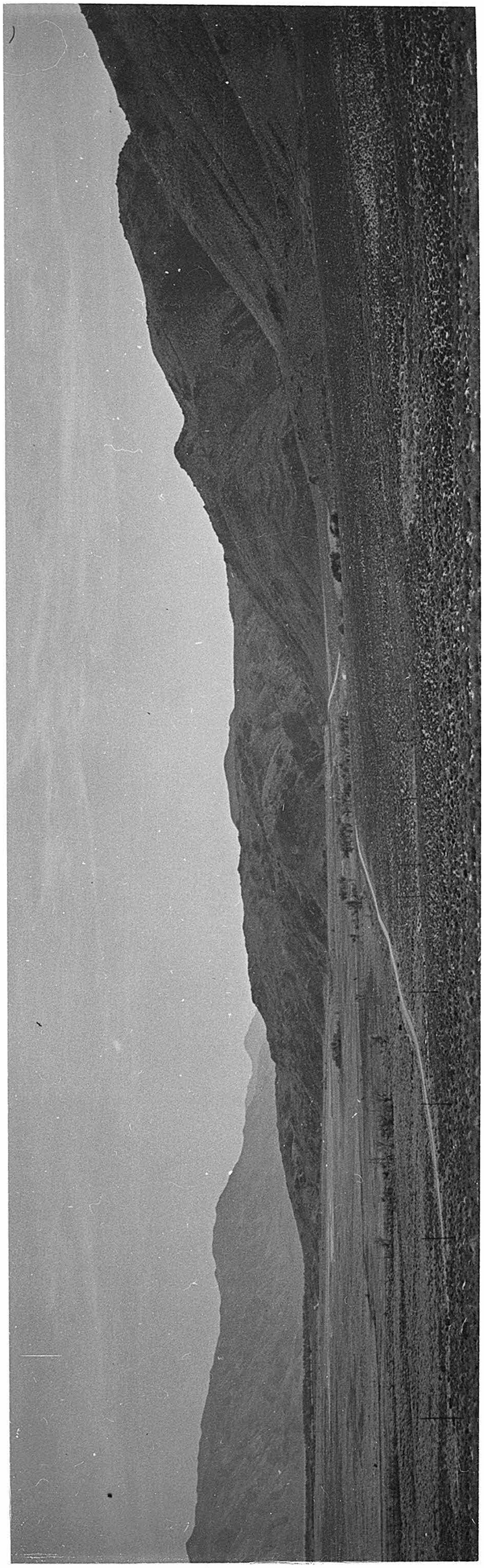


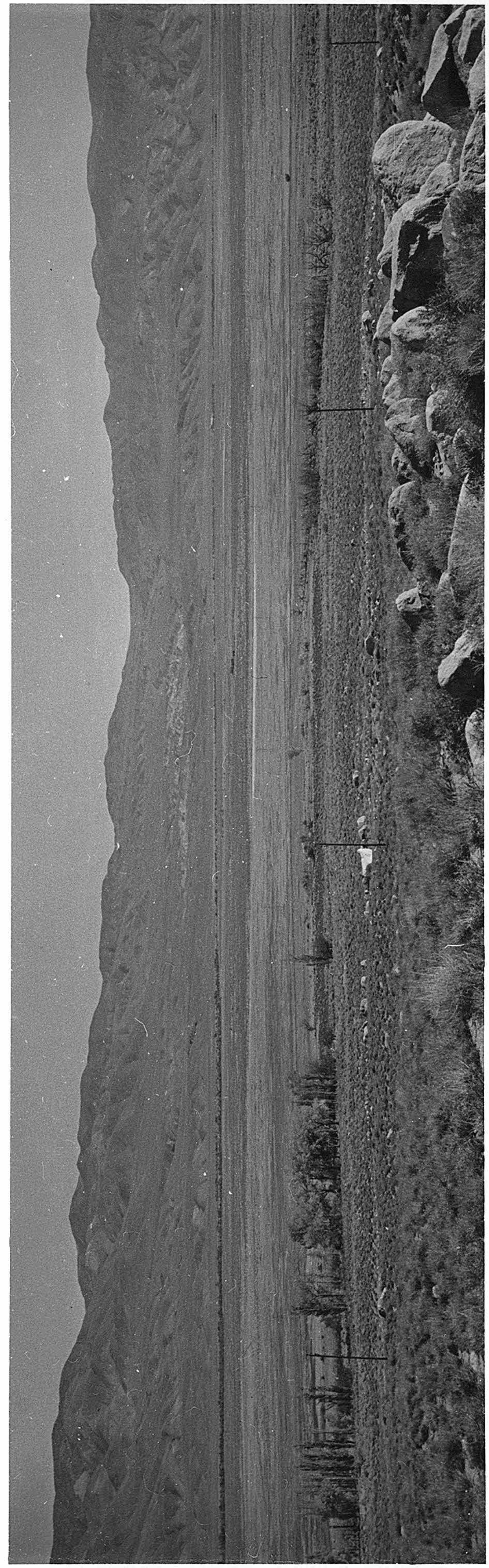
PLATE 16
DISTRIBUTIVE
FAULTING
NEAR BIG PINE
N
BIG PINE
SALIENT
ZURICH
BIG PINE
WAUCOBA
EMBAYMENT

Plate 17

A. (left) Big Pine Salient of the Sierra Nevada from the north. The Inyo Range is to the left across Owens Valley. See page 43.

B. (right) Waucoba Embayment of the Inyo-White Mountain Range from the west across Owens Valley. Several of the scarplets which cut the Zurich formation are visible in this view. Zurich station is located on the east side of Owens Valley near the right center of the view. See page 42.





Salient is nearly equal to the width of Owens Valley yet neither feature extends into the valley a very great distance beyond the general base line of the mountain masses.

To return to a consideration of the Big Pine Salient we see that as a result of the distributive faulting as postulated the resulting surface after suffering more or less erosion will be an inverted basin sloping to the east. The original surface before erosion was a series of curved steps with various radii and displacements, and this surface is well reflected by the present topography, which shows just such characters, modified of course by erosion. The northern part of the salient shows the step-faulting much better than the southern part since the latter is largely buried by alluvial and glacial deposits, to say nothing of the recent lava extruded by Crater Mountain.

Cowhorn Valley

The peculiar depression known as Cowhorn Valley located about 7 miles southeast of the southern end of Deep Spring Valley is very similar structurally to the latter feature although it is considerably smaller. Both valleys are the result of down-faulting of an area in the central part of the range, and while they differ in some details they are remarkably alike in general features. A slight digression from geology may perhaps be pardoned here to describe briefly several features of general interest connected with Cowhorn Valley. In the whole of the depression and in its immediate vicinity no springs were found at the time that field work was being carried on (August 23-24, 1932). Vegetation is represented by a few scraggly juniper trees on the sides of the valley and a very thin cover of low sagebrush over the general valley floor. The northern part of the valley shows a rather remarkable growth of Joshua trees. These members of the genus Yucca are commonly found at lower elevations than those at this point (up to 7800 feet) so that their appearance is rather strange here.

Cowhorn Valley is a lozenge shaped depression about 7 miles in a NNE-SSW direction and averages somewhat less than a mile in width. It is located near the summit of the Big Pine-Saline Valley road. Its bottom has an elevation above sea level ranging from about 6550 feet near its southern end to about 7200 feet at the north. The valley has interior drainage as a result of which a flat floored, vegetation-free playa has been formed near its southern end. Unless further diastrophic movements ensue, the valley will relatively soon be tapped at its southern end by a tributary of Eureka Valley which is actively eroding headward along the canyon traversed by the Saline Valley road just southeast of Cowhorn Valley. The lowest point in the valley is less than 200 feet below the head of this stream and capture of the valley's drainage seems imminent.

A physiographic characteristic of the valley noticed at once is the sharp angle with which its walls meet the floor practically no transition slopes being present between the steep

Plate 18

A. Lower portion of east wall of Cowhorn Valley near its southern end. The sharp angle with which the scarp meets the flat alluvium filled valley is notable. See page 46.

B. View looking northeast at east side of Cowhorn Valley near its northern end showing recent scarplet to the right center of the photograph. See page 49.

bedrock scarps and the flat alluviated floor. Although the walls are very steep it is remarkable that recently formed scarplets at their base are practically absent. At only one locality, near T 130, was a recent scarplet observed. This feature is a well marked scarp about 50 feet high, facing west with a slope of about 50 degrees, notably steeper than the boundary scarps of the valley in general. It follows the base of the valley wall for a short distance, then turns off to the southeast and follows the northeast side of a small canyon for about a half mile.

Rocks which form the walls of Cowhorn Valley are metamorphosed shales and sandstones cut by a large number of quartz veins. The prevailing dip of these strata is about 40 degrees to the east. The steep scarps which bound the valley are nowhere dip slopes as far as could be determined, they truncate the strike of the beds in many places.

A section of a fault a short distance east of the main boundary fault along the east side of the valley is visible just north of the Saline Valley road at the south end of the valley. This fault shows the same displacement as the boundary fault just west of it. A breccia and gouge zone is plainly visible here and drag clearly shows that the west side has gone down. The steep west dip of the fault plane proves its normal character.

From a consideration of the similarity of the two sides it seems probable that the valley was formed as a unit, that is that the two sides are of the same age. This view is in contrast to the apparent conditions at Deep Spring Valley where the eastern side seems to be much younger than the west side. If it is permissible to compare Deep Spring and Cowhorn Valleys, and it may not be especially when the difference in rocks is considered, it will be seen at once that Cowhorn Valley seems to be of a physiographic age intermediate between that of the two sides of Deep Spring Valley. Even if this conclusion with regard to the physiographic age is correct, it does not necessarily follow, of course, that the dates of formation of the various features is in the same sequence. However, in the absence of more detailed information, it seems allowable to use such a conclusion in formulating a tentative geologic history of the region.

The faults which outline the valley definitely converge to the north but they apparently end before they meet to the south. The southern part of the valley is further complicated by a structural trough which enters it from the southeast. The relations at the southern end were not fully worked out, but appear to be essentially as shown on Plate 1. The probable faults trending southeasterly which bound this trough apparently do not continue far. Their mapping was done on the basis of none too conclusive physiographic evidence. However, it seems difficult to explain this valley as an erosional feature since it runs across the strike of the beds and furthermore is formed near the head (and beyond) of a stream that can have but feeble erosive power here. Farther down its canyon this stream has cut a typical V-shaped canyon with a sinuous course. These characteristics should be even more markedly developed near its head, yet they are wholly wanting there. The balance of evidence thus seems to favor a diastrophic origin for the upper portion of this trough.

Owens Valley

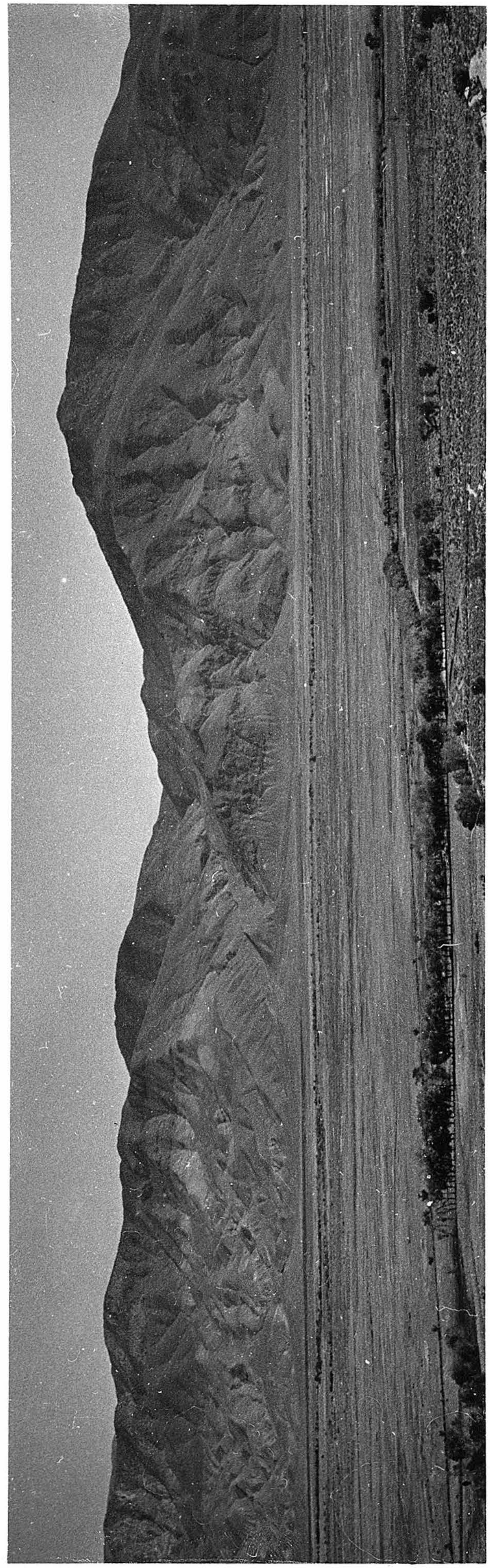
Very little ~~may~~ can be said about the structure of the floor of Owens Valley because little is definitely known. A thick mantle of alluvium over the entire floor effectively conceals bedrock from observation except where small hills such as the Poverty Hills south of Big Pine, and the Alabama Hills, west of Lone Pine,protrude. The depth of alluvium is not known with any degree of certainty at any place. In the center of the valley water wells have been drilled to a depth of several hundred feet in alluvial material, but this is apparently the only information available.

It seems very probable that scarplets that appear in the valley at a considerable distance from the range front are not related to the marginal faults but owe their origin to movement along faults which separate valley blocks. The floor of the valley probably is a mosaic of blocks of varying size which occasionally move with relation to each other forming scarplets at the surface. It is not at all likely that the scarplets at the surface completely delineate the valley blocks for the alluvium is so thick that minor movements along faults beneath it will probably be taken up in the alluvial material before it reaches the surface. We can thus do little more with regard to sub-valley structure than to make the general statement that it seems to be a mosaic of fault blocks which are probably elongated in a north-south direction,

Plate 19

A. (left) View of the west face of the White Mountain Range overlooking Owens Valley near the town of Bishop. The gentle topography of the Zurich formation as it laps up on the bedrock is well shown.

B. (right) Black Mountain and Marble (or Black) Canyon along the west face of the White Mountain Range between Bishop and Big Pine.



and which may still be moving actively with relation to each other. The latter statement is corroborated by a recent scarplet which crosses the valley in a north-south direction north of Lone Pine.

Quaternary Scarps

In discussing relatively recent scarps it will be convenient to classify them according to age and relative size. Various terms for particular types of fault scarps have been rather loosely used by different authors -- for the purpose of the present paper it has seemed desireable to redefine certain terms somewhat more clearly than they were originally defined. The term "scarplet" thus was apparently meant to include only those scarps that are found at the base of a steep, growing mountain face, and which are the result of movement along the boundary fault of the uplifted block. I believe that it is desireable to extend the definition to all scarps of undoubted fault origin, of Quaternary age, of relatively small displacement, for which there is clear physiographic evidence, no matter where they are located. Thus, the recent scarps visible at many localities in Owens Valley, several miles from the Sierran base, and obviously due to movement of the mosaic of blocks underlying the valley, should be called "scarplets" by the above definition, even though they are not related to the uplift of the Sierras. It is also considered desireable to differentiate "alluvial scarplets" and "bedrock scarplets".

The term "piedmont alluvial scarp", introduced by Gilbert (12, p. 33) was intended to be applied to scarps, at the base of a range, which he believed to be due to the sliding of large masses along the plane of the frontal fault of the range. Since the writer has failed to recognize this type of scarp in the Owens Valley region, Gilbert's term will not be employed in the present paper.

Scarps of considerable size (over a few hundreds of feet) largely, if not entirely, on bedrock and an integral part of the main range front, will be referred to as "scarps" with an age designation whenever possible. Thus, the "Quaternary Round Valley Scarp", as contrasted with the "Recent Tinemaha Scarplet". The term "Recent", when capitalized, in understood to refer to the Recent epoch of the Quaternary period; when not capitalized, it is used in the sense of "relatively recent".

The tendency of many writers who deal with Quaternary fault scarps is to regard their formation as a strictly static process taking place by a series of discrete steps; simplification is thus obtained, but always at the expense of accuracy. With the static viewpoint it is possible, for example, to assume a date for the end of one process and the beginning of another, thus avoiding the obvious complications of overlapping dissimilar processes, but it seems probable that at least in many cases the tectonic and erosional processes overlap throughout most of the cycle. It is comparatively simple to postulate the sudden production of a scarp and to follow its subsequent modification by erosion, and while this concept is useful when dealing with small increments of movement, its general use may lead to wholly eroneous conclusions when applied to field occurrences generally. A dynamic viewpoint seems essential to properly relate present stage with rates of uplift and degradation.

The writer believes that scarps are usually the result of a series of relatively small movements (of the order of a few inches or a few feet) which ultimately become integrated to form a visible scarp. A large part if not most of the displacement on faults occurs in small increments, many of which are not readily visible at the surface of the earth because of the inability of the alluvial cover and soil mantle to undergo slight adjustments. In such cases as these, then, it is obvious that a dynamic concept of scarp production and degradation is essential.

Let us consider the factors which influence fault scarp height at any particular locality. It is obvious that the rate of uplift along a fault must exceed the rate of degradation of the scarp if any topographic expression is to be present. The rate of uplift is controlled only by the tectonic forces causing the uplift and is not a function of the scarp height until sufficient altitude above the neighboring block is attained to make effective isostatic forces; if isostasy is considered as a controlling factor in scarp height, the rate of uplift will involve two factors, uplifting force and isostasy. These, however, may be grouped together as "net uplift force" for the present discussion, since they are dependent variables.

The factors affecting degradation of a scarp are several and independent, so it is impossible to group them. Rock type, rate of precipitation, height of scarp, spacing of streams, character of drainage area are all more or less independent factors and all are important in determining the rate of degradation at any particular time.

From a consideration of the various factors affecting scarp production it is evident that with a constant rate of uplift, the rate of degradation of the scarp will increase until the scarp has attained a certain maximum height, at which time the rates will be equal. The rate of scarp growth will thus degrease continuously from the time of first movement until the scarp has attained its maximum height. If uplift ceases at any time after this maximum height has been attained, the scarp will be degraded, rapidly at first, then more and more slowly until it is entirely removed, unless renewed uplift ensues. For most scarps it is impossible to evaluate rates of uplift and degradation, but the conception of the close interrelationship that exists between these rates is very useful in tracing deductively the changes that a scarp will undergo. Generally we may only see the net result, at a particular time, of uplift and degradational forces.

An interesting example of the need of a dynamic concept in dating scarps is afforded by the scarplet which crosses McGee and Birch Creeks near the foot of the Round Valley scarp (See plates 1 and 2). This feature clearly cuts moraines of the latest glacial epoch (Tiogan) yet apparently does not cut the most recent alluvium in the creek beds. It does cut gravels flanking the present stream channels, but it is uncertain whether these gravels are of the latest glacial epoch or are of a more recent age. From these data, therefore, we are justified in saying that "the fault has been active since Tioga time, but has not been sufficiently active recently to visibly displace the most recent stream deposits". We are not justified in saying that, "no faulting has occurred during the period represented by the recent gravel deposits", because movement may have taken place, although less rapidly than degradation and burial.

This type of reasoning should be used when dealing with all of the scarplets of the region, and it seems desireable also to apply it to the major scarps of the area, which are composed of a large number of scarplets and should behave in the same way as the smaller features. When we are dealing with a small scarplet formed in one uplift, or if we wish to treat a single increment of uplift along a major scarp, we may then assume instantaneous uplift and follow the course of subsequent erosion until the next uplist occurs.

If we turn for a moment to a study of Plate 20 which represents diagrammatically a fault scarp, created instantaneously, then remaining at rest during subsequent erosion, we are struck by the fact that the course of erosion is divisible roughly into two stages. The first one commences with the initiation of the scarp and lasts until the slope of the bedrock surface above the scarp is approximately equal to the slope of the alluvial apron below it. The second stage ensues and lasts until the scarp is destroyed. It is obvious that scarps that are being continually affected by faulting will remain in the first class. In the Owens Valley region most, if not all of the scarps are of this type.

Plate 20

Diagram showing erosion of a scarp. (See page 59)

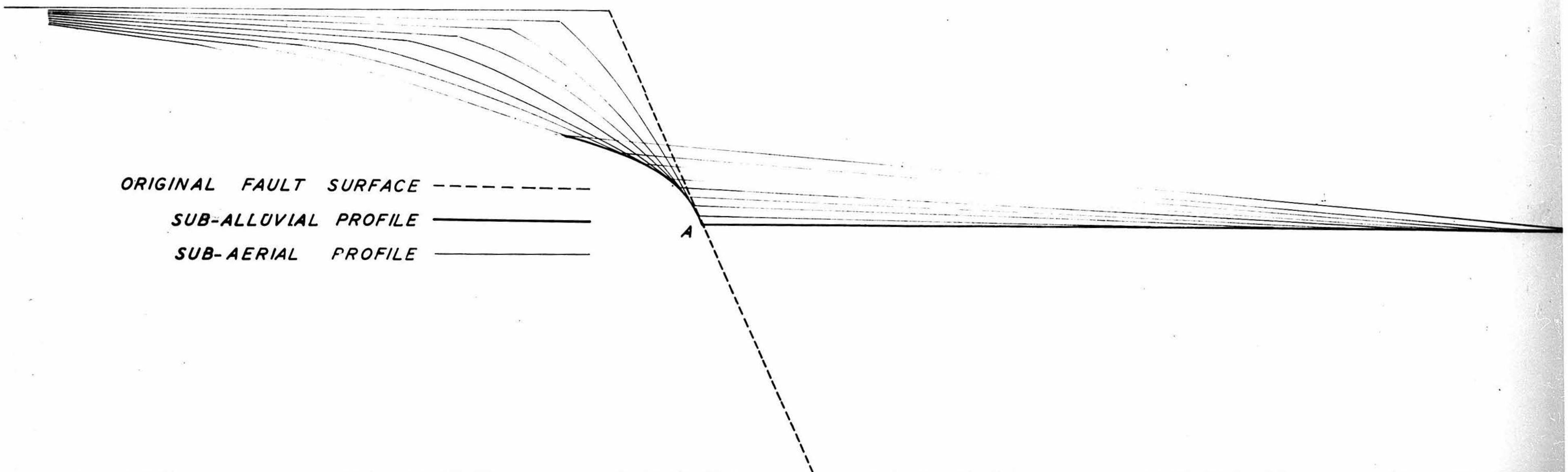
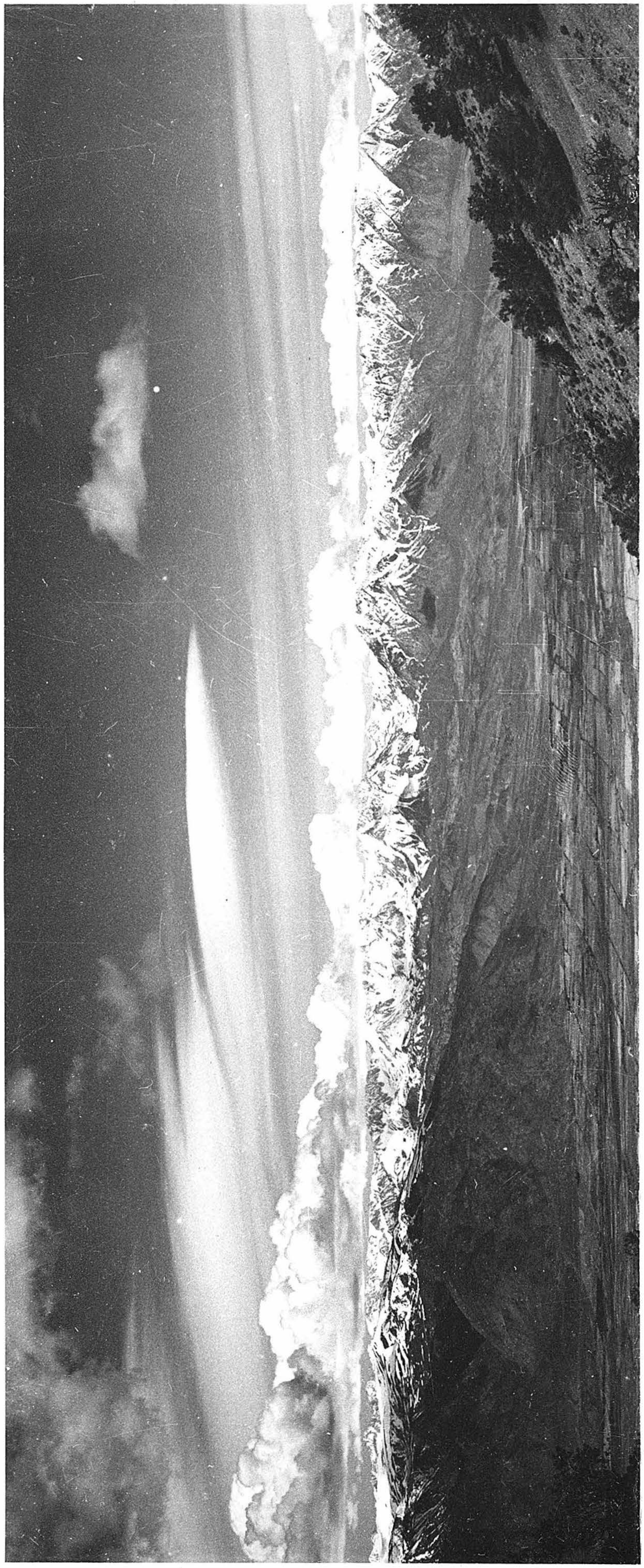

ORIGINAL FAULT SURFACE
SUB-ALLUVIAL PROFILE
SUB-AERIAL PROFILE
A

Plate 21

Bishop Offset of the Sierra Nevada from the White Mountain range to the east. The scarpramp is seen near the center of the photograph. The Round Valley scarp extends from the left center to the right of the view. Pine Creek is located nearly at the right hand edge. The Tungsten Hills are located just right of the center beyond the floor of Owens Valley.



greatly, yet it may be of some value in general considerations.

Scarplets

Quaternary scarplets in the region covered by this paper may be divided roughly into three geographic groups:

a. Scarplets which occur at the east base of the Sierra and within the western portion portion of Owens Valley, and on the Volcanic Tableland;

b. Scarplets which occur at the west base of the Inyo-White Mountain range and within the eastern portion of Owens Valley:

c. Scarplets which occur in Deep Spring Valley.

Each of the three groups is characterized by a common date of formation for the scarplets in that group -- those in group (c) are the most recent; those in group (a) are somewhat older but probably are also of Recent age; those of group (b) are the most ancient and most ofthem probably were formed in early Quaternary time.

In treating scarplets of the region it has been found desireable to discuss in some detail at the outset as many as possible of the criteria used for their field identification. With this in mind, the Pine Creek scarplet will be considered first and, during its description, a critical treatment of the various lines of field evidence used in connection with all the scarplets of the region will be attempted. Following this rather detailed description of the Pine Creek scarplet, I shall describe more briefly the other scarplets of the region.

Pine Creek Scarplet

At the mouth of Pine Creek, where it emerges from the granite of the Sierra to flow between the lateral moraines of the former Tahoan (5, p. 884) glacier, a scarplet descends one moraine and climbs the opposite one in mute testimony of its formation since late Pleistocene time (see plate 22). As is the case with most of the scarplets found near the base of the mountains, this one is truly at the base of the range, being located only a few feet from bedrock. As also frequently occurs this feature is not very distinct and is very likely to escape notice until it is either stumbled upon or is found by searching with that type of feature definitely in mind. In this particular case, Dr. Buwalda and the writer had climbed the northern of the lateral moraines flanking Pine Creek with a view to discovering physiographic evidence for recent faulting, and as luck would have it, we made our climb within a few yards of the scarplet. Dr. Buwalda, whose experience with scarplets in the field was vastly greater than the writer's, ventured the opinion that the topographic features near us could be explained in no other way than by uplift along a fault. Further examination later confirmed this suspicion. The knowledge gained at this locality led to the discovery of several other scarplets well up on the flank of the Sierra that were only found by persistent search, with their diagnostic features constantly in mind.

A common characteristic of recent scarps in this region -- that they are not certainly identifiable on the basis

Plate 22

Recent scarplet crossing the southern lateral moraine of Pine Creek where the creek issues from the mountain face. The displacement on the scarplet is about ten feet with the mountain side up. See page 62.

of their appearance at any particular isolated spot -- is well exemplified by the Pine Creek scarplet. Its trace along the flank of the lateral moraine here may readily be interpreted as drainage lines, although something anomalous about these lines at once strikes the eye of one accustomed to looking for slight physiographic peculiarities. They do not follow exactly the shortest possible path, nor the steepest path, as the case may be, as they cross the moraines, but traverse them at a somewhat lower than expectable angle. Furthermore, although most of the drainage lines on the practically undissected sides of the moraines are essentially rectilinear gully-like features, nevertheless, the traces of the recent scarplet are somewhat more straight-lined than is commonly the case -- notably more rectilinear, in fact.

When one has digested these facts, he begins to be struck by other oddities about the prospective fault feature that did not appear at first glance. First, and exceedingly striking, is the fact that while most of the slight deviations from a normal gully traversing a steep embankment, mentioned above, are entirely explicable through the coincidence of normal features, the presence of <u>exactly similar features</u> on opposite sides of the canyon of Pine Creek, on two distinct lateral moraines, is enormously improbable through the mere accidental occurrence of normal, water-formed features. On further investigation, one soon sees that the two sides of the gully that marks the supposed fault trace are not on exactly the same elevation, but that the rim closer to the mountain face is several feet higher than the rim farther removed --

in short that the region mountainward from the supposed fault is several feet higher than the region toward the valley.

It will be seen that the above evidence for the existence of the fault was all gathered on the two inward flanks of the lateral moraines along Pine Creek. If we now begin to look farther afield for substantiating facts we find several interesting features. First, no signs of the scarplet are to be found in the bed of Pine Creek, between the flanking laterals. This is significant in that it plainly indicates that insufficient activity has occurred during the deposition of the detritus in the bed of the stream to effect any visible displacement of it. Furthermore, since no acquisition of material to the lateral moraines is taking place at present, but rather a vigorous dissection of them and since the scarplet as it crosses them does not appear to have a particularly recent physiographic aspect, the rather obvious inference is that activity along this scarplet has not occurred especially recently, possibly not within the last few thousand years, not within the last few hundred years at any rate. The trace of the scarplet indicates that the fault plane dips eastward at an angle of 60-70 degrees.

Having examined the various lines of evidence for the presence of the fault in the valley of Pine Creek as it flows between the moraines, it is now desireable to look for evidence of the continuence of the scarplet along the mountain face to the north and south. If we do this we find at once a confirmation of our suspicions when we see the gully-like features of the morainal flanks continuing unbroken across the crests of the moraines in the form of typical scarplets with two parallel surfaces, one higher than the other, separated by a more steeply sloping face. In the case of the southern moraine, this feature occurs but a few feet from the granite face of the mountain front, where the mountain abuts against it. The scarp interrupts the crest of the northern moraine at a similar point.

A line of features ascribable to the fault is now seen to extend north and south of the canyon along the base of the Sierra. Since the tops of the lateral moraines slope very gently toward the valley, and since their sides are relatively smooth, drainage falling on them tends to pass directly down the sides, and hence has little tendency to obliterate features that cross them more or less normal to their length. On the other hand, scarps running along the base of the range are almost exactly normal to the mountain front and are thus especially susceptible to burial by detritus derived from the mountain face. Because of these facts, scarplets which cross moraines and then continue across alluvial fans have very different appearances -- where they cross the moraines, they are distinct and readily followed, where they continue along the adjacent fans, they are indistinct, difficult to follow, and frequently entirely buried.

The Pine Creek scarplet shows these characteristics exceptionally well. Its course across the lateral moraines along Pine Creek is very distinct, but it may be traced only with very considerable difficulty along the mountain face to the north and south. Here, the features that lead to its recognition are often so obscure as to cause a person uninitiated in this use of physiography no little doubt as to the validity of the interpretation, but when they are analyzed both individually and as a group there can be little doubt that one interpretation and one alone may properly be placed on them. One of the most decisive of these minor physiographic features used in identifying faint scarplets is an apparent drainage line which runs in an abnormal direction with relation to the main drainage down the alluvial fans that flank the mountain face. The normal course for drainage is along the radii of the fans; when a streamlet is observed, therefore, whose trend is approximately or nearly normal to the fan radii, suspicion arises at once as to whether it may not owe its course to faulting. This suspicion grows into practical certainty when the anomalous feature is traceable across several drainage lines that flow in a normal manner down radii of the fan.

Alignment of features which by themselves apparently have little significance is of course a common physiographic method of locating faults. Thus, a minor "break in slope" on a hillside will often escape notice, or arouse but little interest if discovered, when it appears alone; but when it is in line with other similar features, the probability of all of them being due to unrelated physical causes becomes smaller and smaller as the number of such features increases. The recognition of a "break in slope" -- an interruption in the profile of a hillside so as to produce two essentially parallel surfaces separated by a steeper surface -- unless it can be explained positively in some other manner, must always be considered to be presumptive evidence of faulting, since the development of such a feature by normal stream action on a homogeneous surface is highly improbable. As a special type of a break in slope, the "faceted spur" has already received much attention at the hands of physiographers and is well established as a useful criterion in the identification of faults.

The average height of the Pine Creek scarplet, as evidenced by faceted spurs and breaks in the slope of ridges is approximately 25 feet. This is somewhat greater than the apparent displacement along the scarplet as it crosses the lateral moraines at which points the apparent offset is about 15 feet.

The Pine Creek scarplet is somewhat over 2 miles in length, gradually terminating at either end, as it becomes less and less distinct. This comparatively short length and tendency to terminate gradually is typical of the scarplets along the base of the Sierra and along the west base of the White Mountains, whereas the very distinct scarplet along the east side of Deep Spring Valley is practically continuous and exceedingly plainly marked for over 10 miles.

Sherwin Hill Scarplet

No scarplets are present along the Sierran base from the point at which the Pine Creek scarplet terminates about half-way between Pine Creek and Wells Meadow to a point about five miles north. Along the southern part of Sherwin Hill, however, a fairly distinct scarplet follows the base of the

Round Valley scarp for about 2 miles. This scarplet shows the same general characteristics that are present along the Pine Creek scarplet where the latter follows the mountain base north and south of Pine Creek, At the southern end of the Sherwin Hill sdarplet, the floor of Round Valley meets the steep bed-rock mountain face with an exceptionally abrupt junction. This sharp dividing line between the steep and gentle slopes is due to the fact that drainage from Sherwin Hill to the north flows roughly parallel to the range front here for a short distance; as a result of this the alluvium-bedrock contact has been sharpened. For this reason, the transition slopes, that commonly occur high up on the alluvial fans, just below the bedrock scarp face are almost completely lacking. The scarp-let thus occurs only a few hundred feet above the gently sloping alluviated floor of Round Valley, on the very steep talus slope about 100 feet below the bedrock base.

A displacement of 30 to 40 feet is indicated for this feature both by a strongly pronounced break in slope of the oversteepened fan and by breaks in the alluvial rims of small canyons. As is the case with the Pine Creek scarplet, this feature is difficult to trace along the even surfaces of the alluvial apron between drainage lines, because the large quantity of detritus derived from the scarp face above it tends constantly to obliterate it by burial. As the scarplet continues to the north its height varies somewhat from place to place, probably because of varying amounts of burial at different localities. The trend of its southern half is N30W, which changes to N10W toward the north.

The Sherwin Hill scarplet, for most of its length, cuts alluvium of the steep fan apron, although at a few places it marks a bedrock-alluvium contact and is notable for that reason. One very diagnostic feature of scarplets in general, a diagonal course up one side of a spur and down the other, is well displayed by this one at several localities. A series of springs marks the line of the scarplet rather closely -- whether these springs are directly attributable to the fault marked by the scarplet is not certain, but this seems at least rather rather probable.

Mt. Tom Scarplets

Two recent scarplets of exceptional distinctness cut the alluvial mantle, and also the bedrock to some extent, at an elevation of about 7000 feet on the northeast flank of Mt. Tom. As is commonly the case, these scarplets occur almost up at the head of the alluvial fan, near its contact with bedrock. They cut the alluvium of the steep canyon north of Horton Creek, at which point they may be seen from the valley below as two lines converging toward the south; this convergence represents actual merging of the scarplets, which then continue to the south as a single feature. North of the point where the scarplets show with such clarity, they continue as separate physiographic features, somewhat less distinctly.

The upper scarplet is the more interesting, since it cuts bedrock at several places. At one locality, in particular, a portion of a marble roof pendant in the bedrock complex shows not only a physiographic break at the point where the scarplet occurs, but also an unmistakable fault breccia and polished surfaces. The presence of indisputable structural evidence of faulting so intimately connected with physiographic evidence seems to me to be especially noteworthy.

A matter of some interest in connection with the pattern of these scarplets is the sharp bend that the upper one exhibits a few hundred feet north of the;point where it diverges from the lower one. The scarplets proceed diverging at a slight angle for a short distance then the upper one turns sharply northwestward up the northern side of the alluvial fan, crosses a few hundred feet of bedrock, then turns northward again nearly parallel to the lower scarp. The two scarplets then continue to the north essentially parallel for over a mile. Several possible explanations may be advanced for the sudden change in direction of the upper scarp. It may represent an original sinuousity in the course of the fault plane or the plane may steepen as it passes from bedrock below to alluvium above. The upper scarp shows its sharp bend at the point where it passes from alluvium to bedrock, whereas the lower scarp which shows no sharp bend is in alluvium for its entire length. Thus there seems to be some justification for believing that the upper fault does not show any appreciable bending, but that the turn in the scarplet trace is due to variations in alluvium thickness. It seems more likely, however, that the fault plane must have showed a considerable amount of initial irregularity, because the bend in the fault plane is more abrupt than commonly observed in similar cases where the fault passes from alluvium to bedrock.

A suspicion that the Mt. Tom scarplets might be landslide features was entertained for a short time at the outset of their investigation. When, however, the scarps were seen to continue in essentially a rectilinear fashion across several separate talus cones (and the intervening bedrock in the case of the upper scarplet) and when arcuate landslide forms were not found, it was concluded that they must have been formed by faulting. Structural evidence, as mentioned above, verified this conclusion.

Birch Creek Scarplet

The southernmost scarplet related to the Round Valley scarp is located on the lower flank of Mt. Humphreys and Basin Mountain 2 or 3 miles north-northwest of North Lake, at an elevation of about 10,000 feet (see Plate 2). This scarplet cuts lateral moraines of the Tioga epoch (5, p. 881) on both Birch and McGee Creeks, in a manner very similar to the scarplet that crosses Pine Creek, although the moraines at the mouth of Pine Creek are probably of Tahoe age. At the points where the Birch Creek scarplet crosses McGee and Birch Creeks a well defined scarplet in the gravels that flank the present stream channels plainly marks its course. The presence of this scarplet in the canyons of McGee and Birch Creeks in the one case and its absence in the canyon of Pine Creek may be explained in two ways -- either the Birch Creek scarplet is distinctly younger than the Pine Creek scarplet, or the considerably larger size of Pine Creek has brought about the burial of the scarp in that locality although it may have been formed at the same time as the Birch Creek feature.

Since the freshness of the two scarplets outside of the canyons seems to be about the same, it seems that the difference in stream size is the most likely explanation of the scarplet's presence in the canyon bottom in one case and its absence in the other.

The Birch Creek scarplet has a maximum height of 15-20 feet as it crosses the lateral moraines along McGee Creek. Its height along the fan face between McGee and Birch Creeks is much less than this because of partial burial by detritus from higher up on the mountain slope. A short distance south of the north fork of Birch Creek the scarplet is noteworthy for the fact that it cuts several budrock spurs with plainly visible displacement.

The dip of the fault plane as indicated by the trace of the Birch Creek scarplet seems to be 60-75 degrees to the east, though this is but a rough estimate. The fault, of course, is normal, the west side having gone up with respect to the east.

Finding the Birch Creek scarplet is considered of considerable interest because it indicates accurately the position of the major zone of uplift along the Round Valley scarp in this latitude. Since the Buttermilk Country is heavily covered with both glacial and fluvial detritus, it would have been practically impossible to locate the position of the Round Valley fault without the evidence presented by the Birch Creek scarplet. As has been the case with all of the scarplets described along the base of the Round Valley scarp, the Birch Creek scarplet occurs well up at the head of the alluvial mantle that flanks the bedrock of the range.

Bishop Scarplets

Scarplets which appear along the Bishop-Big Pine segment of the Sierran scarp, not including those in the Big Pine Salient, will be referred to as the "Bishop scarplets". These differ in many ways from the scarplets along Round Valley -- they appear to be older, they face both toward the valley and toward the range, they cut the bedrock at many places, they are usually of considerably greater length, they are often located at a distance of several hundred yards from the actual base of the range, they show on the average a greater displacement. All of these differences, most of which indicate greater age for the Bishop scarplets, are consistent with the hypothesis that the Round Valley segment of the Sierran scarp is younger, in part, than the Bishop-Big Pine segment.

Although several scarplets which face the mountains are present in the Bishop system, the most westerly scarplet at any particular point invariably faces toward the valley. It is difficult to decide whether the westward facing scarplets close to the mountain front are due to movement along valley blocks essentially unrelated to the mountains, or whether they are due to movements along faults that are closely related to the general frontal fault system. It is significant, in this connection, that some of the westward facing scarps are continuous for a considerable distance practically parallel to the mountain base; it is hardly likely that valley blocks unrelated to the frontal faulting would show such parallelism, neither is it likely that faulting so close to the range front as that displayed by fault Q could be unrelated to the frontal fault system. It seems, therefore, that all of the scarplets shown on Plate 1 in the Bishop system are members of the general zone of uplift of the mountain mass. Why some of them should show an abnormal displacement is not readily explicable. No displacement of the alluvium of Owens Valley north of the bedrock of the mountain mass southwest of Bishop was observed.

Scarplet P

The most westerly scarplet of the Bishop series is also the most prominent. It has contributed to the most recent uplift of the range here as is evidenced by its fairly steep fresh scarps crossing the alluvium at the mouths of several canyons, notably the small canyon just north of Keough's Hot Springs. Throughout much of its length this scarplet follows the base of the steep bedrock scarp and has obviously continued, recently, uplift that must have been going on along this line for a considerable time to produce the large amount of visible displacement. Perhaps the best exposure of this scarplet may be found between Shannon and Freeman Canyons where it forms a prominent scarp 100-150 feet high across the alluvium. It is also marked for a part of its length by a bedrock scarp face.

As is pointed out elsewhere in this paper (page 140) the course of Shannon Canyon falls directly in line with the continuation of this scarplet, but no evidence of recent displacement is visible in the canyon, so it is concluded that it probably represents an old line of faulting that has not been active recently. A possible line of faulting extending for a short distance south from T 134 may mark the southern continuation of Scarplet P, although no recent activity was found near T 134 -- merely evidence of old faulting such as alignment of kernbuts, kerncols, springs and a slight steepening of slope. This point is somewhat east of the possible fault of Shannon Canyon and it is entirely possible that either line of "faulting" or both, may be due to arrangement of joints.

The northern end of Scarplet P bifucrates at Rawson Creek, and continues north to the edge of Owens Valley as two faults, diverging slightly northward. They are both clearly shown as scarps in the bedrock, although they do not clearly cut the alluvial mantle, indicating that in this locality Scarplet P has suffered no recent activity of sufficient magnitude to form a scarp in the alluvium. From a consideration of the facts that no visible displacement of the alluvium may be observed along the northern portion of this scarplet, and that readily apparent displacement does occur along the middle and southern portions, we may infer that the northern portion has undergone comparatively little displacement recently.

The northern portion of this scarplet has formed the western side of a prominent topographic gap in the bedrock at the northern edge of the mountain mass. This col -like feature is a recent physiographic land form which is the result of normal faulting on its two sides -- that is, it is a small graben that has suffered but little changes from its initial appearance. Its flat floor and steep sides developed in essentially homogeneous rock transverse to the drainage lines of the mountain slope, together with its alignment with scarplets P and Q to the south, point to its almost certain fault origin and direct connection with the scarplets to the south.

Scarplet Q

Peculiarly enough, the most persistent scarplet in the Bishop group shows an abnormal direction of displacement, with the valley side up with respect to the mountain side. This feature is clearly traceable along the entire length of the Bishop-Big Pine segment of the Sierran scarp north of the Big Pine salient;throughout all of this distance it faces west. Displacement generally amounts to about 150 feet; bed-rock frequently forms the scarp face. (see Plate 23)

A number of important springs are closely related to the zone between Scarplets P and Q. Keough'$ Hot Springs, from which hot mineralized water flows in considerable quantity apparently rises along the upper fault, while a number of cool or slightly thermal springs rise at the base of Scarplet Q.

It is fairly obvious from the amount of topographic displacement along scarplet Q that its total movement has been relatively slight -- not over 200 feet -- whereas scarplet P, located at the base of the main bedrock scarp is but the latest manisfestation of a long period of uplift along that zone. In spite of the relatively slight displacement along this westward facing scarplet, however, an explanation of the mechanics involved in its formation is difficult to find. Other scarplets facing toward the range at whose base they are found are commonly at a considerable distance from the base and are to be explained as being the result of differential movement along sub-valley blocks, not directly related to the uplift of the mountains. Scarplet Q, though, appears to be too closely related to the main zone of faulting to be explained in this manner.

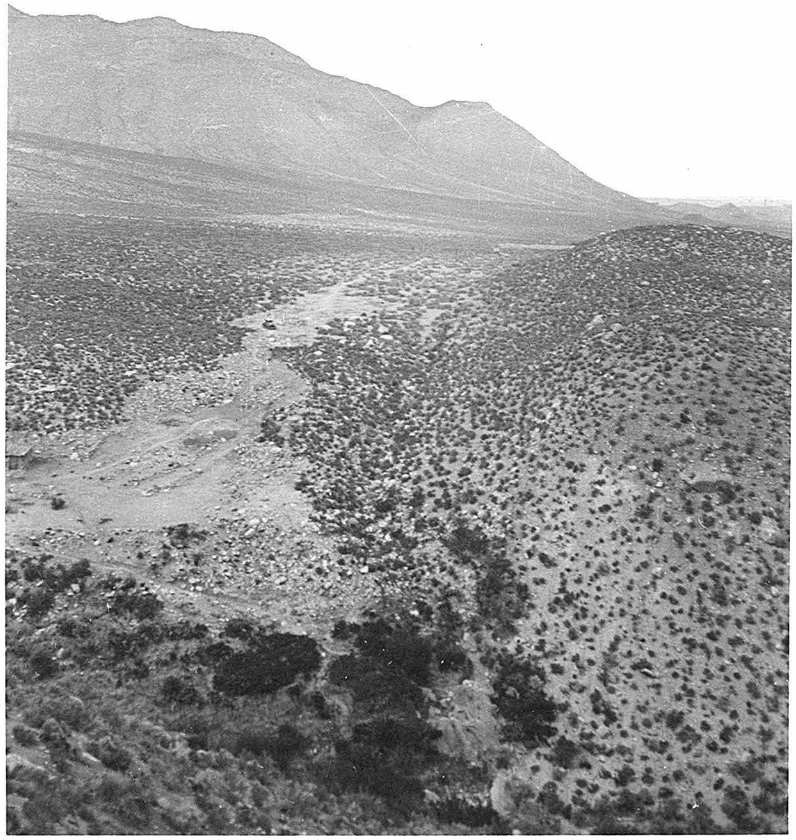
Whether its formation is to be explained by a slight subsidence of the mountain block, followed by renewed uplift, or by a distinct rise of the valley block, is not readily determinable. This question is connected with relative rates of uplift also, for if both the mountain and valley blocks are rising at the same time, the displacements at their borders will be determined by the difference of the separate rates of uplift. In the absence of more data, it does not seem possible to answer this question. It would be well to remember, however, that the possibility of the mountain block undergoing slight, temporary subsidences with respect to the valley block is not inconceivable.

At a point about a quarter of a mile north of Keough's Hot Springs, this scarplet was detected in the alluvium only by a most careful study of the fan profile. The normal concave fan profile here was observed to be slightly <u>convex</u> a few hundred feet west of T 157 (see Plate 24) Since this method of discovering recent scarps in alluvium that show but slight displacement and which have been largely obliterated by

Plate 23

A. Looking north along Westward facing Scarplet Q in Bishop-Big Pine segment of the Sierran scarp just south of Keough's Hot Springs. The scarplet passes to the right of the spur in the distance. The suggestive notch in the skyline near the right of the spur is not related to faulting. See page 77.

B. Closer view of spur shown in above photograph. An eastward facing scarplet runs from left to right at the base of the spur and around its end to the right. See page 75.



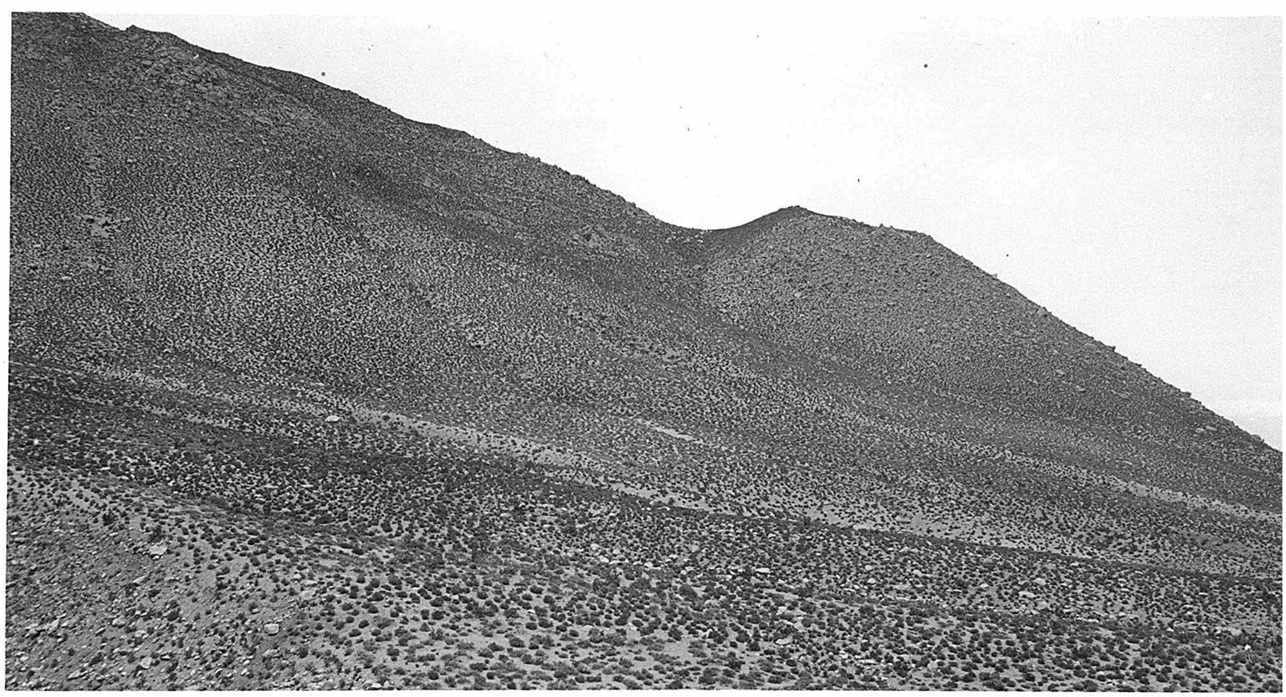
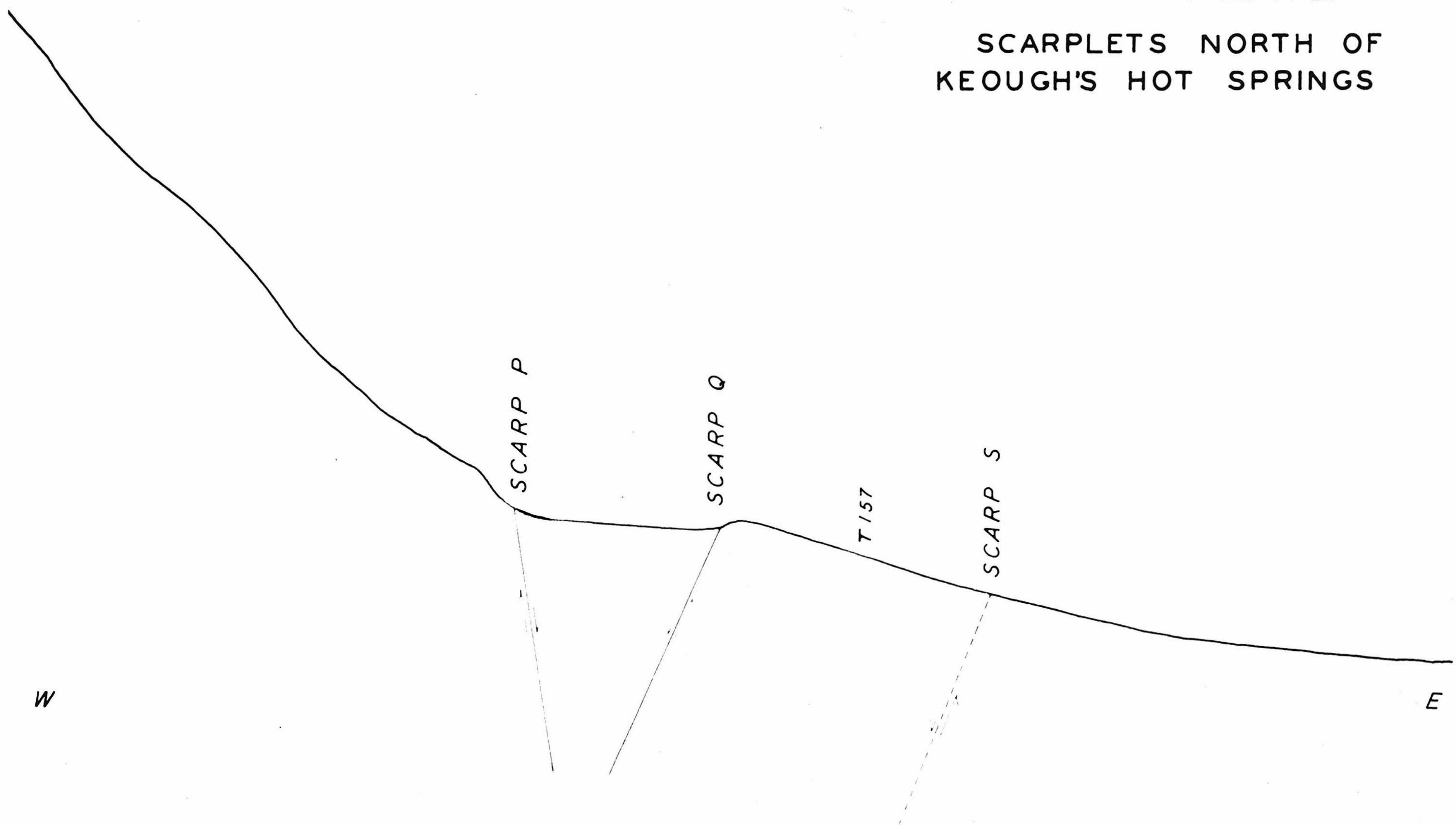


Plate 24

See page 78

PLATE 7

SCARPLETS NORTH OF KEOUGH'S HOT SPRINGS



burial, is often of considerable value, it will be described for this locality in some detail.

In the first place, it might be pointed out that an observer standing at T 157 will have little difficulty in discovering Scarplet P, a clearly defined eastward-facing feature. Scarplet Q, though, does not stand out at all clearly and since it faces westward its face can not be seen from T 157. An observed on the lookout for oddities in fan structure, however, will see that part of the fan surface between him and the base of Scarplet P is not visible. This can mean only that the fan surface is convex in this area. The degree of convexity can readily be judged by noting the point at which a prolongation of the surface immediately west of T 157 meets the land surface west of Scarplet P. In the present instance, this point is some distance up the scarp face.

Having decided that the fan surface is this particular area is abnormal, one will proceed to measure the fan slope near T 157. If this is done, it will be found to have an inclination toward the east of 7 degrees, considerably more than the usual slope of 4 or 5 degrees at other places on the alluvial apron at comparable distances from the mountain front. If one now walks up the fan surface he will have no difficulty in recognizing the point where Scarplet Q passes across the fan, although the recognition of that point without the information obtained from the vicinity of T 157 might not have at all readily been accomplished.

As to the mechanics of the faulting in this area, the cross section presented in Plate 24 presents my conception of the most probable structure as derived from the none too complete information available at the surface. The position of Scarplet S is inferred from its location to the north, and the highly satisfactory manner that it fits in with the structure near T 157 makes its presence there at least probable.

Scarplet R

This feature faces toward the valley in the normal manner, and shows a displacement that reaches a maximum of 150 feet although it varies considerably. It is most clearly displayed about a mile and a half southwest of B.M. 4045, 5 miles south of Bishop, where it lies in front of a prominent terrace on which a small farm has been built. It is also somewhat doubtfully shown in the small granite salient just south of B.M. 4319, two and one half miles south of Bishop, where physiographic evidence points, none too certainly, to a rather old scarp on which no movement has occurred recently.

The region between this feature and Scarplet Q is evidently a narrow horst, and it is best shown as such somewhat less than a mile north of Keough'S Hot Spring, where a granite ridge, parallel to the range front, is bounded by these scarplets.

Scarplet S

Facing toward the west, this scarplet is rather small in throw but interesting because of its comparative recency,, since it cuts rather clearly the alluvial fan at the mouth of Rawson Creek. Its displacement attains a maximum of about

20 feet although the feature is difinitely traceable for less than a mile. With this scarplet, the question again rises as to whether to consider displacement along it a result of movement of sub-valley blocks. Here, as before, the question is difficult, if not impossible to answer on the basis of the data obtainable from the surface.

Scarplet T

This is a comparatively minor feature, traceable only a few hundred yards along the ground, and showing a maximum displacement of less that 20 feet. It is the farthest valleyward scarplet found along this portion of the Sierran scarp.

Big Pine Scarplets

Big Pine Salient, west of the town of Big Pine, is the site of several recent scarplets, some of which face east and some west. Displacement on these features is not great, generally less than 50 feet. The most recent of them is the one that continues to the south and crosses the lava of Crater Mountain -- this one is described under the section on the Crater Mountain Scarplets. The other scarplets, all of them west of this one, seem to be of greater age, but are nevertheless very clearly defined, resembling those along the base of the Round Valley scarp.

The region is noteworthy for the extensive development of scarplets which face toward the mountain front, no less than four of these features being present within the space of a mile along Baker Creek, west of Big Pine. Three of these abnormally facing scarplets cut the alluvium with slight displacements, the one farthest to the west, however, is evidently an older feature and has been the locale of movements totaling aver 200 feet.

Crater Mountain Scarplets

A well preserved set of four Recent scarplets cuts the basalt of Crater Mountain, an extinct volcanic cone about 4 miles south of Big Pine. Three of these lie on the east side of the mountain, face east and show displacements ranging up to 40 feet. The fourth lies on the west flank and faces west with a maximum displacement of about 20 feet. The middle scarp of the eastern group continues for a considerable distance north of the lava of Crater Mountain, passes west of the town of Big Pine and finally disappears at the eastern edge of the granite salient northwest of town. The recency of this particular scarplet as it cuts alluvium appears to be comparable with that of the scarplets near Lone Pine that were developed at the time of the 1872 earthquake; it is possible that this was formed at that time since Whitney speaks of evidences of seismic activity west of Big Pine, although he does not mention any of the scarplets (1, p. 295).

A peculiar characteristic of the middle fault of the eastern group is its tendency to appear as a series of en echelon scarps, instead of in a continuous line; this feature is especially well shown as it crosses the lava of Crater Mountain, where individual segments of the scarplet are generally not over a few hundred feet long. The offset from one segment of the scarplet to the next is generally only a few feet, but it is sufficient to be readily noticeable. Great brittleness of the lava, and a resulting inability to bend probably account for this pattern of the fault trace although a similar phenomenon was noticed at one locality north of the lava flow in alluvium.

Although the Crater Mountain scarplets are for the most part located at some distance east of the actual base of the mountains, and are probably related to movements along the mosaic of bedrock blocks underlying the valley, yet one of them, Scarplet M, passes rather close to the frontal fault system north of Big Pine. It seem likely that this is due to a convergence of the valley blocks which approach the piedmont fault system here.

The easternmost fault of the Crater Mountain group is well displayed west of Fish Springs where it forms an impressive scarplet near the edge of the lava field. West of Fish Springs school it has cut in two and displaced a small parasitic crater on the flank of Crater Mountain. The displacement along this scarplet reaches a maximum of about 40 feet.

The westernmost fault of the Crater Mountain group, Scarplet K, is notable for the fact that it faces west, thus showing a direction of displacement opposite to that of the mountain face. Displacement along this scarp reaches a maximum of about 20 feet. The northern end of this scarp cuts the southern part of Crater Mountain west of Fish Springs hill; south of the edge of the lava, the fault continues in a more or less straight line toward Red Mountain, which it, however, does not cut. The occurrence of Red Mountain, as especially perfect cinder cone, exactly on the prolongation of the scarplet, suggests strongly that the scarplet is the surface expression of a deep-seated fault along which the eruption that produced Red Mountain occurred.

About a quarter of a mile east of Red Mountain a small scarplet, facing east, cuts the alluvium with a displacement of about 15 feet. This feature is in line with the group of eastward facing scarplets on the east side of Crater Mountain, but is not in a direct prolongation of any of them. It seems likely, however, that it is the result of movement along one of the bedrock faults that formed the scarplets to the north, which have simply not been sufficiently active recently in the intervening region to have cut the alluvium.

Tinemaha Scarplet

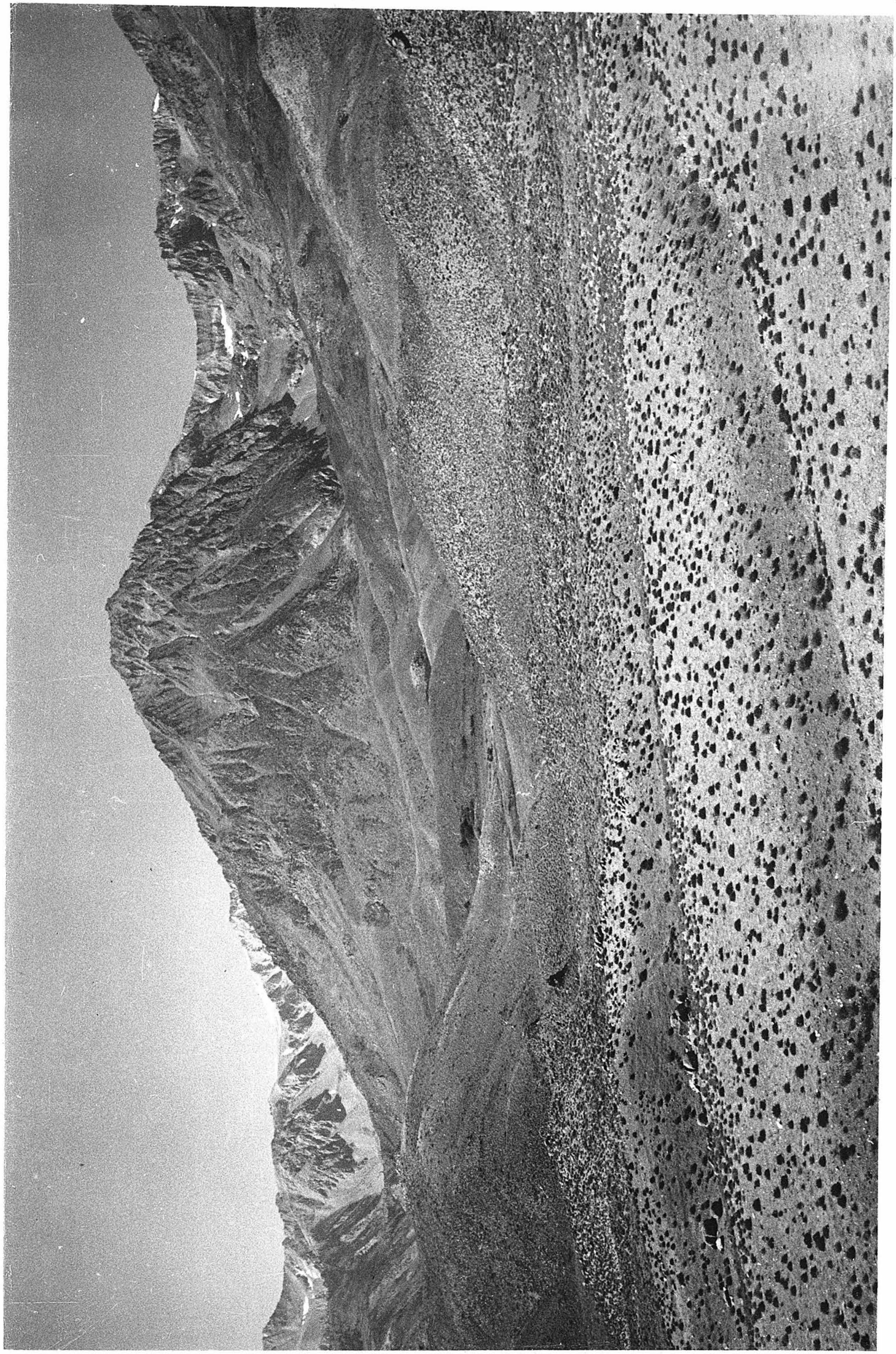
A markedly straight scarplet cuts the talus cone between Tinemaha and Red Mountain Creeks at an elevation of about 8100 feet, practically at the base of the bedrock. The scarp ends abruptly about half way between the two creeks without the usual gradual diminution in displacement. To the north, however, it continues across Tinemaha Creek into the drainage basin of Fuller Creek along the east flank of Birch Mountain. The displacement along most of this scarplet, which faces westward, amounts to about 20 feet. Several springs rise along the line of this scarplet, but whether they are related to the faulting or simply occur at the foot of the bedrock of the mountain is not certain. The fault is visible for some distance out in the valley; Knopf recognized its presence, in fact, at the time that he executed the field work for Professional Paper 110 (2, p. 79). I should recommend this feature as a very fine example of a Recent Scarplet to anyone interested in a study of these features.

In age, this scarplet appears to about the equivalent of the Pine Creek and Birch Creek scarplets of the Mt. Goddard Quadrangle. It clearly cuts moraines of the Tioga epoch yet does not cut the most recent alluvium in the canyon bottoms. Further, at this point we have an apportunity to observe its behavior as it crosses moraines of both Tioga and Tahoe ages. It seems to affect both of them to the same degree, so we may safely say that it suffered all of its observable displacement since the conclusion of the later, or Tioga glaciation. It probably, but not at all certainly, was formed at approximately the same time as the scarplets along the Round Valley scarp. It appears to be somewhat older than the scarplets that cut Crater Mountain, although an estimate of relative ages is difficult here, because the two localities under consideration are not being subjected to the same conditions of erosion.

About a mile southeast of the southern end of the Tinemaha scarplet, two very minor scarplets cut the fan near the mouth of Red Mountain Creek. They both face east and show a displacement of only about 10 feet. Their age may be definitely set as Recent since they cut the surface of Recent talus cones.

Plate 25

View of 12,543 mountain just south of Birch Mountain, southwest of Big Pine. The Tinemaha scarplet, not visible in this view, crosses tha flank of this peak at an elevation of about 8100 feet at the head of the alluvial fan. See page 86.



Waucoba Quaternary Scarplets

The Waucoba embayment, located east of the town of Big Pine, contains a series of lacustral and fanglomeratic beds which I have grouped as the Zurich formation and an overlying series of fanglomeratic deposits all dipping toward the valley with a gentle inclination. A series of low, but persistent scarps crossing the embayment in a general north-south direction, is very noticeable when the embayment is viewed from the vicinity of Big Pine. That these might be fault features struck Dr. Buwalda some time ago when he was visiting Owens Valley.

Physiographic evidence that faults created these scarplets, quite similar for all of them, is a straight or gently curving base, the presence of vertically offset parallel physiographic surfaces above and below the scarp, alignment of sharply faceted spurs. Since, however, these features could be strike scarps formed by retrogressive erosion of a hard cap bed, and since the Zurich formation contains resistant beds it was necessary to obtain corroborative structural evidence for faulting to support the somewhat equivocal physiographic evidence. It should be pointed out here however, that even in the absence of definite structural evidence, the amount and type of physiographic evidence would have warranted the postulation of "highly probable" faults at the base of these scarps. The finding of a small scarplet, very recently formed, at the base of one of the larger scarplets well toward the eastern edge of the embayment practically completed the chain of testimony necessary to establish the faulted origin of this particular feature, and inferentially, of the other scarplets.

Structural evidence for these scarplets consists of crushed zones, discordant dips, vertical offset of beds, fault surface, and rectilinear alignment of these features. None of the scarplets shows all of these structural characters, and some of the scarplets do not show any of them, but the fact that all of these typical fault features were found at one or another locality along the bases of the scarplets demonstrates, in association with the physiographic evidence, that the scarplets are of fault origin.

Scarplet A

The first scarplet to be considered is located near the eastern edge of the Waucoba embayment, it is considered first because it shows the most conclusive evidence for its fault origin. It is furthermore an exceptionally well developed topographic feature. The surface below the scarp slopes off gently to the west. It is practically undissected and hence contrasts strongly with the highly dissected topography east of the scarp. The latter also slopes westward considerably more steeply. The gulches that cut the surface east of the scarplet end abruptly at the scarplet, suggesting strongly that uplift along the fault caused their formation by increasing the stream gradients. The scarp is about 200 feet high, trends in a north-south direction, and is distinctly traceable for about two miles. Partly cemented alluvial breccias of the Zurich formation are exposed along the scarplet. At no place has the fault brought bedrock to the surface.

At the point where the scarplet crosses the canyon in which (most optimistically) a road is shown, about three-quarters of a mile north of Waucoba Canyon, a very excellent exposure of the fault may be observed. It dips 43 degrees west and trends N15W at this point. White Zurich beds to the east abut sharply against brown beds on the west side of the fault. Strangely enough, no disturbance of dip has occurred near the fault plane, although displacement amounts to at least 200 feet. This fact is of importance in that it means that the absence of disturbed beds along a scarp in fanglomerate does not constitute an a priori reason for believing that the scarp is not of fault origin.

About one quarter mile north of the canyon mentioned above, a very recently formed scarplet appears at the base of the main scarplet, cuts the flood plain deposits in the gulches and indicates in every way that it has been formed in the last few tens of years. Its dip was determined rather satisfactorily from its trace along canyons cutting the main scarplet and found to be about 45 degrees to the west. Its trend is that same as the larger feature but because its dip differs from the slope of the main scarplet it does not follow its base exactly. The small subsidiary scarplet is traceable for about a mile.

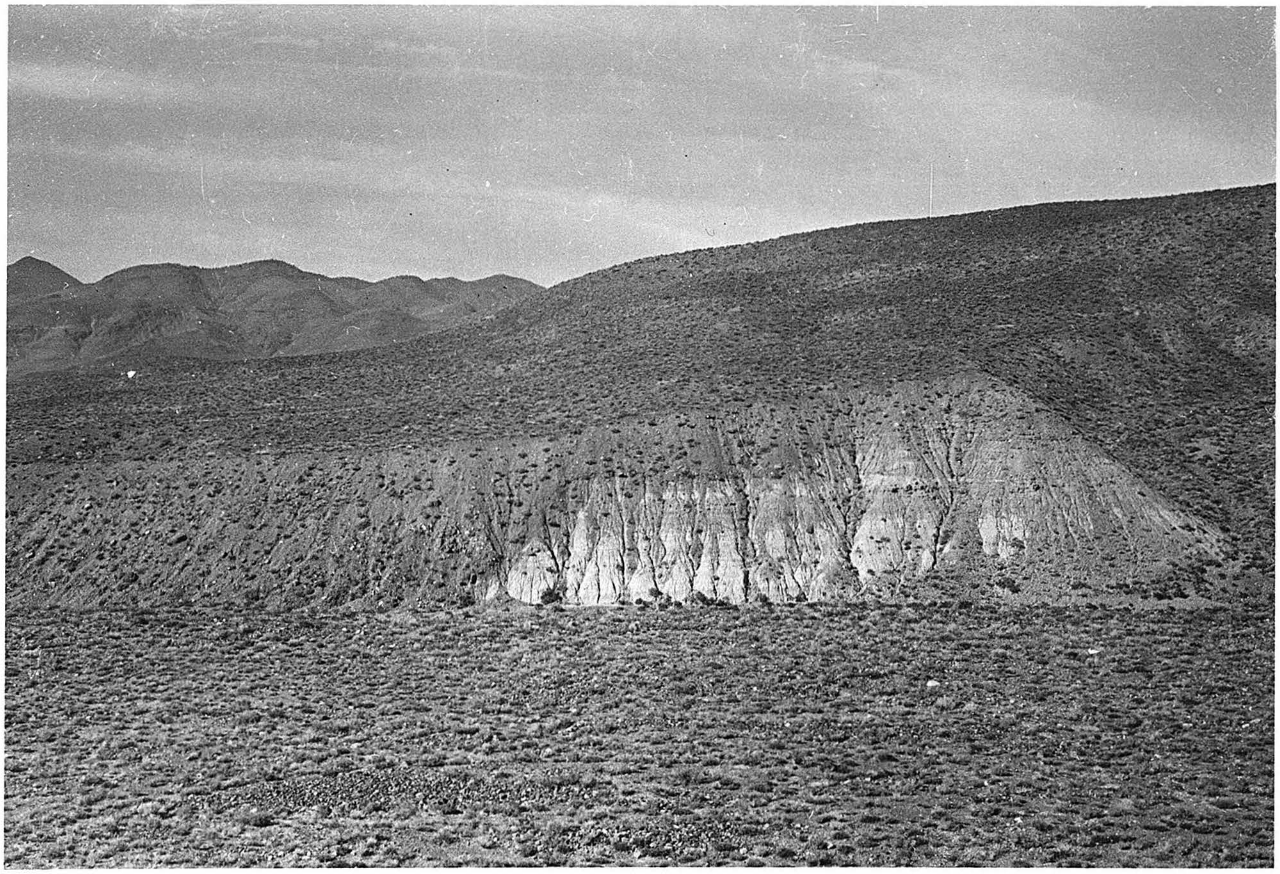
Scarplet B

This feature, actually a triple scarplet, is located in the alluvial apron near the mouth of Waucoba Canyon about two miles southeast of Zurich at an elevation of about 4200 feet. Trending approximately N35W these three overlapping

Plate 26

A. Scarplet A in the Waucoba Embayment. In this view, looking toward the north, the topographic expression of the scarplet may be clearly seen above the exposure of the fault as it cuts Zurich beds near the middle of the photograph. See page 91.

B. Detail of fault shown in above view. The fault plane dips to the west (left) at an angle of 43 degrees. The white lacustral beds to the right are faulted up against brown fanglomerates to the left. See page 91.



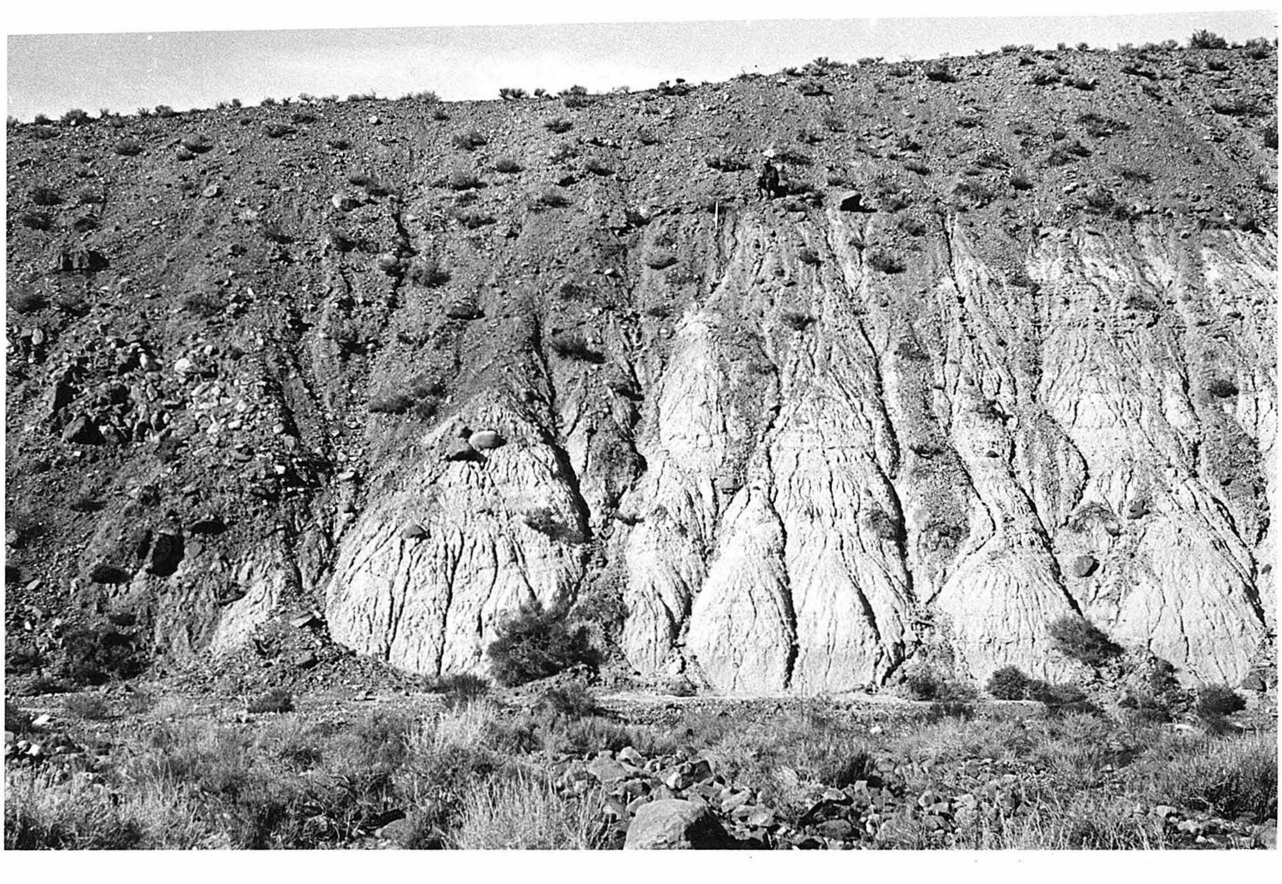
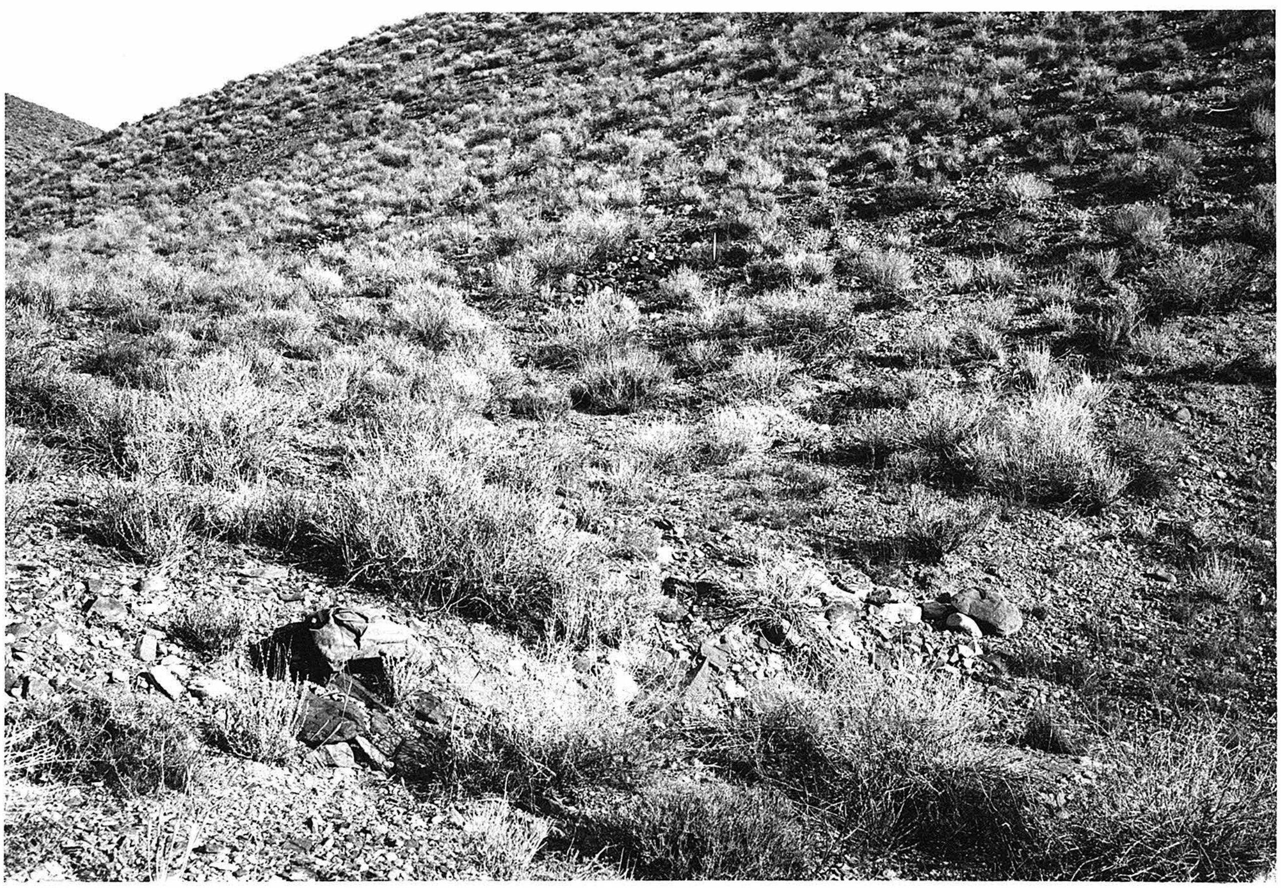


Plate 27

A. View looking south, of scarplet A cutting Zurich formation in the Waucoba Embayment. The small subsidiary scarplet runs diagonally down the slope from the man's figure to the small ravine in the foreground. See page 91.

B. Detail of subsidiary scarplet crossing small ravine. The manner in which the most recent detritus in the bottom of the ravine is displaced is most striking testimony to the recency of formation of this scarplet. The small scarplet with a displacement of about 3 feet is a minor feature on the larger one at whose base it occurs. See page 91.



scarplets show a displacement that amounts to about 3 feet on the average with, however, an offset in bedrock at one place amounting to 18 feet. In all cases these scarplets show displacement expectable in that the valley block dropped with reference to the mountain mass. Most striking, especially in connection with such minor physiographic features in alluvial material, was the finding of actual displacement of the rude stratification lines in the fanglomerate on the two sides of the eastern scarplet of the group at one point where it crosses a small dry wash.

Interesting and abundant phenomena demonstrate the extreme recency of formation of these dislocations in the fan surface. The scarplets cross small washes with apparently the same displacement of the land surface in the washes as on the adjacent portions of the fan surface. Further, the small streamlets that flow in the dry washes at times of rainfall have not yet cut notches the entire height of the scarplets, but instead flow over them by way of miniature hanging valleys and waterfalls. All of which seems to indicate strongly that this group of diminutive scarplets has been formed in the course of the last few tens of years. The fact that a bedrock scarp 18 feet in height forms part of one of the scarplets points to faulting at a former time, the scarp in alluvium produced then having since been obliterated. The recent revival of movement along this fault then formed the recent features in the alluvium and added roughly three feet to the height of the scarp in bedrock.

These recent features were found the more readily because they occur along a prolongation of the line of frontal faulting south of Waucoba embayment and it seemed likely therefore that recent scarplets might occur here. That indications of such recent revival of movement should be found was surprising, but the location of the line of faulting along which the revival occurred was exactly where it was expected. A search for similar recent scarplets east and west of the group being described was made but none was discovered.

Scarplet C

Located approximately on a line joining Graham Spring and B.M. 4502 on the Deep Spring Valley road, and about half way between these points, Scarplet C is a very prominent topographic feature, second only to Scarplet A in its clear physiographic implications of recent faulting. Displacement along this scarplet is rather uniform along most of its length and amounts to about 100 feet. The face slopes southwestward at an inclination that varies somewhat, but which averages about 30 degrees. The total length of this scarplet is about one and one-half miles. It terminates abruptly at both ends.

No exposures of the plane of this fault were found. Disturbed strata west of the fault were found at one locality near the northwest end of the scarplet; strata east of the fault dip rather uniformly to the southwest at inclinations ranging from three to six degrees. The physiographic offset at the scarplet is clearly defined and amounts to about 100 feet as mentioned above. The two surfaces, above and below the scarp, are essentially parallel and do not show any great difference in their physiographic appearance as do the surfaces at Scarplet A. The face of the scarplet is strikingly rectilinear, and is little modified by stream channeling.

About a quarter of a mile east of Scarplet C a small fault with about the same trend but with opposite direction of displacement appears and makes of the intervening area a miniature horst. The amount of displacement on this small fault is only a few tens of feet, enough to produce a small scarplet facing toward the mountains but not enough to nullify the uplift along Scarplet C. The place of this small subsidiary fault is plainly displayed along the walls of several small canyons which cut across it, the dip is about 70 degrees to the east and the trend is N30W. Its presence is also indicated by considerably disturbed beds immediately adjacent to it and by a narrow brecciated zone that appears on the surface as a white streak.

Scarplet D

The most northerly fault feature mapped in the Waucoba Embayment, scarplet D is somewhat less sharply marked physiographically than the others described above but nevertheless is plainly visible as a distinct topographic feature that can hardly be explained by erosional processes alone. When,further, clear structural evidence of the existence of faulting is present along its base in several places it may be safely regarded as a certain fault feature. This scarplet trends about N30W, and is roughly parallel to Scarplet C whose northern end is less than a half mile to the east.

This feature is somewhat over 3 miles long. It is indicated physiographically by a face about 100 feet high separating two essentially parallel surfaces of little relief developed on the Zurich formation. In general, these surfaces have about the same inclination as the Zurich strata on which they have been formed -- four to six degrees to the southwest. Relatively high angle dips in the Zurich formation near the southern end of this scarplet have probably resulted from movement that has taken place along it. It is notable that in this case there has been disturbance of beds for some distance to either side of the fault, whereas in Scarplet A, no visible distortion of the beds near the fault was observed.

An interesting feature of the structure a short distance west of both Scarplets C and D is that the beds on the downthrown side of the fault in both instances show a strong tendency to dip into the fault planes, as if the margin of the block in which they are located was tilted eastward at the time of faulting. This same feature was noticed elsewhere along the White Mountains (see page 104) and in the tuff breccia series along Fish Slough (see page 112). It is suggested that this phenomenon is characteristic of relatively thin incompetent beds. Under the influence of the forces of tension faulting and gravity the faulted margin of the lower block should tend to slump downward. Thick, competent sedimentary deposits and plutonic rocks on the other hand would be able to sustain the form of their faulted margins against gravitative settling, though they would be more susceptible to drag than less competent beds.

Physiographic evidence for the presence of Scarplet D, as mentioned earlier, is not as clear as in the case of some of the other scarplets in the Waucoba embayment. However, the essentially rectilinear line of sharply truncated spurs and smooth interstream areas points strongly to its fault origin. Further, several small sag ponds along the line of faulting have but recently been breached. This scarplet appears to meet the general zone of frontal faulting at a slight angle near its southern end, although it terminates before it reaches definite scarps along the mountain base north of the embayment.

Minor faulting is in evidence at a number of localities near the main scarplet. Whether these small displacements are directly related to the main one, or are merely minor slippage planes in the fanglomerate, is doubtful. It seems likely, however, that they were caused by the same general forces directly or indirectly as a result of movement along the main fault.

Scarplet E

This topographic feature, located a short distance west of scarplet D, is not especially well outlined and appears to be considerally eroded from its original shape; Its base is marked by a rather pronounced line of faceted spurs and comparatively little inter-stream area of the scarp remains undissected. The slope of the fault face, too, is not over

20-25 degrees, considerably more than the general fan surface, but much less than other scarps in the embayment. Displacement along it, averaging about fifty feet, is less than is the case with most of the other scarplets.

The Zurich formation near the scarplet dips to the west at angles up to thirty degrees. East of the scarplet low and varied dips both to the east and to the west have been recorded.

It is not possible to determine with certainty whether this scarplet marks a fault or a sharply flexed anticline. However, when the steepness of the dips near it is considered it seems most probable that it is a fault for it is unlikely that a fold with dips up to thirty degrees would develop in the incompetent fanglomerate except as a result of faulting. This is a case in which a rather large number of structural data are available, but in which they are somewhat contradictory. The physiography of the feature seems to indicate faulting although an anticline might produce almost the same topographic form.

The trend of Scarplet E is slightly more to the north than Scarplet D, which is located about a mile to the east. This convergence toward the north is to be expected under the view that the embayment is the result of distributive faulting (see Plate 16). Scarplet E appears to be the expression in the alluvium of the westernmost fault of the distributive system that has formed Waucoba embayment. It seems to be continued farther to the south, after an interval devoid of scarps, by a rather indistinct scarplet about a mile east of

Zurich. This feature, further, seems to be aligned with the very recently produced Scarplet B. It is impossible to determine with certainty whether these scarplets are all parts of one line of faulting because they do not form an unbroken scarp but it seems more than probable that they are all surface expressions of a single line of dislocation.

Black Mountain Scarplets

Several scarplets cut the western base of Black Mountain north of Waucoba embayment. Of these, the westernmost is an extension of Scarplet D of the embayment, while the other two, apparently discontinuous parts of a scarplet closely related to the first do not extend into the embayment. They indicate, however, the distribution of faulting along the frontal fault system in this region. Although these scarplets were traced largely by means of physiography, the eastern one was positively identified as a fault scarp near its northern end by an exposure of the fault plane in a small prospect tunnel at T 147. Displacement of about 75-100 feet each is indicated for these scarplets, which face west. Their trend is about N15W and the scarp faces slope toward the valley steeply. Declivities as steep as thirty degrees were seen, although these were undoubtedly oversteepened by stream undercutting.

An abnormally steep dip of 11 degrees in the Zurich formation about one hundred feet above the upper scarplet near its southern end points to some disturbance as a result of the faulting. It is notable that no signs of these scarplets are visible in canyons crossing them, indicating that they have been comparatively inactive recently. The general appearance of the scarps further tends to substantiate this view, for they are considerably dissected over their entire surface and the faults have presumably not been active for a considerable period.

North of the group described above, and crossing Black Canyon near its mouth is a scarplet that is traceable north nearly to Poleta Canyon. Its trend is somewhat more westerly than the range front and it finally disappears under the recent alluvium. In general appearance this scarplet seems to be rather old, older in fact than most of the other fault features along the base of the White Mountains. Its position in crossing Black Canyon is marked by a clearly apparent step in the profile of the fan on the northern side of the canyon and by a step which has been somewhat altered into a saddle on the narrow ridge of alluvium which appears on the southern side. South of this point its course is continued by a notably rectilinear canyon cut in bedrock, which suggests that an old line of faulting in the bedrock has been revived to produce the scarplet to the north. The fault was not found in the bedrock, however.

North of Black Canyon this scarplet may be traced by its rectilinear base and faceted spurs. No significant structural evidence for its presence was observed but physiographic data point fairly convincingly to its fault origin. Displacement is generally about thirty feet, with the east side up throughout its length.

A small fault cuts the Zurich formation about a half mile north of Black Canyon and just east of the scarplet described above. It shows the same direction and approximate magnitude of displacement, and seems to converge toward it southward. Strangely enough it shows very little physiographic evidence of its existence, actual displacement of beds being the criterion used for its identification. This suggests that it was caused by slumping of the Zurich formation formation during its deposition although lack of other similar instances makes such a possibility somewhat remote.

About halfway between Black and Poleta Canyons a scarplet appears high up on the great alluvial fan at the base of the bedrock slope of the mountain face. It forms, in fact, part of the lower part of the bedrock (here Cambrian quartzitic sandstone) face lying immediately above the fan. Displacement is not great -- about thirty feet -- with the east side upward. A twenty degree east dip in the Zurich formation a few hundred feet west of the scarplet further points to disturbance here. Once again,this scarplet appears to be of considerable age -- it is indistinct, considerably dissected and the surface above it shows evidence of having undergone a rather large amount of stripping since movement ceased along its base. This last line of evidence is rarely to be found in this region so it will be explained, as it is shown here.

One of the steep streams that descends the mountain face above the scarplet has a most peculiar course that apparently can be explained in only one way -- that it is superimposed. Its course, instead of following the shortest and easiest way down the bedrock face, bends rather sharply and then cuts a deep gash across a hard bedrock spur. A few yards to the south the stream could have avoided the work necessary to cut into the spur. The conclusion is that the alluvium formerly extended up onto the face beyond the present course of the streamlet and that the course of the stream was determined when it was flowing on the alluvium. When the stream cut through the alluvium it became incised in the hard rock spur and it has remained there and deepened its channel, until now it is apparently superimposed.

Poleta Scarplet

A scarplet of rather ancient appearance crosses Poleta Canyon near its mouth and may be traced for about a mile across the fan. Its displacement is not great -- about 20-30 feet -- and shows that the mountain block has risen. No offset appears in the beds of the present streams. Erosion has considerably modified the original outline of the scarplet no evidenced by marked oversteepening of dips in the Zurich formation and not by a rectilinear base as with scarps recently formed. The trend of the scarplet is about N15W and its slope is about 20 degrees toward the west, the slope of the general fan surface is about six degrees to the west.

A good section of the Zurich formation is afforded in the walls of Poleta Canyon from an elevation of 4200 feet to about 4700 feet. In the vicinity of the scarplet, a considerable amount of disturbance in the attitude of the beds may be observed. Dips as high as 22 degrees to the west occur near the fault.

Silver Canyon Scarplets

An interesting scarplet about two and one-half miles long crosses Silver Canyon near its mouth at an elevation of 4400 feet. North of Silver Canyon this feature is double, the two branches diverging northward until they are over a half mile apart where they terminate. The valley side of the fault has drppped with reference to the mountain side along its entire length, with displacement ranging up to about 50 feet for each of the branches to the north. Maximum uplift along the single portion of the fault does not exceed about 60 feet. The trend of the single portion of the scarp and of the western branch of the double portion is about N15W, the eastern branch trends about N10E.

Physiographically, this scarplet appears rather old, showing considdarable dissection throughout its extend. The western branch of the double portion, especially, has been greatly modified, so that it is now outlined by a series of low hills elongatte parallel to the range front and separated from one another by rather wide gaps.

The eastern branch is somewhat more clearly defined, and its faulted origin is clearly bespoken by repetition of the pumice stratum (see page 24) of the Zurich formation, indicating a displacement of 50 feet. A number of anomalously steep dips appear in the Zurich formation, indicating that the beds to the east of the fault have also been dragged down. The common occurrence in this region of beds on the downthrown side of faults which dip toward them seems to suggest that the phenomenon is characteristic of incompetent beds which thus seem to slump into the fault plane. The fault place, exposed in several localities, is nearly vertical, beds immediately west of it dip toward it nearly vertically in places.

The fault plane is at places a short distance east of and within the spur ends that mark the base of the scarplet. A possible explanation for this is that the uplift was distributed along two faults a few tens of feet apart and that the scarp is thus composite.

Faulting is not as well substantiated for the southern portion of the single portion of the scarp as for the northern part just described. The occurrence of several large springs, however, at a considerable distance from the fan heads points favorably toward faulting. These springs are aligned closely with a faint scarp that is a southerly prolongation of the western branch of the scarp farther north. The evidence thus favors the continuation of the fault scarp south of Silver Canyon as mapped.

Gunter Creek Scarplets

One of the few eastward facing scarplets along the west front of the White Mountains crosses Gunter Creek at an elevation of 4700 feet about a half mile up the canyon from its mouth. This feature apparently does not extend north of Gunter Creek although it is distinctly traceable for about one mile to the south. The scarplet may be traced down the southern side of the canyon of Gunter Creek, then disappears completely and cannot be found at all on the northern side of the canyon or to the north of it. South of the canyon it is delineated rather distinctly by physiographic features which are aligned with the definite trace of the scarp down the south side of the canyon of Gunter Creek.

Displacement along the clearly marked portion of the scarplet as it passes down the southern side of the canyon of Gunter Creek amounts to about 10 feet. However, the total height of the scarplet, both here and to the south is about thirty feet, indicating that the movement has occurred in several stages and that the latest displacement resulted in offset of about ten feet along the sharply defined portion. No structural evidence for a fault was obtained, but the clearly defined physiographic characters of the scarplet render highly probable the existence of a fault. At the point where the fault crosses the southern side of Gunter Creek it appears to have raised bedrock on the west against the Zurich beds on the east, although it is possible that the bedrock outcrop may merely represent a protruberence of the bedrock on which the gravels have been deposited.

Overlapping the southern end of the scarplet somewhat, a westward facing scarplet about one mile long continues southward to the first large canyon north of Silver Canyon. The total displacement along this feature is difficult to estimate because while the displacement in the Zurich formation is only about forty feet, the apparent displacement along the west side of the 5310 hill is over 300 feet and it is uncertain how much of this height is the result of displacement and how much is the result of differential degradation.

Coldwater Canyon Scarplets

Several scarplets some facing east and others west occur near the mouth of Coldwater Canyon and a short distance to the southwest. A few hundred feet southwest of the Southern Belle mine a small east-facing scarplet is traceable for somewhat over a quarter of a mile. It is in line with the similar feature that crosses Gunter Creek less than a mile to the south, but between the two features nothing occurs to suggest their continuity. It seems probable that the fault is an old structure that has been revived along portions of its length since the deposition of the Zurich formation.

About a half mile west of the Southern Belle Mine another eastward-facing scarplet is well exposed in an excavation. There the fault plane dips steeply to the east and the hanging wall has dropped. Fine "lake beds" on the east side once overlay coarse alluvial breccias on the west side. This relationship frequently seen in exposures of the Zurich formation points to interbedding of fine and coarse material not to deposition of fine material followed unconformably by coarse material. Displacement along this fault is not accurately determinable but does not appear to exceed 100 feet. (See Plate 28 A)

A few hundred yards to the west occurs a westward-facing scarplet which is one of the clearest along the White Mountains in this region. Its face is sharply defined by the west side of the elongate hill on which the triangulation point "Belle" of the city of Los Angeles is located, and it is continued to the south by a line of faceted spurs and a notably rectilinear base (see plate 28 B).

Plate 28

A. View from triangulation station "Belle" looking north along west face of White Mountains near Laws. The eastward facing scarplet in the Zurich formation is seen near the left of the photograph. See page 107.

B. Looking south from same viewpoint along the clearly defined westward facing scarplet. See page 107.

The total length of the feature, trending approximately N15W is somewhat over a mile. Displacement varies considerably usually exceeding 100 feet and attaining a maximum of about 200 feet. A rather large spring rises along the scarplet somewhat south of its midpoint and lends support to the belief that a fault exists along its base.

Although this scarplet is one of the most clearly defined along the mountain front in this region, it has attributes indicating considerable age. Widely breached in several places the scarp slope while comparatively steep (about thirty degrees maximum) has probably been much lowered from its original inclination.

Crossing Coldwater Canyon where the stream debouches onto its fan at an elevation of about 4800 feet a scarplet trending N15W appears. It forms the lower portion of the steep mountain face for most of its length. Its course in the alluvium is indistinct although it follows the range face north and south of the canyon rather clearly. Because of this relation it is possible that it is an old line of faulting part of which has been recently exposed by the removal of alluvial material from the range face. A similar situation occurs, it will be remembered, at the fault near the range front between Black and Poleta Canyons.

The scarplet indicates downward displacement of the valley block with relation to the mountain block. The movement registered in the fan is only a few feet, but the total displacement along the bedrock scarp above the scarplet has been very much greater.

About a quarter mile west of this feature are two small scarplets, one facing west and the other east. These breaks are so situated that the area between them forms a small graben, lowest near its midpoint. These features are both shown by unusually steep slopes marked by notably rectilinear bases. Several springs tend to confirm the presence of faulting here. The eastward facing is rather closely aligned with the eastward facing scarplet about a mile south described above. Between the two features, however, no evidence of displacement is visible in the alluvium.

The trend of the Coldwater scarplets, about N5W, is somewhat more northerly than those farther south. Displacement on the latter two is about the same and amounts to about 75 feet in each case. They appear to be of considerable age, older than the scarplet west of "Belle" described above.

Volcanic Tableland Scarplets

The surface of the Volcanic Tableland, north of Bishop, shows a remarkable development of recent scarplets of relatively small displacement. These features occur in large number over as much of the southern part of the Tableland as was examined, and are known to be present generally over the entire surface to the north. The surface of the Tableland over practically its entire extent is a single, relatively thin stratum of highly resistent rhyolite tuff breccia. Due to regional tensional forces, this bed has been fractured along innumerable lines of normal faulting which run in a general north-south direction.

The displacement along most of these faults is between twenty and thirty feet, only a few of them having throws of over one hundred feet. Of especial interest is the tendency of these faults to show a pivotal or scissors character of offset. Many of them thus show a relative displacement in one direction at one end and a displacement in the opposite direction at the other end, with a point of no movement in the middle.

The material underlying the tuff breccia cap bed is very soft pumiceous breccia only slightly compacted. This makes it probable that movements of the cap bed have taken place with little tendency of the underlying material to move as a unit. The pumiceous breccia very probably was able to move laterally and to become compacted sufficiently to enable the relatively thin cap bed to undergo a slight amount of shifting. At no place is the base of the soft pumiceous material exposed, but its thickness is probably at least two hundred feet.

Because faulting over the Tableland seems to be everywhere much the same, comparatively few of the total number of scarplets were mapped. Enough were followed to make possible the formulation of a general idea of the fault system, and they were mapped in some detail along the southern border of the Tableland but their mapping is very incomplete.

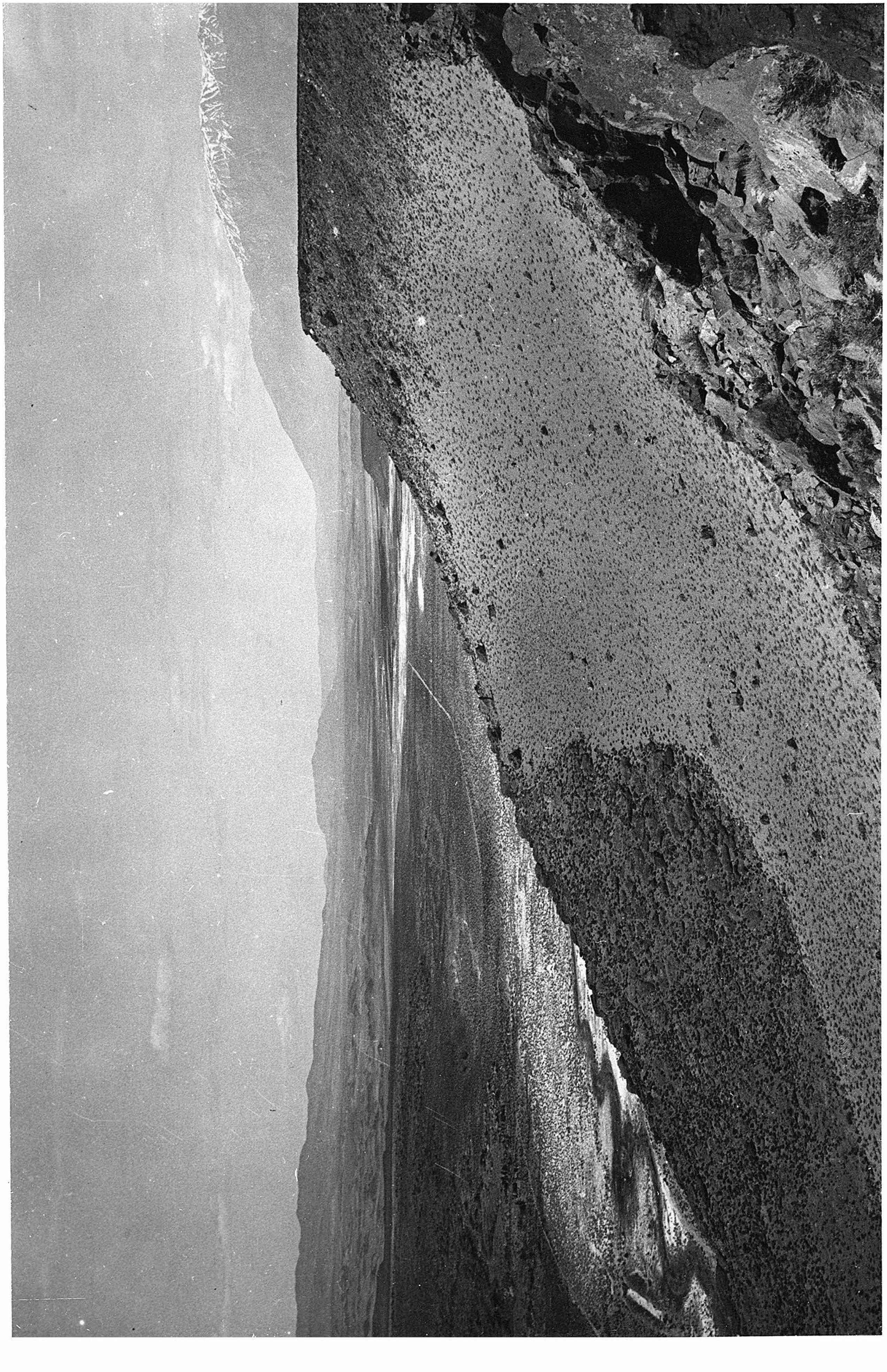
Fish Slough Fault Zone

Faulting along the east side of Fish Slough is on the largest scale of the southern part of the Tableland and, furthermore, shows several interesting features that are not shown by the faults of small magnitude elsewhere. For a considerable distance north of B.M. 4646, which is about two miles north of the edge of the Tableland, the eastern side of Fish Slough is bounded by a very steep scarp about 300 feet high which is capped by the tuff breccia member of the Bishop formation. This is a single fault scarp in this vicinity and it has kept its original steepness because of the resistence of the capping stratum and the relatively great weakness of the underlying pumiceous member. A short distance south of B.M. 4646 the simple outline of the scarp is interrupted by three hinge faults that strike into the main fault from the southwest at a small angle. (See plate 29) This strange phenomenon seems to be caused by the tearing of small slices from the downthrown block as the upthrown block moved along the fault. This particular type of distributive faulting was not observed at any other locality, and seems to owe its presence here to the fact that the main zone of faulting is diminishing its throw in this direction, a fact that is attested by the pronounced southern slope of the southern edge of the Tableland. All of the faults of this system are normal. The displacement of the hinge or tear faults varies from zero at one end to the full amount of the displacement along the main fault at the other.

The downthrown side of the main fault shows an interesting feature that was also observed in some of the faults in the alluvium along the White Mountains. This is a tendency for the beds on the downthrown block to dip toward the fault plane instead of showing the customary drag effects.

Plate 29

View north along east side of Fish Slough a short distance south of B.M. 4646 showing the hinge character of the faulting here. The tuff-breccia member of the Bishop formation is seen to the left dipping gently into the fault. It is displaced about 150 feet along the Fish Slough fault zone. See page 112.



As was mentioned in the section on the Silver Canyon scarplets, this is apparently due to a slumping effect of the beds of the downthrown side of the fault and is apparently a phenomenon characteristic of brittle and incompetent beds when they are not buried deeply. The cap bed on the west side of Fish Slough shows very clearly that it is dipping into the fault plane at the base of the scarp on the east side.

West of the scarp bounding Fish Slough on the east, several fairly large faults with displacements in the opposite direction and a NNW trend are related to the Fish Slough fault system. These faults, showing a hinge character, have their greatest displacement to the north. Their effect is thus to lower the top of the Tableland toward the southeast.

Scarplets West of Fish Slough

Scarplets which cut the southern edge of the Tableland between Fish Slough and the point where Owens River leaves its gorge trend in a general NNE direction, roughly perpendicular to the edge of the Tableland. As a result of the alternation of faults with the downthrow on the east and the west, the southern edge of the Tableland has been divided into a series of blocks which have moved up and down relative to each other. The net effect of all of the small faults has not caused any appreciable rise in the Tableland either to east or west.

The characteristic pivotal nature of the faults on the Tableland is well shown along the road which crosses it in a northwest direction from the mouth of Fish Slough to

Casa Diablo Mine. This road crosses several scarplets at their points of no displacement. On one side of the road a scarp will increase in height as it faces toward the east, while on the other side it will increase in height as it faces west. Several miles north of the southern edge of the Tableland the trend of the scarplets swings around to the north and then to the north-northwest.

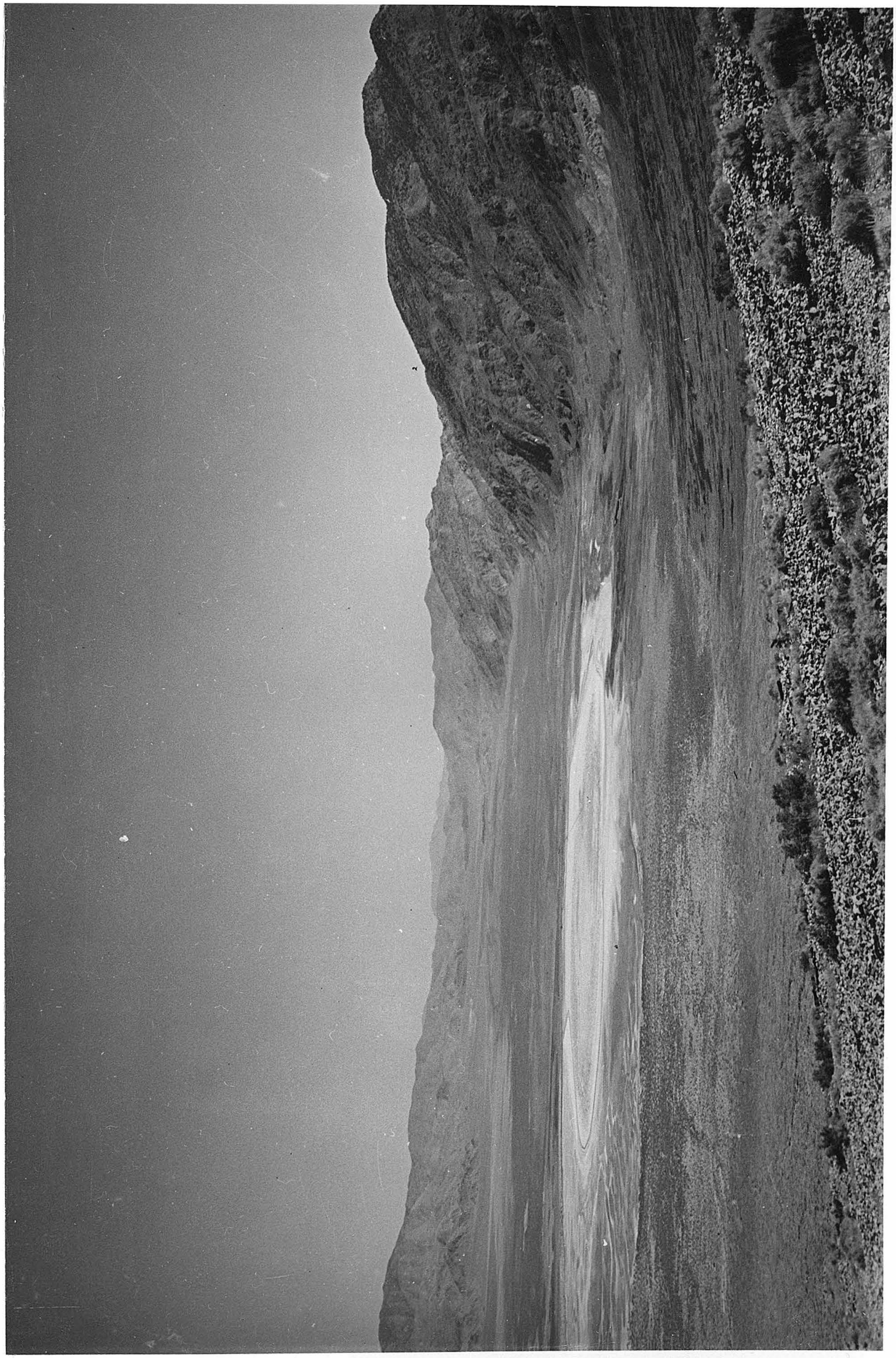
A fault that extends across the gorge of Owens River about three miles below its confluence with Rock Creek shows a further example of the tendency of the beds on the downthrown side of a fault to dip into the fault plane. Displacement on this fault varies from 40 feet a short distance northeast of Owens River to 20 feet just southwest of it, the northwest side has gone down along the entire length of the fault. A small sag is present near its northern extremity.

Deep Spring Valley Scarplets

A description of the scarplets along the east side of Deep Spring Valley very properly will begin east of Deep Spring Lake where they are better displayed than at any place in the valley. (See Plate 30) It is doubtful, in fact, if a better locality at which to study extremely recent scarplets exists in the Great Basin region. The best time to view these scarplets is in the early morning with the light back of them, so that their faces are in shadow. With this type of lighting they stand out with the greatest distinctness. It is well, whenever searching for scarplets, to make certain that the lighting is as described above, for under such conditions the slightest breaks in the fan surface stand out very clearly.

Plate 30

View along eastern side of Deep Spring Valley from its southern end. Some of the scarplets east of Deep Spring Lake may be observed faintly near the base of the very steep granitic scarp to the right. See page 115.



The very prominent scarplet which is visible along the entire eastern side of the valley north of Deep Spring Lake a single break becomes distributive near the lake and forms a complex scarplet system extending south for about two miles. Beyond the southern end of this distributive zone the scarplet continues as a single break for a short distance, then diminishes and terminates and is not again seen to the south. The general line of recent faulting continues for about seven miles farther but shows no extremely recent breaks such as characterize it to the north.

Deep Spring Lake, now entirely salt encrusted, receives its only important water supply from springs that rise along the scarplet zone at the base of the east wall of the valley. These springs, some of them slightly thermal, vary considerably in the kinds and quantity of salts contained, but seem to be of fault origin for the most part.

Scarplets immediately east of Deep Spring Lake face both east and west, as a result of which several small fresh water ponds have formed in the fault troughs between opposite facing scarplets. Here, as along the entire east face of Deep Spring Valley, the latest fault activity appears to have been of the very greatest recency, it does not seem possible that it could have occurred over a hundred years ago, fifty years seems even more likely. Scarps formed by the offset of cemented fanglomerate, that are beautifully exposed east of the lake, retain practically their original vertical position. At one point in particular, just east of T 108, the cemented alluvial breccia shows a displacement of 30-40 feet along a vertical scarp the top of which is capped by a well cemented stratum of the same material. Several hundred feet east of this scarp another one appears with displacement of 10-15 feet. In both of these instances the scarps face west, normally. The scarplets in this area show very little modification from their original form, having been but little incised by streamlets cutting across them, and having suffered little burial by detritus from above. The main scarplet of the system east of Deep Spring Lake follows a relatively simple trace while the smaller features east of it follow a rather sinuous course, running well back in the small canyons and out on the intervening spurs, following the irregularities of the granite front.

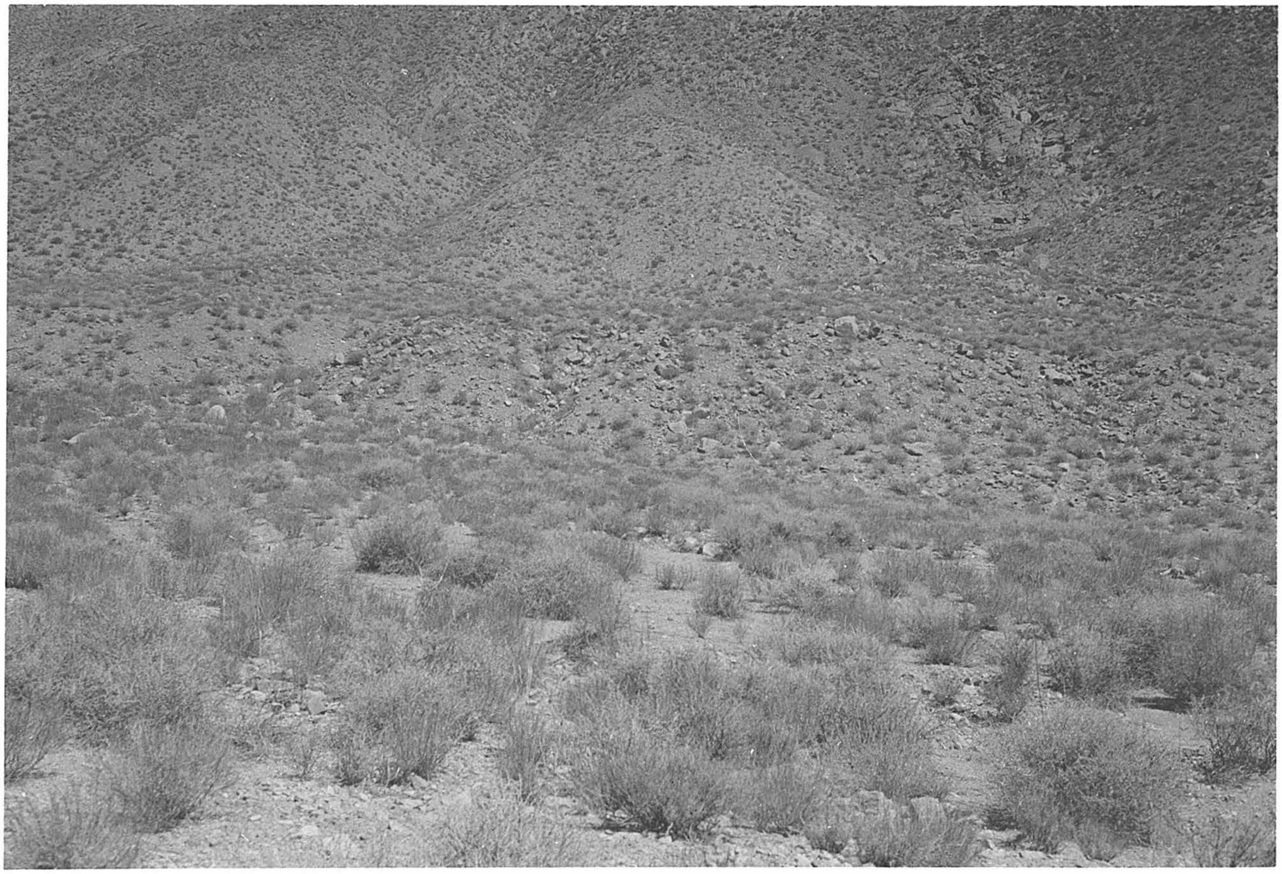
It seems probable that it is more than a coincidence that the point where the recent scarplet diminishes its throw to the south is marked by a tendency of the faulting to become distributive, but if a valid reason exists for this I do not know it.

North of Deep Spring Lake the scarplet may be seen from the west side of the valley to continue uninterruptedly to the north end of the valley. In order to make sure of this, however, I walked along the entire length of the scarplet and found that it is indeed possible to trace it without break along the entire east side of the valley. Practically every one of the small fans formed at the mouths of the steep creeks which descend the steep eastern wall of the valley are cut by the scarplet (see plates 31 and 32). Displacement is on the average about 10-15 feet. The scarplet always faces toward

Plate 31

A. Recent scarplet cutting alluvium a short distance north of Deep Spring Lake. See page 118.

B. View of Deep Spring scarplet taken about one-eighth mile north of A. See page 118.



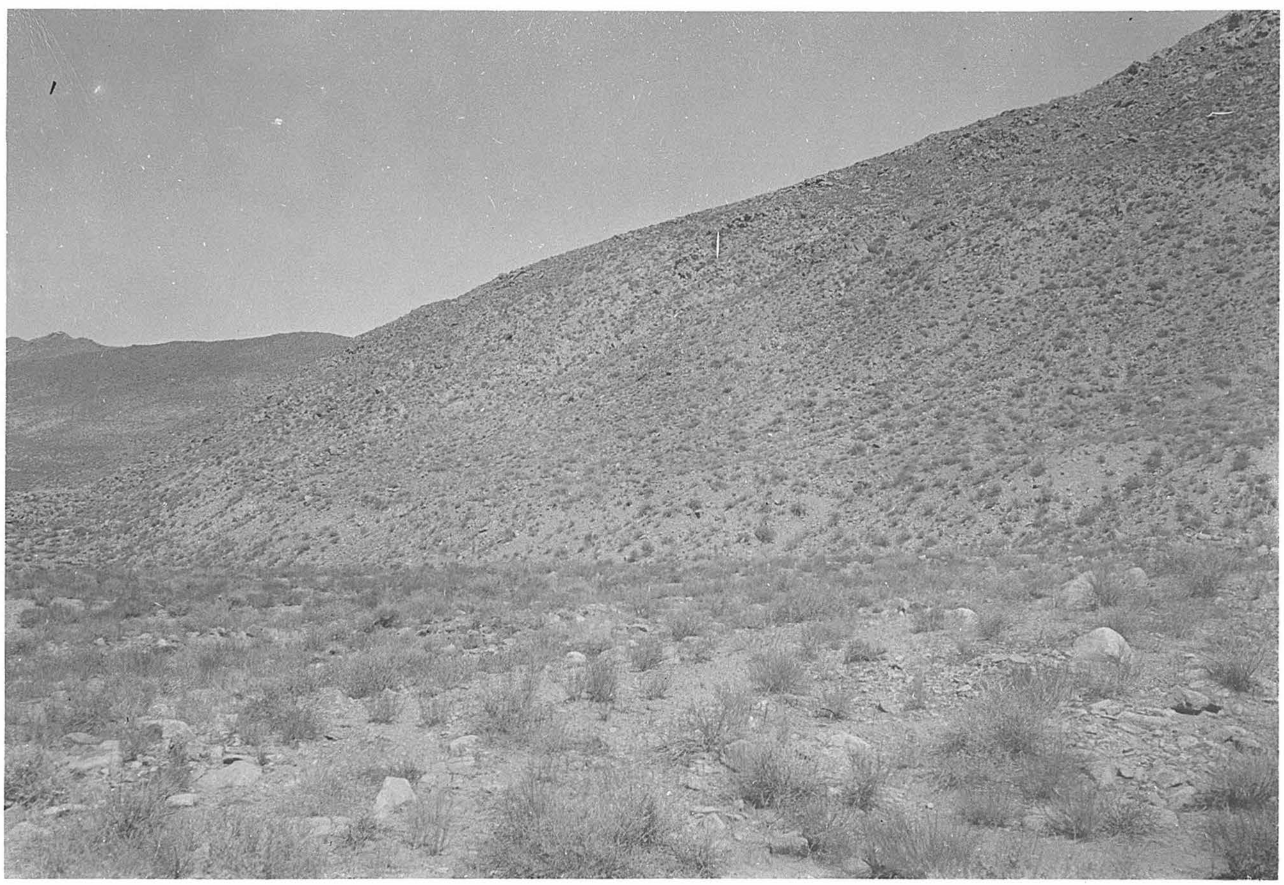


Plate 32

A. Recent scarplet cutting well cemented talus breccia about two miles northeast of Deep Spring Lake. See page 118.

B. Alluvial fan cut by recent scarplet a short distance north of A. See page 118.

the valley. A measurement of the dip of the fault plane, near the north end of the valley shows it to slope to the west with an inclination of 55-60 degrees. It is not maintained that this indlination is characteristic of the fault, however, for it is believed that its dip in the alluvium is generally steeper than this.

The strange tandency of the scarplet to follow contour lines as it crosses small canyons is not readily explicable. This is distinctly not wholly due to the dip of the fault plane, for the amount of curvature could only be explained in some cases by a practically horizontal fault plane, whereas the scarplet plainly shows in all cases that it dips steeply to the west. It is not known whether the original trace of the fault at the time that uplift began was crooked in detail, sufficiently so to control the stream spacing, or whether the recent scarplet merely tends to follow the range front. The latter explanation seems much the more likely. Whatever the cause, the scarplet does show a marked tendency to follow the base of the mountain face rather than to run straight across the mouths of small canyons and over spurs.

That it cannot be an old strand line is shown at a number of localities toward the north of the valley where the scarplet crosses granite spurs with approximately the same displacement and inclination as in the adjacent alluvium. The inclination of the plane cannot be determined as accurately as one might desire, either in the granite or alluvium since sufficient slumping has occurred everywhere to cover up the original fault surface, even where it crosses steep gullies and spurs.

In the vicinity of Deep Spring Ranch (Stewart's Ranch of the topographic may) the scarplet branches as it crosses a bedrock salient, the two branches showing a considerably lessened throw from that to the north and south where the scarplet is single. It is not known whether the salient is a cause for the branching of the scarplet or an effect of similar distributive faulting during the uplift of the mountain wall. An answer to this question would be of the greatest interest since it bears directly on a similar problem with which we are confronted in both the Big Pine Salient and the Waucoba Embayment along Owens Valley.

At the north end of Deep Spring Valley, recent uplift along the east margin has resulted in the vertical displacement by means of step faulting of recent basaltic flows by over 1000 feet. The lava consists of two flows, each about 10 feet thick, about 40 feet apart and separated by a pumice breccia deposit. The flows themselves are andesitic toward their bases and basaltic toward their tops. The lower flow seems more acidic than the upper one. Rather complicated fault relations are displayed in the northern part of the valley where these flows are cut by an intersecting group of faults, all of them evidently of great recency. The scarplet that is present along the entire eastern side of the valley, however, dies out against one of the large faults that has cut the basalt series and none of the series of the faults along the north side of the valley shows such recent movement as that recorded by the scarplet along the east side. The very striking manner in which the lava flows record the offset along the faults cutting them, however, makes the northern region one of great interest.

GEOMORPHOLOGY

Pre-Quaternary Land Forms

Sierran Block

The earliest definitely established geologic date in the Sierra Nevada in the area covered by this paper is that of a Cambrian roof pendant west of Big Pine (13, p. 219). This limestone mass was intruded, probably in Jurassic time, by the main batholithic mass of the Sierra. Subsequent to this, no stratigraphic record is present here until late Cenozoic time. Geomorphic evidence, however, points to active diastrophism and erosion of region from the close of the Cordilleran Revolution until the present.

The territory described in this paper contains, high up on the east slope of the Sierra, two well preserved remnants of early erosion periods. The earlier and higher of these is represented by the flat surfaces of Table Mountain and Coyote Ridge, both about 11,500 feet in elevation, evidently parts of the same surface which has been deeply incised by the South Fork of Bishop Creek. The lower and later of the two Surfaces, Coyote Flat, is about 1500 feet below the Coyote Ridge-Table Mountain surface and lies a short distance to the east, at the brink of the Big Pine-Bishop segment of the Sierran scarp, overlooking Owens Valley. Both of these surfaces show the undulating topography of middle old age -- gently rolling flat areas, relief of several hundred feet, isolated remnants of resistent rock. Neither one of them is a peneplane in any sense of the word. From a comparison these surfaces with erosion surfaces in the Mt. Whitney and upper Kern region, it seems highly probable that they correspond with Lawson's Summit Plateau and his High Valley Zone or Chagoopa Plateau (14, pp. 308, 315). The difference in elevation between the higher and lower surfaces at the two localities is approximately the same and the actual elevations show close correspondence. An important difference is that the surfaces in the Bishop region are on the east side of the range crest whereas those in the Mt. Whitney region with which they are correlated are on the west side.

Knopf finds difficulty in accounting for the presence of the two groups of surfaces on opposite sides of the range crest without postulating epeirogenic uplift of the entire region (2, p. 88). He apparently does not think it possible for such surfaces of rather low relief to be developed unless the entire region be reduced to low relief. He would thus not subscribe to the view that the surfaces in both instances are the result of interrupted uplift along the east side of the range, which has allowed the development of areas of old physiography on both sides of the range crest. Yet it seems to the writer that just such a sequence of events may have occurred.

A test of the hypothesis would be the relative westward tilts of the Subsummit Plateau and the Chagoopa Plateau. If the uplift between the two physiographic epochs had been of epeirogenic character, the surfaces should be essentially parallel. If, on the other hand, the uplift between the two epochs had been along the eastern margin of the range, the two surfaces should show lack of parallelism, the higher one sloping westward steeper than the lower one. Although evidence on this score is very scanty, nevertheless, in the Bishop Region at least the higher surface represented by Table Mountain and Coyote Ridge has a distinctly asymmetric east-west profile that shows tilting toward the west. The lower surface, represented by Coyote Flat shows no apparent asymmetry. It is true that the amount of difference in slope is slight, but it should be only slight according to the theory advanced, and it is in the direction that would be expected.

It is apparently Knopf's belief that an old age surface such as the Chagoopa Plateau could not develop on the east side of the range crest if the uplift preceding its formation was along the eastern boundary fault of the range. The writer, however, fails to see any important objection to such an idea, since the dissection of the older surface during the formation of the younger may occur as long as the lower surface is graded to an adjacent lowland. The lower, or Chagoopa surface was graded to Owens Valley while it was being cut according to the present hypothesis and should have been as able to evolve its old age physiography as well as though the entire region had been uplifted epeirogenically. This view receives support when cognizance is taken of the small benches that are present on the Sierran scarp about 2000 feet above Owens Valley. These benches are actually small areas in an old age stage of physiographic development and it seems entirely possible that larger areas such as Coyote Flat could have been formed in exactly the same manner.

Sufficient information is not available at present to reach a final conclusion as to the method of uplift of the eastern scarp of the Sierra Nevada. I am inclined to believe, however, that all of the present scarp is the result of differential movement between the mountain mass and Owens Valley after the entire region had been epeirogenically uplifted in late Mesozoic or early Tertiary time. I cannot believe that the two old age surfaces, the Sub-summit Plateau and the Chagoopa Plateau resulted from epeirogenic uplift of the entire western Great Basin region.

Inyo-White Mountain Block

A rather well-marked surface near the crest of the White Mountains north of the latitude of Bishop is interpreted as an old erosion surface. Its average elevation from Reed Flat, approximately its southern limit, to Campito Meadow on the north is about 10,500 feet with a gentle slope to the south. It is proposed to call this feature the "Reed Surface" from its development at Reed Flat. This surface apparently disappears at Campito Meadows and a short distance farther north another surface, some 1500-2000 feet higher, and sloping strongly up to White Mountain Peak, makes its appearance. It is possible that this is the same surface as the one to the south, although it does not appear likely. The surfaces in the White Mountain Quadrangle are discussed by Mr. G. H. Anderson (8) so will not be considered further here.

The Reed Surface apparently does not extend south of Reed Flat, and as far as could be determined, no other old erosion surfaces extend south of that point. The several flat areas near the crest of the range are at widely varying elevations, most of them considerably below the summit. It is not thought possible, certainly not desireable to attempt to correlate these surfaces with those on the Sierra, since they are on separate orographic blocks.

Quaternary Land Forms

In undertaking a discussion of the geologic history of Quaternary time, the writer has a distinct feeling of trepidation, for the number of events that apparently must be crowded into this short epoch seems almost unbelievably large. A person accustomed to the relatively uneventful glacial periods of eastern North America will certainly have difficulty in conceiving of the complicated history of diastrophism, sedimentation, erosion and vulcanism that transpired during the Pleistocene and Recent epochs in the Owens Valley region. It should be pointed out, however, that geologists of the Pacific Region have been becoming more and more dissatisfied with the chronology presented by eastern records. An example of this trend in thought is presented by the stimulating article by J. E. Eaton entitled, "Divisions and Duration of the Pleistocene in Southern California", which appeared about five years ago, and in which the author advocated strongly the necessity of revising our ideas of the length of Pleistocene time (4).

Northern Owens Valley appears to almost unique in the degree to which glaciation, volcanic activity, sedimentation, and recent diastrophism are interrelated. Because of the close relationship of these various chapters in the geologic history of the area, it has been possible to arrive at an unusually complete understanding of the later geologic history of a region in which fossil evidence of the precise age of the various formations is lacking. The portion of geologic time with which we are concerned in the present discussion includes most of the Quaternary, a brief moment indeed when compared to the geologic column as a whole, but an extremely eventful time in the Owens Valley area.

In formulating the Quaternary history of this region it has been found convenient to assume that the Pleistocene epoch ended with the retreat of the glaciers of Tioga (Wisconsin) (5, p. 881) time. This is probably not strictly true, for as Eaton has pointed out, an important post-glacial time interval, equivalent to the Champlain subsidence, probably occurred during uppermost Pleistocene time in California (4, p. 134). Since apparently no record of this interval is present within the Inyo territory, however, it seems desireable in connection with the present discussion to consider that the end of the Tioga glacial epoch marks the Pleistocene-Recent boundary here.

Within the area covered by this paper evidence is at hand for three of Blackwelder's glacial epochs, the Sherwin, the Tahoe, and the Tioga (5). The type section of the McGee stage is only a few miles north of the Round Valley region and it seems probable that the Owens Valley area was affected by this glaciation. Since, however, the relations of the McGee with the Bishop formation are not known it cannot be accurately fitted into the chronology presented here.

The relations of the other glacial periods to the volcanic series are very plain, however, since till of the Sherwin stage lies unconformably upon the tuff breccia member of the Bishop formation near Sherwin Hill. Furthermore, the volcanic series is known to be at least in part equivalent to the Zurich formation of the western slope of the White Mountains (see page 28). The Zurich formation has been shown, on the basis of vertebrate and invertebrate evidence, to be of probable Pleistocene age. (see page 28) There is reason to believe, too, that the Sierra Nevada attained part of its present elevation subsequent to the deposition of the Zurich formation, and it is also possible according to Blackwelder that it suffered some uplift between the Sherwin and the Tahoe glacial stages (5, p. 900).

Volcanic Tableland

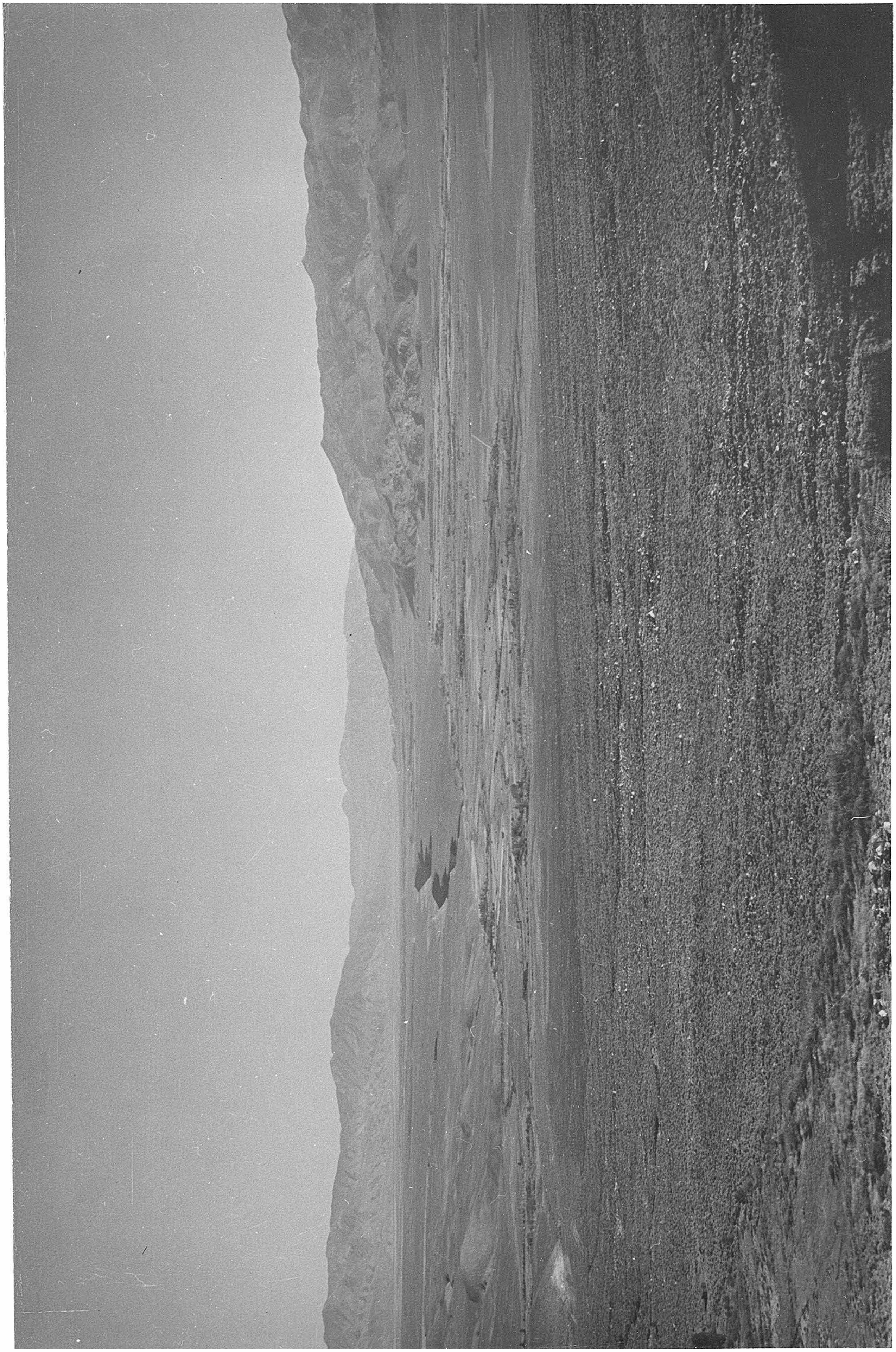
The most prominent geomorphic feature in the region north of Bishop is the Volcanic Tableland, a flat surface sloping gently south toward Bishop from Casa Diablo Mountain. It is underlain by a relatively resistent stratum of rhyolite tuff breccia, (See page 28) one of the members of the Bishop formation. The surface of the Tableland is one of remarkably little relief, being broken only by a great many normal faults having a displacement of a few feet, and a number of small hummocks rising several feet above the monotonous plain. A series of very soft pumiceous and sandy strata underlies the resistent cap rock throughout the Volcanic Tableland region as a result of which streams which have cut their way through the cap rock deepen their channels very rapidly to form steep-sided gorges. Since the entire volcanic series is very porous there is no water in the form of springs or streams anywhere on the surface of the Tableland. As a result there is very little vegetation on its surface and its aspect, especially in the heat of the summer, is exceptionally desolate.

The patterns, both of Owens River and Rock Creek, are not those one would expect to be developed by consequent streams flowing down the present surface of the Volcanic Tableland, but seem rather to represent a superimposed pattern developed at a time when a series of soft beds overlay the present hard cap rock. It is difficult to explain otherwise the curious course of lower Rock Creek just above its confluence with Owens River (see Plate 33). Rock Creek, which to the north has been flowing along the western border of the volcanic series has cut a deep gorge through the rhyolite tuff breccia cap rock and the subjacent pumiceous strata whereas its expectable course is this vicinity would be around the south edge of the Tableland to meet Owens River after it had left its gorge. Furthermore, Owens River does not exhibit a truly consequent pattern, since it assumes a considerably longer course than expectable in crossing the Tableland.

The presence of the occasional hummocky prominences mentioned above which lie on top of the breccia capping at numerous places and which seem to be somewhat softer than the cap rock itself, suggest the former presence of a relatively soft stratum lying on top of the present rhyolite tuff breccia.

Plate 33

View looking southeast from the base of the Sierran scarp just south of Sherwin Hill. The Tungsten Hills and the Bishop Offset to the right. The Volcanic Tableland to the left with the White Mountains beyond. The Confluence of Rock Creek and Owens River with the superimposed character of the drainage may be seen on the Tableland a short distance to the left of the middle of the photograph. The alluvial apron of the Sierra Nevada is in the foreground. See page 130.



From a consideration of these probable remnants of a former extensive series of rocks lying above the present cap rock of the region, and the anomalous patterns of Rock Creek and Owens River, it seems highly probable that the present surface of the Volcanic Tableland represents a surface of degradation.

The southern border of the Volcanic Tableland is noteworthy for its extremely straight plan. It would appear at first, that this border might be marked by an east-west fault, but investigation has shown that no such fault exists. In direct prolongation of its possible extension to the west of the point where Owens River leaves its gorge to enter Owens Valley, an erosion remnant of the Tableland occurs undisplaced. Several other remnants of the capping stratum occur at points well to the south of the possible fault, yet show no hypsometric discordance with the main cap bed on the Volcanic Tableland. The cause of the rectilinear plan of the southern border appears to be found in the character of Owens River, which in this vicinity meanders intricately over Owens Valley in a general east-west direction (see plate 12 A). In doing so it has cut the scarp which forms the southern border of the Volcanic Tableland.

The western border of the Tableland gives the appearance of having been buried by alluvium from the Sierras as it dips gently toward them (see Plate 33). The eastern border has been faulted to some extent, modified considerably by erosion and is now in the process of burial like the western edge.

Owens River

North and northwest of Bishop, the Owens River has a peculiar meandering course and is bordered for a considerable distance by swampy land, indicating that its rate of flow is much lower here that either to the north or to the south where it flows in relatively swamp-free country (see plate 12 A). A possible explanation for this sluggishness is that the river has not become adjusted to the Round Valley Syncline which may still be in the process of formation or has but recently ceased growing. According to this explanation, the grade of the river between Laws and Poleta should have been considerably lessened as a result of the northward tilting of the land here. A natural corolarry of this tilting would be the lowering of the grade of the river above this point and the inception of the present swampy era.

Sierra Nevada Scarp

One of the boldest major mountain faces known, certainly the boldest within the United States, the east face of the Sierra Nevada facing Round Valley is a fault scarp of surpassing grandeur. This great granite face seems to rise almost vertically from the floor of Round Valley to its crest over 7000 feet above. It is interesting to note that while the scarp contains precipitous cliffs a thousand feet or more in height the steepest portion of the scarp as a whole, located just above Wells Meadow, has a slope of 32 degrees (63 percent). Of almost comparable steepness, the west face of the White Mountains exhibits a slope of 28 degrees (56 percent) just west of Pellisier Flats. These scarps are perhaps the finest known examples of great mountain faces which are, in their entirety, the result of normal faulting. The Round Valley scarp is perhaps more impressive than the White Mountain scarp since it exhibits a uniformly steep front over a considerably greater distance than the latter.

In spite of the fact that the Round Valley scarp is so outstanding an example of a recently formed fault scarp, it is most significant that it owes much of its present steepness to a fortuitous arrangement of its joint planes, the major set of which is roughly parallel to the range front and dips steeply toward the valley. (See plate 36 B) It has, further, been pointed out in this paper that the most recent faulting along the range has occurred directly at the base of the bedrock face and that these recent scarplets always show a steep dip (60-75 degrees) toward the valley. From a consideration of these facts we see at once that the face of the remarkably steep Round Valley scarp is not nearly as steep as its bounding faults, even though it has had its steepness overemphasized at places by the attitude of the jointing. This conclusion falls in sharp disagreement with an hypothesis frequently advanced (16) : that basin range fronts tend to retreat from their original position as outlined by faulting, <u>without showing notable change in declivity</u>. The Round Valley scarps shows that it has neither retreated from its original position nor retained its original steepness as determined by faulting.

Although the rather straight course of Pine Creek, roughly perpendicular to the range front, suggests that faulting may have influenced it, the undisturbed traces of several

Table 1

Slopes of Owens Valley Walls

Latitude	Sierran Slope	Inyo Slope
36° 30'	14 percent	16 percent
32	18	16
34	28	16
36	27	21
38	30	27
40	32	31
42	29	34
44	37	29
46	29	32
48	26	30
50	24	18
52	35	15
54	30	17
56	37	18
58	34	26
37 00	26	19
02	37	35
04	24	26
06	21	36
08	17	11
10	--	10
12	30	11
14	30	14
16	22	38
18	18	19
20	--	16
22	43	16
24	34	17
26	41	18
28	50	16
30	40	18
32	--	26
34		27
36		23
38		31
40		33
42		31
44		36
46		37
48		33
50		33
52		27
54		28
Average	30%	24%
Steepest	63% (Wells Meadow)	56% (Pellisier Flats)

Plate 34

A. View of Round Valley scarp of the Sierra just north of Pine Creek, west of Bishop. The Pine Creek lateral moraines of Tahoe age may be seen near the left of the photograph. The scarp angle, from base to crest, near the center of the view is about 27 degrees although it appears to be much steeper. The elevation of the highest point shown is about 12,900 feet, the valley floor at the scarp base is about 6000 feet.

B. View looking north along Round Valley scarp across lateral moraines of Pine Creek. This is a different viewpoint of the portion of the scarp shown above.

Plate 35

View looking north along the Round Valley scarp from the northern lateral moraine of Pine Creek. The influence of jointing on scarp declivity is well shown in this view. The Volcanic Table-land and Casa Diablo Mountain appear faintly toward the right.

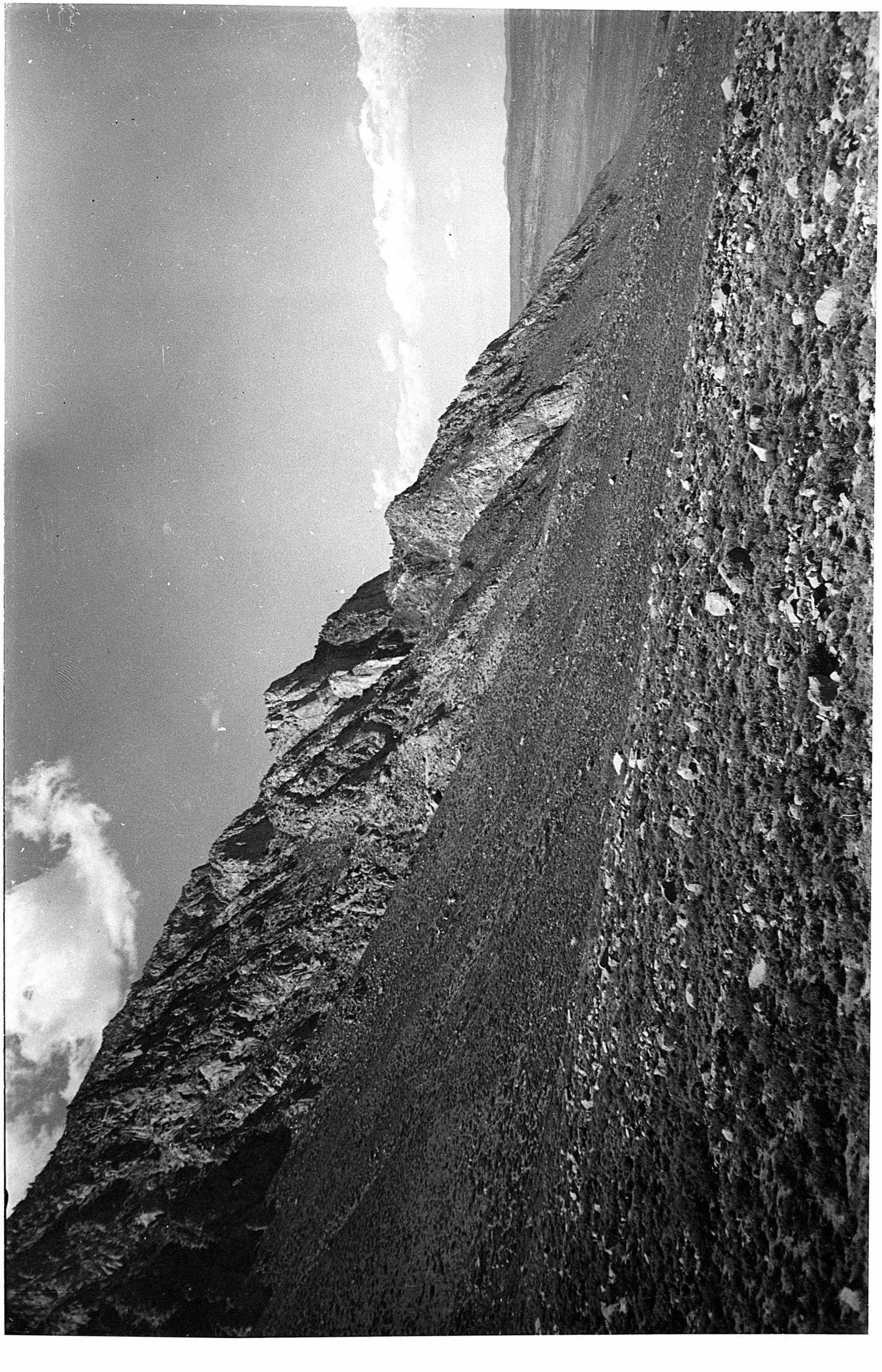
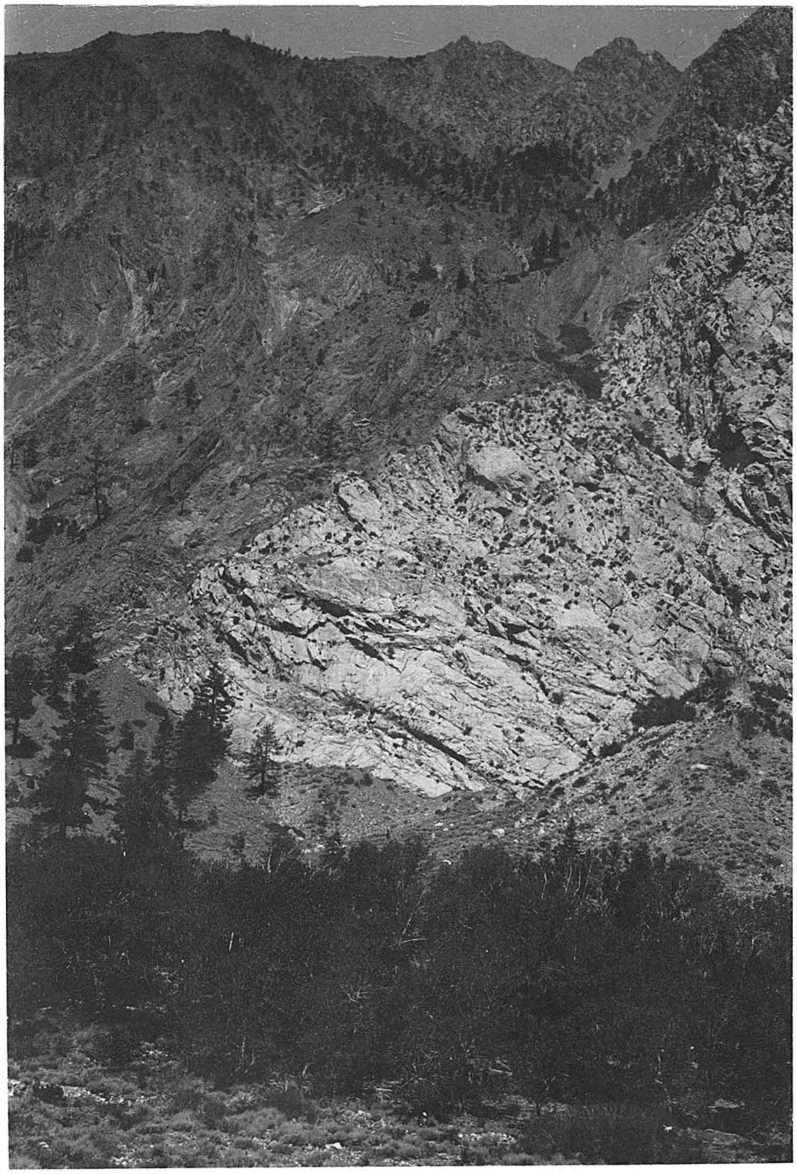


Plate 36

A. Contact between granite (to right) and schist roof pendant, on north wall of Pine Creek at an elevation of 7100 feet. The continuation of this contact unbroken across the canyon shows that a major fault does not follow its trend; See page 139.

B. Jointing in north wall of Pine Creek about one half mile west of its mouth. Note the decrease in the dip of the joint planes as the range front is approached to the right (east). See page 134.



contacts between old metamorphics and plutonics which cross the canyon prove that important faulting has not occurred. (See Plate 36 A) Several anomalous draingge lines along the east and northeast flanks of Mt. Tom prove to be related to variations in the character of the bedrock and not to faulting. The bedrock here consists of a rather heterogeneous complex of old metamorphic rocks intruded by granitic plutonics.

The Round Valley scarp, as an individual physiographic feature terminates southward near North Lake, on the north fork of Bishop Creek. About two miles north of this point the Birch Creek scarplet marks the most southerly undoubted evidence of recent faulting along this zone. The region south of North Lake offers no suggestion of the presence of the Round Valley fault zone. In fact, the old age surface represented by table Mountain and Coyote Ridge, probably the equivalent of the Subsummit Plateau in the Mt. Whitney region (see page 124), lies unbroken in the path that the Round Valley fault zone would follow if it continued south of North Lake.

The region east of the southern portion of the Round Valley scarp including the Buttermilk Country and the Tungsten Hills is interpreted as being part of the scarpramp that has resulted from the Bishop Offset, which has been somewhat modified by minor east-west dip-slip faulting and later erosion. This region is thus on the downthrown side of the Round Valley scarp. The contours of its southern portion have been greatly smoothed out by glacial deposits of Tahoe and Tioga age, as well as fan material brought out by creeks such as Horton and Bishop Creeks.

Possible reasons for the comparatively low slope of the Big Pine-Bishop segment of the Sierran scarp are several. Distributive faulting has been found to be important in the Big Pine Salient. The attitudes of the joint planes here are generally not nearly as steep as they are along the Round Valley scarp. The range front here has been much more dissected by erosion and it has been notched by streams to a considerably greater degree than along the Round Valley scarp, facts that point to a greater physiographic age.

Stratigraphic evidence to establish age relations is lacking but physiography strongly suggests that the Round Valley segment has been formed in part since the Big Pine-Bishop segment. Proof of this is lacking but the physiographic evidence points in that direction.

A striking phenomenon frequently encountered along the eastern front of the Sierra is the occurrence of physiographic features, suggestive of faulting, yet which show no evidence of recent movement, in direct alignment with clearly defined recent scarplets. Shannon Canyon, located between big Pine and Bishop, shows this characteristic clearly. The westernmost fault of the frontal fault zone in this region is plainly indicated north of Shannon Canyon, but apparently ends near the bend in the canyon near its mouth. The canyon, south of this point, was examined with a view to discovering evidence for faulting, and while positive evidence was not found, certain physiographic features on the east canyon wall, such as marked difference in slope from the west side, and a line of springs, points to the possibility of a fault occuring here. If it does exist, it is considerably older than the frontal faults, however.

It thus seems probable that some of the lines of faulting that have been active relatively recently are the result of a renewal of activity along old faults. This same situation seems to exist in other localities along the Sierra and also along the White Mountain scarp (see page 101). Apparent structural lines, parallel to the range front are present in the region north of the headwaters of Rawson Creek, southwest of Bishop. Here, several canyons show a pronounced rectilinear trend, nearly parallel to the main frontal fault system, yet they evince no signs of recent movement and no clear signs of faulting at all. Yet the subsequent character of the streams, which is apparently not related to rock differences, and their general alignment makes it seem probable that they represent old structural lines, possibly connected with former fault activity. The above suggestions are very poorly supported by evidence and are offered merely as possibilities.

Inyo-White Mountain Range

The wide variations in physiographic aspect presented by the west face of the Inyo-White Mountain range were noted by Knopf (2) but he did not attempt a discussion of its geomorphology. The general situation may be epitomized as follows:

To the north, in the region about White Mountain and Montgomery Peak, the boldness of the scarp is very pronounced; in fact the average steepness here is greater than at most places along the Sierran scarp as it faces Owens Valley. In this region there can be no doubt of the great distinctness of the evidence for recent fault activity.

The southern part of the range, near Owens Lake, also shows incontrovertible evidence of recent uplift, as is demonstrated by step faulting involving recent lava flows. Here, the steepness of the range front is not particularly notable since the dislocation has been effected by step faulting although this very low scarp angle, has proved of interest in its application to other sections of the Inyo-White Mountain range as well as to the Sierra.

The section between the two portions of the range where the evidence for faulting is indisputable has been very puzzling because definite evidence for faulting of recent date is very rare.

Several alternative explanations for the difference in physiographic appearance of the range at various localities must be considered. First, the entire scarp may have been produced at essentially the same time and with essentially the same frontal appearance -- the very diverse appearance of the scarp today may be entirely the result of differential erosion. Second, contemporaneous elevation and erosion may have acted much as would have acted separately. Third, the various segments of the range front may have been produced at different times so that the region to the north near White Mountain Peak may have been formed considerably after the region immediately south of there -- in this case the uplift would have been partly of a rotational character with the first uplift pivoting about a point some distance north of

Laws and the second point revolving about a point considerably to the south of here. Fourth, the variations in scarp angle may be in whole or in part the result of distributive faulting.

A further possibility, and one that has not been advanced for this region, is now presented, tentatively it is true, but in the writer's opinion as the most plausible one of which he is aware. This explanation may very well be combined with others and modified in that way to a considerable extent.

Let us assume a surface of relatively low relief to be acted upon by more or less vertically directed forces from below. It seems certain that the strains resulting from such stresses will not be the same in different rocks. Stratified rocks will tend to be arched up in a broad anticline, which will be faulted parallel to its axis and near the margins of the block affected by the uplifting forces. Granitic rocks, on the other hand, will not be able to arch up to the extent of the sedimentary rocks, and as a result, faulting near the margins of the block will ensue much earlier than with the sediments. In the Inyo-White Mountain ragne these relations seem to be well brought out. The segment of the range from Big Pine to Bishop is composed almost entirely of stratified rocks, metamorphosed to a considerable degree. Here, the physiographic evidence points to relatively slight uplift along the margins; on the other hand, the evidence points rather clearly to a broad warping along the axis of the range, accompanied by minor faulting along the margins.

To the north of this region, however, recent uplift of important magnitude along both margins of the range is indicated, and here the range is composed almost entirely of granitic rocks.

A possible inference from these facts is that the region now represented by the Inyo-White Mountain range was subjected to a more or less vertical force from below. The region from Bishop to Big Pine was able to relieve the stress by simple warping, accompanied by a minor amount of faulting whereas the region to the north composed of resistent rocks was able to relieve the stress only by important faulting.

The magnitude of the displacement resulting at the two regions may have been nearly the same, according to this hypothesis, but the mode of deformation was greatly different. Therefore, the highest points of the range, near the middle, do not differ greatly in elevation, but the profiles differ considerably. Further, the series of small normal faults, roughly normal to the general range trend, as developed especially in the Big Pine-Bishop region seem to be tension faults formed at the time of the anticlinal arching.

The hypothesis is only intended to explain the deformation that originally blocked out the range. Later diastrophism, such as that which has caused the relatively minor uplift along the western margin since the deposition of the Zurich formation, and which has caused westward tilting of the range, also since the deposition of the Zurich, is not intended to be explained by this hypothesis. Further, while this theory apparently explains fairly well the difference in the aspect of the Inyo-White Mountain scarp at various localities, it does not explain the difference in time of production of the Sierran scarp and the Inyo-White Mountain scarp, which is pointed to strongly by the stratigraphic evidence of the Zurich formation.

According to this evidence, the Sierra Nevada seems to have been uplifted a considerable amount after the Inyo-White Mountain range had attained approximately its present elevation. From a consideration of these data it would seem very likely that the Sierras should show throughout a greater physiographic recency than the Inyo-White Mountain range if they were uplifted later. A study of the scarp angles of the two ranges, however, has disclosed that the northern portion of the Inyo-White Mountain range is fully as steep as any part of the Sierra, with the exception of the Round Valley scarp, and steeper than much of the Sierran face (see Table 1, page 135). Since the evidence presented by the Zurich formation, though, seems to be trustworthy, we must accept, tentatively at least, the theory postulating two dates for the most recent important uplift of the two ranges, first the Inyo-White Mountain range, later the Sierra Nevada.

The stratigraphic evidence of the Zurich formation will be presented here, since it is of importance in connection with the relative ages of the two mountain ranges.

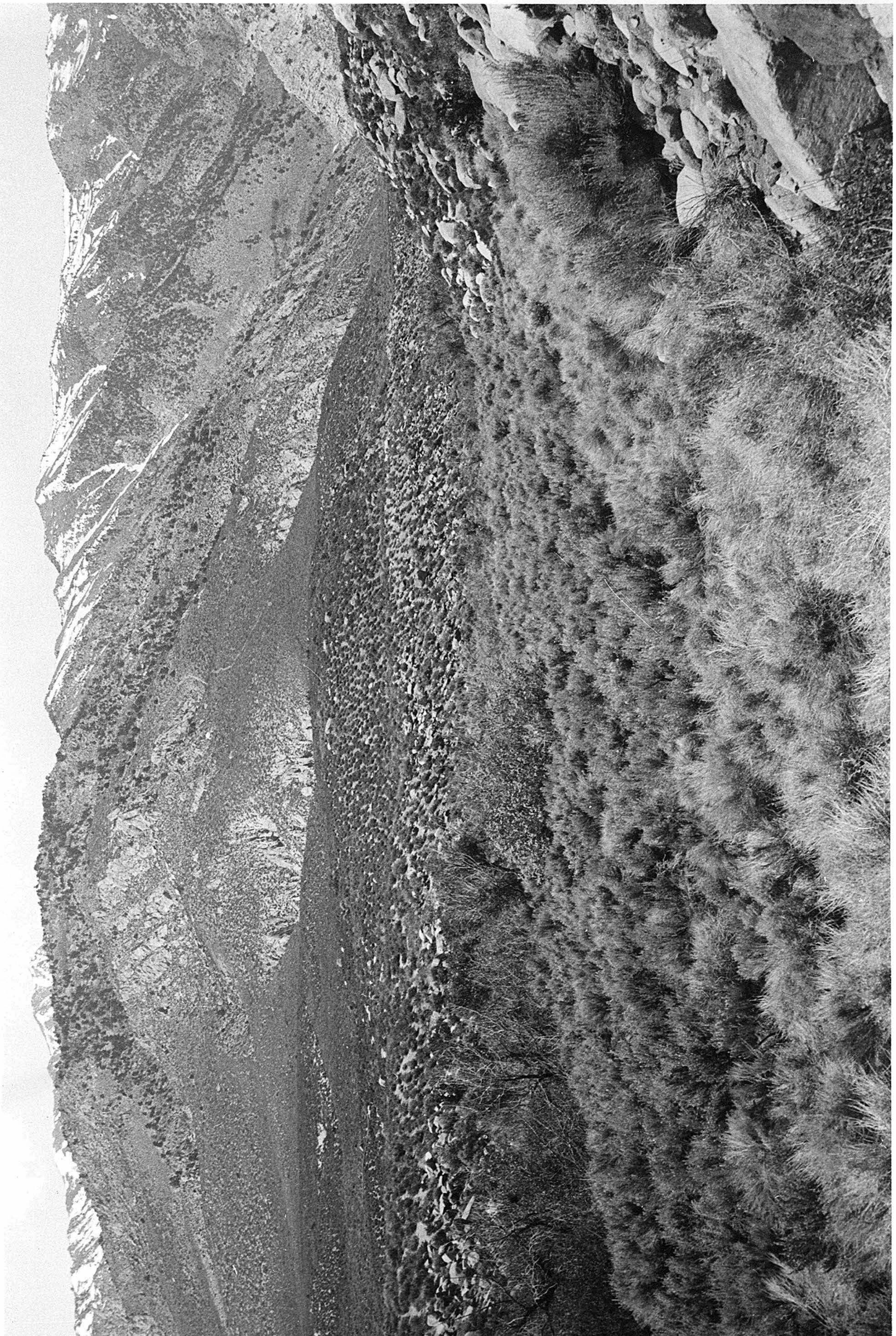
Younger Talus Cones of the Sierra

Younger than the great cones constituting part of the Zurich formation, the talus cones flanking the Sierra are nevertheless very largely pre-Tahoe in age. Practically no important additions to them have taken place since Tahoe time and the moraines of that stage, very slightly dissected, lie on the Sierran cones. These differ very greatly from the old Zurich cones which flank the Inyo-White Mountains. They are very slightly cemented and lithified, if at all. Actually they represent merely the fans which are now being formed. They are but slightly dissected. They contain no fine material such as characterizes the Zurich formation at many localities. They contain no pumiceous beds, and this is of the greatest importance since it indicates strongly that they have been formed later than the pumiceous series of the region and therefore subsequent to the Zurich and the Bishop formations.

Further, their distribution differs greatly from the Zurich beds, for instead of dilling large canyons along the range they are confined to the front of the mountains as an apron which extends but a little distance back into the canyons. The strong implication from these facts is that since the Sierra fans are subsequent to the Zurich formation and the Bishop formation, the Sierras must have undergone a major amount of uplift since Zurich time because if the present cones had been in progress of formation at that time, they would almost certainly record the pumice epoch. An alternative explanation for the absence of the pumice is that it is buried and not visible for that reason. That, however, does not invalidate the conception of late Sierran uplift since the present cones represent the present stage of uplift and any earlier cones, buried or removed, must have accompanied an earlier stage of uplift.

Plate 37

View looking west, upstream at terraces along Freeman Creek just south of Keough's Hot Springs along Sierran scarp. Three levels, cut in the younger talus cones of the Sierra, are represented here. See page 148.



The amount of this postulated post-Zurich uplift cannot be determined from the data at hand. It is suggested that it may have been approximately 2000 feet, the amount of uplift represented by the small benches overlooking Owens Valley. No means of verifying this is at hand, however.

Three minor uplifts of a few tens of feet each are recorded in the Sierran fans along the larger creeks of the Bishop-Big Pine segment by several terrace levels. (See Plate 37)

The Inyo-White Mountain correlative of the younger talus cones of the Sierra is a series of very poorly developed cones overlying the Zurich formation and largely the result of its dissection. This recent series is very much less developed than the Sierran fans, largely because of the very great difference in rainfall of the two regions. (See plate 7 A) This effect will be discussed in a later section.

Deep Spring Valley

Although the geology of Deep Spring Valley has been set forth admirably by W. J. Miller, (6) the writer believes it is desireable to treat briefly some aspects of the recent geologic structure of the valley that were discovered in the course of 8 days of rather intensive study during August 1932. Deep Spring Valley is one of a series of most remarkable basins in the Great Basin region although it differs somewhat from some of the larger ones, in that it is actually an integral part of the Inyo-White Mountain range, while more typical basins such as Fish Lake Valley to the north are inter-range features. This type of basin has a very characteristic lozenge shaped plan, is outlined in whole or at least largely by faulting and has only interior drainage -- in short it is best described as a "hole in ground". In the immediate vicinity of Deep Spring Valley are located a number of basins of this general type -- Cowhorn Valley, Fish Lake Valley, Eureka Valley, Saline Valley, Panamint Valley, Death Valley.

Deep Spring Valley is outlined by two main fault zones, converging at the northeast and southwest ends of the valley. The fault zone along the east side of the valley continues several miles beyond the southwest end of the valley as a prominent scarp facing toward the northwest and trending across the Inyo Mountains south of Soldier Canyon. It dies out at approximately the crest of the range. The fault zone along the west side of the valley is not as clearly defined as the eastern zone -- in fact, as will be pointed out below, it is believed to be considerably older than the eastern fault zone. Relatively minor east-west faults are present at several points along the valley walls and ancient structures, both faults and folds, have strongly affected the rocks around the valley. These older structures will be but briefly touched upon for as was mentioned in the introduction of this paper the writer's main concern in the field was the recent structure.

By all odds the finest example of a well preserved Recent scarplet in the entire southwest region may be observed along the base of the east wall of Deep Spring Valley. Displacement along this feature varies somewhat from place to place along its length but averages about 20 feet with the valley block dropped down along a plane that appears to be nearly vertical. The trace of this scarplet is rather sinuous, since it follows the details of the base of the main scarp unusually closely. The marked freshness of this feature points to its formation within the last few hundred years, and the length of unbroken scarp -- about 10 miles -- causes one to speculate as to the intensity of the seismic disturbance that must have occurred at the time of its formation. (Assuming that it was formed practically instantaneously, an assumption that seems highly probable, but that is by no means certain.) Apparently there is no historical, legendary or otherwise, of any great earthquake in the region, except th 1872 tremor.

At a point just north of the northern end of Deep Spring Lake the bedrock face for several hundred feet above the scarplet has a slope of about 53 degrees and appears strongly as though it were a part of the original fault surface. Upon careful scrutiny, however, it soon becomes evident that the remarkable steepness of the scarp here is the result of the jointing, which is here exactly parallel to the scarp face. At other localities along the east wall, the steepness while very pronounced does not attain the value found near the lake largely because the jointing does not exhibit the same distinctness or attitude in all places.

Measurements of the declivity of the lower portion of eastern Deep Spring scarp were made at several localities and are given in the table below:

Station	Lower 200 feet	Lower 500 feet
T 123	38 degrees	27 degrees
T 125	30 "	25 "
T 127	27 "	--
T 128	36 "	28 "
T 129	31 "	28 "
T 110	53 "	38 "

Plate 38

A. Prominent "kernbut" and "kenrcol" along west side of Deep Spring Valley which are not the result of faulting. Closely spaced jointing determines the col.

B. View across alluvium-filled Deep Spring Valley to its east wall south of Deep Spring Lake. Camera stands on metasedimentaries of probable Cambrian age.

An analysis of these figures leads to some interesting conclusions. First, we see that the slope of the lower 200 feet, which should approach that of the fault plane if any part of the scarp does, averages 32 degrees if the greatly oversteepened part of the scarp at T 110 be neglected. Now if we grant for the moment that the part of the scarp at T 110 gives a measure of the dip of the fault plane we see that the average slope of the scarp has already receded some 21 degrees from that on the fault plane. This, inspite of the fact that the slope, even at T 110, is probably not nearly as steep as the dip of the fault plane as inferred from the dip of the Recent scarplets and from their detailed trace near the north end of the valley. Further, we see that the slope of the lower 500 feet, not over a quarter of the total scarp height, is very much less than that of the lower 200 feet, showing conclusively that wearing back from the original fault plane takes place very rapidly.

The purpose of the above discussion is twofold: First, it shows that scarps do not retain their original steepness for any appreciable time at all after formation; Second, it shows that fault faces do not retreat from their base line, retaining as they do so their original inclination, but rather that they wear back very rapidly from their original inclination without any retreat whatever. If they do retreat, they will have lost most of their original steepness before the recession commences. (See also the discussion of the Round Valley Scarp.)

Interesting physiographic evidence to indicate the recency of displacement along the eastern fault of the valley may be seen directly south of the valley, above its scarp. To the east of B.M. 8513 a large flat area containing several closed depressions may be identified. These unnatural features were evidently ponded at the time of the uplift of the east wall of Deep Spring Valley, their drainage being changed from exterior drainage to the northwest to interior drainage. Although but little rainfall falls in this region, the streams that flow into Owens Valley seem to be more vigorous than those flowing into Deep Spring Valley and already appear to be making headway in capturing the drainage of the flat and enclosed areas. Before the uplift of the east wall of Deep Spring Valley, streams flowing immediately east and west of B.M. 8513 probably flowed in large part to the north instead of to the south as at present.

The fact that the lowest portion of Deep Spring Valley is at the base of the eastern scarp points strongly toward the hypothesis that the floor of the valley has been subsiding recently, rather than the scarp rising. The relative amounts of such subsidence of the valley and rise of the region east of the fault is not determinable, but it seems probable that subsidence of the valley floor accounts for a considerable amount of the observable scarp height.

The west side of Deep Spring Valley is greatly different physiographically from the east side. Although it may have originally had its general outline determined by faulting, it has been greatly modified subsequently by erosion. Its outline is now "fan-bayed" in contrast to the barely "fan-dented" outline of the east wall (15, p. 392 for definition of terms). It is even a question as to whether or not the west wall may not have been largely determined by warping, accentuated somewhat by faulting, while the east wall is certainly a true fault scarp. The steepest portions of the west wall prove upon investigation to be in part dip slopes formed on the steeply east dipping metamorphics, and in part up-dip slopes capped by resistent strata. The only certain faults along this side of the valley are old features that show no evidence of recent activity.

It is hoped that measurements of the depth of alluvium in Deep Spring Valley may be made by seismic methods. These will yield definite information bearing on the question of the method of formation of the valley.

Rain Shadow Effect of the Sierra Nevada

The interesting "rain-shadow" effect of a mountain range on neighboring territory has long been recognized by geographers and geologists. In this phenomenon, the region to the lee of a high mountain range has a very much lower rainfall that the region to windward, whenever the prevailing winds blow across the trend of the mountains. The effect is especially marked in situations where the atmosphere to windward has a relatively high moisture content before reaching the mountains. In this case a very large amount of water is precipitated on the windward side of the range while the lee side of the mountains receives both relatively and absolutely little rain, the amount of difference in rainfall on the two sides depending on the elevation of the mountain mass above the adjacent territory as well as on the moisture content of the wind.

Although the importance of this rain-shadow effect on the climate of the present time is well known, its influence on geologic processes of the past apparently has not received attention from geologists. Regions that are affected by relatively rapid folding or faulting, for instance, may experience a change of climate that may be reflected in the characters and amounts of sediments deposited on the two sides of the uplifted area. To the lee of a newly uplifted mountain range the climate would become more arid and rate of degradation would be reduced, while to the windward the climate would become more humid and the rate of erosional degradation would be increased. It appears that such a situation has arisen in connection with the post-Zurich uplift of the Sierra in this region.

This uplift has been mentioned earlier, (see page 145), and was determined by a study of the distribution of pumiceous material in the region. The pumice zone intercalated in the Zurich formation has been correlated with the tuff breccia member of the Bishop formation and this zone has not been found in the Sierran fans. Because of this and other reasons, it was stated that the Sierra Nevada has undergone a considerable amount of uplift since the deposition of the Zurich formation. The exceedingly fresh Sierran scarp, especially west of Round Valley, as well as the comparatively limited development of fans in the larger canyons, points to the recency of the production of much of the present scarp.

Ample structural evidence of recent uplift occurs in the form of the series of recent scarplets at the base of the Sierran scarp (see section on structure).

If one considers the very feeble erosive and transporting power of the Inyo-White Mountain streams today one is almost forced to the conclusion that at the time of formation of the great fans of the Zurich formation the amount of rainfall must have much greater than at present. The lake bed character of portions of the Zurich further substantiates this view. Some explanation for the former excessive rainfall seems to be needed.

Since there is no satisfactory evidence of uplift exceeding several hundred feet along the Inyo-White Mountains since early Pleistocene time, it is probable that this mountain block had approximately its present elevation when the Zurich formation was being deposited. This view is substantiated by the fact that a comparatively minor amount of diastrophism has affected the beds of the Zurich.

The Sierras in the Bishop region stand 7000-9000 feet above the floor of Owens Valley, If we assume that about 2000-3000 feet of this elevation has been due to the most recent movements along the frontal scarp, an assumption whose validity is attested to by the benches about 2000 feet above the valley, we arrive at the conclusion that when the Zurich formation was being deposited against the Inyo-White Mountain range, the Sierra stood at a height much less than at present, not much over 9000 -10,000 feet on the average.

Thus, if the White Mountains stood at approximately their present elevation at a time when the Sierras were at a considerably lower average elevation the rain shadow effect of the Sierra Nevada, so very pronounced now, would have been of much less importance and precipitation would have been considerably greater over the White Mountains and Inyo Range.

In order to bring out the very great effect of the rain shadow effect in this area today, the table below has been prepared. Rainfall figures east and west of the Sierra at various altitudes are shown, bringing out forcibly the immense influence of the mountains on the surrounding region. The prevailing winds from the Pacific Ocean some 150 miles west of the western base of the Sierra lose some of their moisture in passing over the Coast Ranges, but nevertheless strike the western face of the Sierra Nevada still heavily laden with water. Practically all of this is precipitated in the foothills and mountains, giving rise to the heavy rainfall at localities such as Huntington Lake, directly west of the Bishop Region.

When these winds reach Owens Valley, however, they are so thoroughly dessicated that they produce very little rain indeed. The higher portions of the region east of the Sierra receive more rainfall than the valley floor, of course, but even at an elevation of 8500 feet, on Bishop Creek, the rainfall is but a small fraction of that at the same altitude west of the summit.

Table 2

Showing comparative rainfall east and West of the Sierran summit. Localities are listed in pairs, one east and one west of the summit, at about the same altitude. Data from U. S. Department of Agriculture, Weather Bureau.

Locality (East of summit)	Elev.	Rain	Locality (West of summit)	Elev.	Rainfall
Bishop Creek	8500 ft.	9.51 in.	Huntington Lake	7000 ft.	31.28 in.
Bishop	4450 "	6.74 "	Cascada	4900 "	30.88 "
Independence	3957 "	5.32 "	Northfork	3000 "	36.85 "
Lone Pine	3728 "	5.70 "	Springville	4000 "	35.48 "

The very considerable importance of the Sierra Nevada of the rainfall of neighboring regions thus seems to be well established and from a consideration of the later geologic history of the area, the conclusion that the deposition of the Zurich formation was largely a result of relatively heavier rainfall than at present at a time when the Sierran mountain mass was lower than at present, seems probable.

It should be understood that this is but a tentative hypothesis, as yet insufficiently supported by evidence to make it entirely acceptable, even to the author.

Whether or not this phenomenon has operated in other regions is not known. Other ranges in the Great Basin province undoubtedly were uplifted at rates comparable with the Sierra, but in these cases the amount of difference in rainfall on the two sides must necessarily have been relatively slight since rainfall on either side would have been small.

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