STRUCTURE AND STRATIGRAPHY
OF A SECTION ACROSS THE WHITE MOUNTAINS,
CALIFORNIA

By

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ABSTRACT

The paper deals with the detailed physiography, stratigraphy, and structure of a section two miles wide across the White Mountains of California and Nevada. In the study of the detailed problems of this area many of the observations made suggest general relationships involving the White Mountains as a whole. The White Mountains consist of a tilted horst block, raised along marginal faults which separate the range from the relatively depressed graben blocks on either side; Owens Valley on the west, Fish Lake Valley on the east. The range trends northwest-southeast, having an average elevation of 11,000 feet.

The area is characterised by extremely rugged topography. The physiographic features include steep, straight, marginal scarps, jagged ridges, precipitous V-shaped valleys, a relatively flat crest area, glacial cirques and moraine covered U-shaped valleys, and giant alluvial cones complicated by faulting and stream rejuvination.

Both sedimentary and igneous rocks occur in the area. The sediments include old pre-Cambrian rocks and young Quaternary material. The older sediments have been folded, faulted, intruded, and, for the most part, highly metamorphosed. They include conglomerates, quartzites, phyllites, argillites, limestones, dolomites, and schists. The younger sediments consist of coarse, unconsolidated glacial till and stream gravels. The moraines are all above 8,500 feet. The alluvium flanks both sides of the range in the form of alluvial cones. Igneous rocks form a major portion of the area. The intrusives are a part of the Inyo batholith of middle or late Mesozoic. Three principal intrusive types occur in the area; two granites and a quartz-diorite. The intrusives have altered both the attitude and composition of the sediments into which they have risen. The extrusives in the area are all basalt and include pre-Cambrian, Tertiary, and Quaternary flows.

The structure of the area is complex. Folding and faulting have played major roles. Examples of both regional and of local drag folding were found. Faulting is evidenced by very numerous faults of widely different extent and displacement.

The geologic history of the White Mountains as derived from the area mapped, is essentially that typical of mountains of the Basin and Range Province.

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INTRODUCTION

Location and General Characteristics: The White Mountains together with the Inyo Range form a single continuous mountain chain 110 miles long marking the eastern wall of Owens Valley. This great chain is the first range east of the Sierra Nevadas which form the western margin of Owens Valley. The division between the White Mountains and the Inyo Range is an arbitrary one, as was pointed out by J. D. Whitney in 1865 (T-546). Wm. Irelan Jr. in 1888 (H-282) proposed that the trail leading from Owens Valley near Big Pine Creek across the range to Deep Spring Valley, be taken as the line of separation. Walcott in 1895 (Q-169) employed this line as the boundary between the two portions of the range. Spurr in 1903 (N-200) used the term "White Mountains" to relate to the entire chain. In 1918 Kirk and Knopf (I-17) wrote, "the line of demarkation has usually been placed along the Saline Valley Road which crosses the range east of Big Pine", but they prefer to apply the term "Inyo Range" to the entire chain. Anderson writing in 1935 (A-5) prefers to use the term "Northern Inyo Range". Although there is no structural nor geological break between the two portions of the chain, and they might therefore be better considered under one name, the term "White Mountains" occurs frequently in the literature and is further sanctioned by local usage, so that in this report it will be used to indicate that portion of the range north of the Saline Valley road.

To a large extent, the White Mountains lie in the White Mountain quadrangle which is located between latitudes 37°30' and 38°N. and longitudes 118° and 118°30' E., the northern end of the quadrangle being due east of San Francisco. The southern end of the mountains lie in the Bishop quadrangle.

The mountains lie between Owens Valley on the west and Fish Lake Valley on the east. The range is partly in California and partly in Nevada; the greater portion being in California with only the northeast end being within the state of Nevada.

The range trends northwest-southeast its average elevation being 11,000 feet. As a whole it has a somewhat triangular shape, being broadest at its southern end and growing narrower northward, the crest terminating to the north in Mountgomery and Boundary Peaks. The highest point of the range is White Mountain Peak with rises to an elevation of 14,242 feet, approximately 9,750 feet above Owens Valley and 9,500 feet above Fish Lake Valley.

Lying, as they do, in the Basin and Range Province, the White Mountains show characteristics of typical ranges of this area. The range margins are steep and straight, the transverse canyons are deep and narrow, the ridges sharp and steep. Great alluvial cones extend out from the mouths of the canyons onto the broad flat valleys on either side of the range. The range is characterised by extremely rugged topography and semi-arid climatic conditions.

The area with which this thesis deals, consists of a section two miles wide extending the full width of the range from Owens to Fish Lake Valley, a distance of some 18 miles. The total area mapped is about 36 square miles. The northern boundary of the strip is 1.65 miles south of White Mountain Peak; the southern, one half mile south of McAfee Meadows. The eastern end includes the mouths of Toler, Iron, and Wildhorse creeks, while the western margin includes the mouth of Milner creek. The southern boundary of the area lies about 3.5 miles north and east of the town of Bishop, California. These relations are shown by the index map on plate I.

__Field Work and Acknowledgements:__ The field work connected with the mapping of this area was begun in the summer of 1936 and continued in the fall of that year and the spring of 1937. The maps used were the U.S.G.S. topographic sheets of the White Mountain Quadrangle which were edited in 1917 and reprinted in 1932. Enlargements of this map were employed in the detailed field mapping.

The area presents numerous difficulties to one trying to map its geology. The extreme ruggedness of the topography makes complete coverage of the area extremely difficult. Some of the canyons, notably Milner Canyon on the western margin of the area, are almost impenetrable. While most of the exposures are excellent, many are covered by talus slides or by moraine and alluvial material, making accurate determinations of contacts impossible in some cases. The sediments of the area are intensely folded, faulted, and intruded by large plutonic bodies which, by greatly altering and metamorphosing them, have added considerably to the complexity of determining stratigraphic and structural relations. It is evident that the determination of structural and age relations from the limited data gathered in a narrow strip, arbitrarily limited, and cutting directly across a geologic unit, is not always possible, and frequently in this paper material gathered in work done outside of the area herein described has been used in deciphering such relations.

Acknowledgement is to be made to Dr. G. H. Anderson, of the California Institute of Technology, under whose guidance this work has been done. He introduced the writer to the White Mountains and to the problems involved, criticized the manuscript, and offered numerous suggestions without which the work could not have been brought to completion. The helpful suggestions of Mr. R.P. Bryson, some of whose photographs have been included in this report, and profitable discussions of the problems involved with other members of the

Institute staff and graduate school, have been of great value to the writer.

BIBLIOGRAPHY

The bibliography given below, while a fairly comprehensive review of the literature concerning the White Mountains, is by no means complete in this detail, nor is it confined to papers dealing with the White Mountains. In the course of this report reference will be made to most of the papers here listed. Each reference has been given a letter appearing in the first column below, and these will be used in the following pages to refer to the works listed below. Exact reference to page will be made by giving the number of the page after the key letter, separated from it by a dash. This will eliminate the unnecessary repetition of titles in the pages to follow.

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Whitney, J.D.
T-- California Geological Survey v. 1 (1865)

GEOMORPHOLOGY

General: The physiographic features of the White Mountains are essentially those common to the Basin and Range Province. Gilbert (G), Lauderback (L), and others have expressed the view that the mountain ranges of this province have been formed primarily by block faulting in which the vertical component of the displacement is dominant. The White Mountains lend support ot this theory and the physiographic features of the range are largely expressions of faulting, folding playing a minor role. Most of the present features are the result of relatively recent diastrophism. The range as a whole is in the late youthful stage of the cycle of semi-arid errosion. The cycle has been interrupted by recent rejuvinations and complicated by glaciation.

Marginal Scarps: The range is bounded on both east and west by straight steep scarps which rise abruptly form the adjacent graben valleys. The scarps, though straight when viewed from a distance, are in detail very irregular having an echelon character. The scarps trend northwest-southeast. The transverse stream canyons which cut these scarps are typical narrow V-shaped, or, in some cases, wine-glass-shaped valleys. The valleys are truncated abruptly by the marginal scarps, beyond which the streams flow out into the adjacent graben valleys on broad alluvial cones which extend far up into the canyons and well out onto the adjacent valleys. The canyons are typical of a youthful stage of the erosion cycle and the streams are working headward into the range crest. The streams, for the most part, are typical fault scarp consequent streams and their canyons are commonly filled with debris carried during flood conditions. Falls and rapids are common and the stream gradients are very high, as is necessitated by the steep scarps. Since the streams drain an arid region, they do not,as a rule, carry much water, but during flood times they become very large, carry enormous loads, and cause great denudation. An example of this was seen in the summer of 1936 when, after heavy rains, McAfee creek, which is just north of the area mapped, so altered its canyon as to make it almost unrecognizable. Usually, however, the streams are small; commonly they are intermittant. The creeks to the west expel into Owens Valley which drians into Owens Lake, south of the White Mountains. Those on the east drain into Fish Lake Valley, whose drainage center is Fish Lake, located on the eastern margin of the valley near the Silver Peak Range. Most of the streams sink down into the alluvium before reaching the valleys or are diverted for irrigation.

The ridges between the canyons are steep, jagged structures which, like the canyons, are sharphly truncated by the marginal scarps. This truncation leads to the formation of large, regular triangular facets all along the range fronts. Such facets especially characterise the western front where they are remarkably well developed. The ridges are truncated by the range front regardless of their composition or structure. Thus many excellent cross sections of the internal ridge structures are exposed on the truncated faces.

The western scarp of the White Mountains, facing the great Sierra Nevada scarp across Owens Valley, compares very favorably with this great scarp. While somewhat lower than the Sierra scarp, it is quite as impressive and appears to be almost vertical when viewed from the valley. White Mountain Peak rises 9,000 feet above the valley over a horizontal distance of six miles, giving the scarp at this point a slope of 16 degrees. The scarp is steepest at its

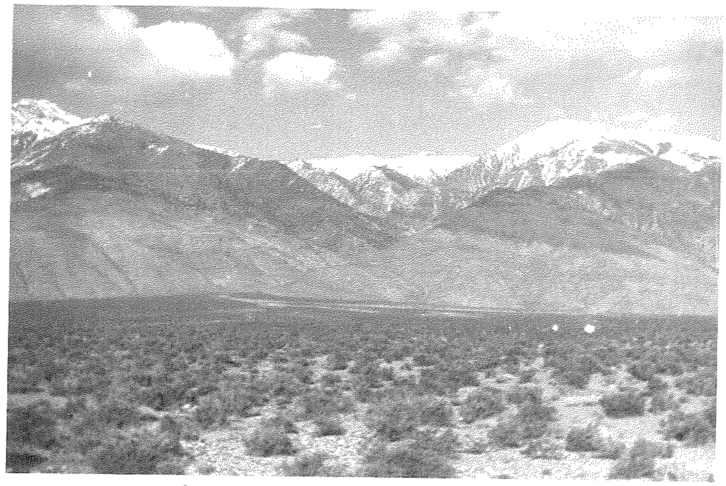


Figure 1. Western Margin of Area
Western marginal scarp from Owens Valley.
Milner Creek at center, White Mountain Peak
on skyline to left, 13,023 benchmark to right.

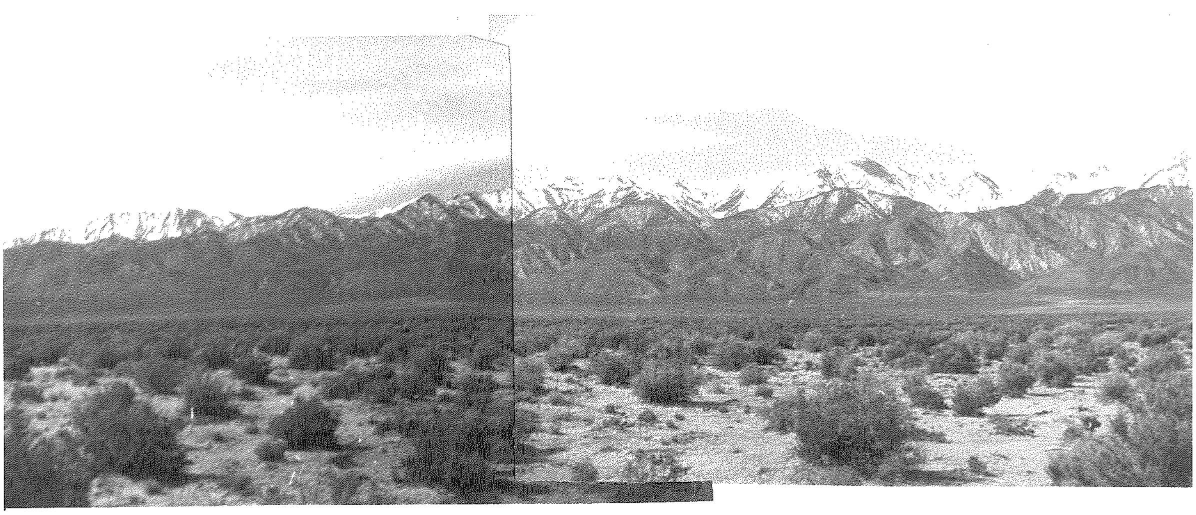


Figure 2. Eastern Marbin of Area
Eastern Marginal scarp from Fish Lake Valley.
Toler creek at right, Wildhorse at left.

northern end; toward the south the crest moves eastward relative to the western range margin, the scarp becomes less steep.

The eastern scarp, while less imposing and trenched by several broad alluvium filled valleys, is still steep and abrupt enough to be called a scarp. Its length and general straightness are especially notable. The slope here is on the order of 11 degrees directly east of White Mountain Peak. As might be expected from the migration of the crest, the eastern scarp is steepest to the south near Saline valley and becomes less steep northward.

Range Crest: A significant topographic feature of the area is the flat crest area which seems to represent an old erosional surface. This area, which is one-half to two miles wide, is especially notable in this region of extremely rugged topography because of its low relief. It is formed for the most part on the surface of the quartz-diorite batholith and is located about two-thirds the total width of the range from the eastern range margin. Its average elevation is about 12,000 feet and it locally forms the drainage divide of the range. It would appear to represent a peneplain, probably formed before the uplift of the block into the present mountain mass. As such its present elevation may indicate the approximate vertical displacement along the marginal faults. Since Tertiary volcanics are distributed over the crest, the peneplain was probably formed during late Tertiary time by the stripping of the sediments from the roof of the batholith upon which the volcanics now lie. The peneplain must have at that time been level with the adjacent blocks which now form Owens and Fish Lake Valleys. A measure of its elevation may then be gained by determining its present elevation above the valley floor. Its present elevation of 12,000 feet is approximately 8,000 feet above the adjacent valley alluvium to the west. Adding

Figure 3. Range Crest
View of crest south of White Mountain Peak (on skyline) from Piute Mountain.

Figure 4. Range Crest
White Mountain Peak on skyline. Note undulating surface and basalt patches.

to this the depth of the alluvium, which may be arbitrarily assumed to be in the neighborhood of 1,000 feet, the vertical uplift would appear to be roughly 9,000 feet.

The crest varies in width from only a few hundred feet in some places to one or two miles in others. For the most part it is gentley undulating. Bergschrund action has cut enormous glacial cirques into the crest which is at present being cut away and narrowed by the headward action of the streams which drain the area.

<u>Glacial Features:</u> Glaciation has had a considerable effect upon the physiography of the White Mountains. In the area studied, all of the glacial effects are to be seen on the eastern side of the range crest. The northeastern side of the range was more suited to the accumulation of glacial ice because the prevailing westerly winds would tend to blow the snow across the crest to the eastern side of the range where it would then accumulate to form glacial ice. Then too the northeastern side of the range would have a less rapid rate of melting, being the more protected side, which would favor the formation of glacial ice.

In the area mapped, glacial effects were noted in both the north and south branches of McAfee creek. Large well formed cirques occur at the heads of these creeks. The cirques are semicircular in outline and the vertical walls rise abruptly from the valley floors. The valleys immediately east of the cirques are U-shaped and contain large morainal deposits. These cover the valley floors and have been cut through by the present streams leaving them beautifully exposed in cross section. They are characterised by a very heterogeneous assortment of material ranging from fine to very large fragments, characteristic of glacial till. Some of the boulders are polished and striated. The moraines appear to be terminal deposits, although

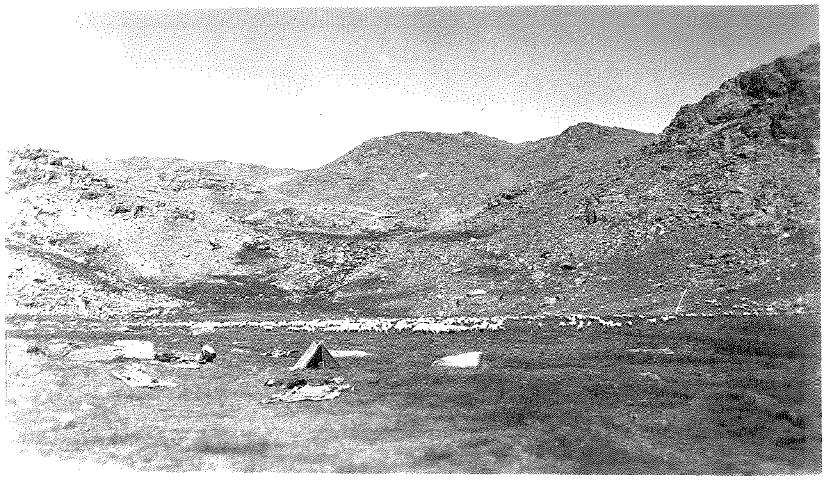


Figure 5. Glacial Cirque
Head of south fork of McAfee Creek. Field camp in foreground.

Figure 6. Glacial Moraine
South fork of McAfee creek, 2 miles east of McAfee Meadows.

the stepped character of those in the north fork imply that they may be recessional. The glaciers must have been very short ones as no glacial effects were seen below 8,500 feet. The abrupt change in the character of the valleys due to glacial erosion is strikingly apparent in both the north and south branches of McAfee creek. The lower unglaciated portions of these canyons are deep narrow V-shaped gorges, while the upper glaciated portions are wide floored U-shaped valleys of comparitivley gentle grade.

Alluvial Features: One of the most striking physiographic features of the area is the great alluvial cones which flank both the eastern and western margins of the range. The apex of these broad low cones are sometimes a mile or more from the range front, far up in the canyons from which the material composing them have been derived. The surface of the cones slopes from their apex at an angle of about six degrees to their arcuate bases far out on the adjacent valley floors. There appear to be at least two, possibly more, ages of cones, the younger having been formed by the erosion and destruction of the older. The topographic features of the valley alluvium are of special interest. Rejuvination is evidenced by the fact that many of the streams have cut down through the cones forming beautifully developed stream terraces. Streams from the smaller canyons have cut thru these deposits corrugating their surfaces with numerous gullies many of which reach considerable size. The gullies do not follow the radii of the cones, as might be expected, but cut laterally across them, seemingly indicating tilting of these features, since their deposition. Great patches of boulders appear scattered over the cone surfaces indicating places where recent streams have carried away the fine material spreading it out in a new series of smaller cones on the surface of, and in front of the older formations, and leaving the large material which they have been unable to carry. Numerous scarps occur in the alluvium along the eastern margins of the area. The scarps are straight steep features paralleling the range front and rising in some places more than 100 feet above the adjacent alluvium. As a group they are somewhat echelon in pattern. All of the scarps seen in this area faced east. The slope of the scarps varies from 25-35 degrees and they are for the most part complex, consisting rather of a broken series of scarps than of a single continuous scarp.

The features of the cones as described above present an interesting physiographic and structural problem and indicate a complex history. The cones flanking the White Mountains differ from those bordering the Sierra Nevadas in several important respects. The individual cones retain their separate identity and do not merge, as they do in the case of the Sierra Nevadas, into a single continuous alluvial slope or alluvial apron. Then too, the cones in the White Mountains extend back into the canyons and are not bounded by the range front as they are in the Sierra Nevadas. This may be explained by the more arid conditions developed in the White Mountains which caused a lessening in the carrying power of the streams and forced them to drop their loads before reaching the range margin. The events in the development of these cones has been fully discussed by Kirk and Knopf (H-5) who have attempted to correlate the stages in the development of the cones with the glacial periods known in the Sierra Nevadas. This will not be discussed fully here, but an outline of the more essential stages may be interesting.

After the White Mountains were formed by the block faulting believed to have taken place in late Tertiary or early Quaternary, great canyons were cut in the range flanks leading to the development

Figure 7. Alluvial Cones and Scarps
Eastern range front from fans east of Red Mt. Toler creek in foreground to right. Wildhorse creek in distance, left of center.

Figure 8. Alluvial Scarp
Toler creek center; Red Mt. to right.

of giant alluvial cones. As the aridity of the climate increased, the streams lost their carrying power and deposited their loads farther and farther up in the mouths of the canyons. This burying of the canyons was ended by a renewal of the faulting and a rejuvination of the streams which then began to cut down through the cones, sweeping the material out of the canyons and into the broad valleys which border the range. Thus a younger set of cones was formed along the range margin. Since this action requires an increase in the stream's erosional as well as transportational power, it must be correlated with a return to a more humid climate. The rejuvenation caused the development of the stream terraces, as well as the alluvial scarps which are the more direct result of renewal of faulting along the range margin. Another effect of this faulting was the tilting of the cones and their subsequent corrugation by minor streams flowing across them rather than following their radii.

Subsequent alternations of humid and arid climate, and of periods of faulting and periods of quiet, have led to alternate erosion and filling of the canyon mouths, resulting in a complex series of stream terraces. Under present arid conditions the upbuilding of the cones seems to be at a standstill. Material is still carried out from the canyons in great quantities during cloudbursts and flood times, but alluviation is proceeding only very slowly. The main process at work, at present, is the filling of the upper canyons by the erosion of the steep tributary valleys.

STRATIGRAPHY AND AREAL DISTRIBUTION OF ROCKS

General: The stratigraphic problems involved in the mapping of this area have been most difficult of solution. In such a limited area the age relations are very hard to make out, especially since many of the contacts are fault contacts where no such relationships are determinable. Many of the conclusions to be presented have been arrived at only by using evidence from areas adjacent to the one described, and by consultation of the literature. On the basis of material gathered wholly within the area, conclutions would be almost impossible to make.

The oldest rocks of the area are the sediments. These have been intruded by the great intrusive masses which now form the core of the range. Upon these ancient rocks Tertiary and Quaternary flows have been extruded. Quantitatively the intrusives make up the most important portion of the area. The volcanics are relatively unimportant in this area, occurring only in minor amounts. The young sediments, the alluvium and moraines, form an important portion of the section.

Sediments ---Old: The old sediments represented in the area have an aggregate thickness of more than 11,000 feet. For the most part they have been folded, faulted, and intruded. They are highly metamorphosed and complexly altered. The age of these sediments has not been definitely determined. It is believed that they are all pre-Cambrian, but lack of evidence makes this a somewhat empirical statement. The beds contain no fossils. Some of the beds, as for example the Reed dolomite, are continuous with beds described as pre-Cambrian in adjacent areas. If these age determinations are correct, then the corresponding beds within the area are also pre-Cambrian. In most cases, however, it has seemed to the author that the determinations found in the literature are not well established, and that at least some of the sediments may not be as old as they have been thought to be. Lacking any conclusive evidence to the contrary, however, the beds have been mapped as pre-Cambrian.

The oldest sediments exposed in the area are believed to be the quartzites and interbedded basalts which are found in the upper part of Milner Creek southwest of White Mountain Peak. As this series forms the slopes of the peak, the name "Peak series" is tentatively suggested, and will be used in the course of this report to refer to these beds. The quartzites are nearly white, bluish- or purplish-grey, but weather to a buff or reddish brown, and as such are strikingly apparent on the slopes to the south and west of the peak. The beds here stand vertically, but south of Milner creek they dip to the southeast at an angle of 32 degrees. They have been repeated by folding and are intensely metamorphosed. Their estimated thickness is 5,000 feet, although the series may be considerably thicker than this.

The quartzites are interbedded with basalts. Two such interbedded flows were seen. The higher and smaller of these flows does not cross the area, but lies near the top and to the west of White Mountain Peak. The lower and larger flow cuts the area just south and east of the peak and attains a maximum thickness of more than 1,000 feet. These volcanics, as exposed on the ridges just south of the peak, have a well developed shistose structure and are highly metamorphosed and somewhat amphibolitized. The basalts are dark in color, varying from dark greys and greens to the more typical black forms. They are best exposed on the ridges south of

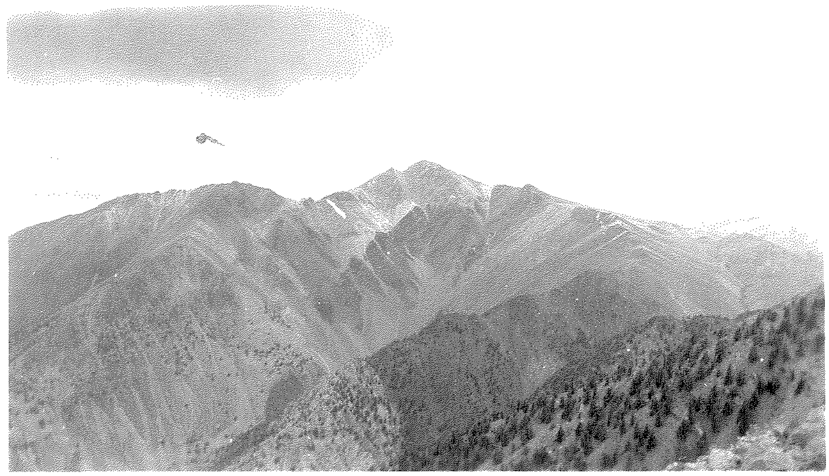


Figure 9. White Mountain Peak
Peak series, interbedded quartzites and basalt, exposed on southern slopes of White Mountain Peak. Milner canyon in foreground. Quartz-diorite on ridge from which picture was taken (lower left corner).

the peak and on the ridge south of Milner Canyon.

The quartzites are not uniform throughout. The principal variations occur along the eastern margin of the series where they have been intruded by the quartz-diorite. Here several varieties are to be found including a dark rick blue quartzite near the contact, several thin strips of white quartzite, and several darker types, one much epidotized which weathers dark green, and another containing considerable amounts of iron which give the rock a dark red color on weathered surfaces. What is believed to be a complex hybrid variety of this series occurs along the ridge just south of upper Milner Canyon. The rocks here lie close to the quartz-diorite contact which seems to swing down across the ridge. These rocks are so altered as to be almost indistinguishable as sediments. They have a texture approaching that of an igneous rock. These migmatites may represent another rock series, but until further work is done in the area they are assumed to be altered members of the Peak series.

The variations discussed above are relatively small units, and the great mass of the quartzite displays to a remarkable degree the uniform dark grey color on fresh fracture and buff-colored weathered surface. The grain size varies, but for the most part the quartzites are coarse in texture.

The eastern margin of the Peak series is an intrusive contact with the quartz-diorite exposed on the range crest. Stringers of the diorite are found running out into the quartzites, and quartzite inclusions are found in the intrusive. The area between the diorite and the typical quartzites is occupied by the complex migmatites already described. To the west the quartzites are separated from the Lone Tree series, to be discussed below, by fault contacts. The discussion as to the age of the Peak series will be taken up after the discussion of the Lone Tree series.

The meta sediments which occur along the western margin of the range consist of a series of interbedded conglomerates, slaty argillites, phyllites, quartzites, and limestones with an exposed thickness of more than 2,000 feet. The name "Lone Tree series" is suggested for these beds, the name being taken from Lone Tree creek, in the mouth of which the series is well exposed. The entire series has suffered intense metamorphism with the development of shistose structures especially in the fine grained members of the series, but also in the coarser conglomerates. The conglomerates consist mainly of fragments of quartzite which occur as well rounded pebbles varying in length upward to 10 inches. Chert and basalt fragments, both rounded and angular, also make up a considerable portion of the conglomerates. The pebbles have been distorted by the metamorphism which the beds have undergone and the entire unit is extremely well consolidated. The conglomerates make up the greater portion of the series and are, for the most part, grey in color although their weathered surface is frequently dark brown. Some of the quartzites of the Lone Tree series are coarse and dark while others are very fine grained and light tan in color. The phyllites vary from green to black with a light grey form being the most abundant. The limestones are the least abundant and are light colored. The series has been subjected to pneumatolitic metamorphism and the hydrothermal solutions have caused considerable alteration and mineralization. Along the southern slopes of the ridge south of Milner creek pseudomorphs of hematite after pyrite occur abundantly in both phyllites and conglomerates. Numerous quartz veins, ranging from a fraction of an inch to several feet in width, cut the series, and at the front of the ridge at an elevation of about 6,200 feet a mineralized zone occurs which has been rather extensively prospected.

No stratigraphic sequence of beds could be determined. The series is composed of lenses and pockets of one unit in another. The units grade into one another both vertically and horizontally, showing remarkable variations in sequence from one location to the next. Knopf (J-549) regards this series as having a fluvial origin due to these pockets and to the irregular arrangement of the conglomerate pebbles.

The series exposed on the north and south banks of Milner Canyon are not the same. The sediments on the southern bank appear to be higher in the series. On the north ridge the section is composed almost entirely of conglomerates, the other units being present in only very minor amounts, whereas on the south ridge the phyllites, quartzites, etc. are much more abundant.

The beds appear to dip gently to the east at an angle of approximately 8 degrees. They do not appear to have been folded to any extent. The cross section exposed on the truncated ends of the ridges north and south of Milner Canyon shows the series to be almost horizontal. To the west they are separated from the Peak series by fault contacts.

In determining the age of the sediments which have been discussed above, no direct evidence was found in the area mapped to indicate their age. From the high degree of metamorphism which they have undergone, the lack of fossils, and reference to the literature, they may be considered to be pre-Cambrian. From evidence gathered outside of the area mapped to the north of White Mountain Peak where members of the Lone Tree series were found to be unconformably overlying the Peak series, it has been concluded that the Peak series is the older of the two. In a personal communication to the author regarding the age of the Peak series G.H. Anderson states, " To the best of my knowledge, nowhere in North

America do interbedded quartzite and basalt occur in the Cambrian, however, they are common in the pre-Cambrian. This, of course, is negative evidence."

Knopf (J-550) in a report dealing with the andalusite mass located in the creek just north of Milner says, in regard to the members of the Lone Tree series there exposed,

"The age of these rocks is in all probablility pre-Cambrian. This conclusion is based on what is known of the structure and stratigraphy of the portion of the Inyo Range to the south. The sedimentary rocks to the south range from pre-Cambrian to Triassic, all the intervening systems being represented expept the Silurian. They aggregate in thickness more than 36,000 feet, but in all this great assemblage there are no rocks that resemble those associated with the andalusite mass. They are in general less metamorphosed, except prehaps the oldest pre-Cambrian rocks recognized; they are not notably conglomeritic; and they are of marine origin. In the northern part of the Bishop quadrangle, which is only 8 miles south of the andalusite deposit, Cambrian and pre-Cambrian strata, intruded by Cretaceous granite, make up the range. The pre-Cambrian consists of dolomite, sandstones, and dolomitic limestones; of these the massive Reed dolomite, 2,000 feet thick, is the most readily recognizable formation. Rocks of this kind do not occur near the andalusite mass, and it is probable, therefore, that the rocks inclosing it are of still older pre-Cambrian age than those in the Bishop quadrangle."

This does not seem to the writer to be very conclusive proof, but lacking any contradictory evidence Knopf's decision has been accepted as the basis for the stratigraphic column of this area. The determination of these rocks as pre-Cambrian is strengthened by the fact that Anderson (A-14), as a result of work done in the northern portion of the range, comes to the same conclusion as does Knopf and states,

"On the flanks of the northern part of the Inyo Range are found dolomitic limestones, argillites, and shists, probably of pre-Cambrian age. On the crest of the range just north of White Mountain Peak and occupying the western slope from White Mountain Peak south to the northern boundary of the Bishop quadrangle, and prehaps beyond, are sandstones, quartzites, limestones, argillites, stream-conglomerates, and meta-volcanics. These may be in part Cambrian, but, for the most part, they are undoubtedly pre-Cambrian."

In spite of this evidence, it seems to the writer best to leave the question as to the age,especially of the Lone Tree series, an open one until further study has been done. Assuming the Peak series to be pre-Cambrian, it seems more than possible that the Lone Tree series may have been deposited during some later period. The younger series has not undergone the intense folding of the Peak series and is separated from it by a considerable angular unconformity north of White Mountain Peak. Lacking any definite evidence to the contrary, however, both series have been mapped as pre-Cambrian.

Next in the sequence are the meta-sediments exposed on the south bank of the south branch of McAfee creek about one and a half miles east of McAfee Meadows. These have been tentatively named the "McAfee series". The section here consists of a series of coarse,dark, reddish-brown quartzites, light banded quartzites, and both coarse and fine dolomitic limestones. Some of the limestones occur interbedded with the darker quartzites, the bands being a fraction of an inch to a few feet in thickness. The beds stand vertically and strike northeast-southwest. They have been partially repeated by an isoclinal fold, as well be discussed later, and constitute a fault slice between the Reed dolomite to the east and quartz-diorite to the west. This relation is shown in figure 12. To the northeast they are cut off by the rejoining of the bounding faults. The series is 1750 feet thick.

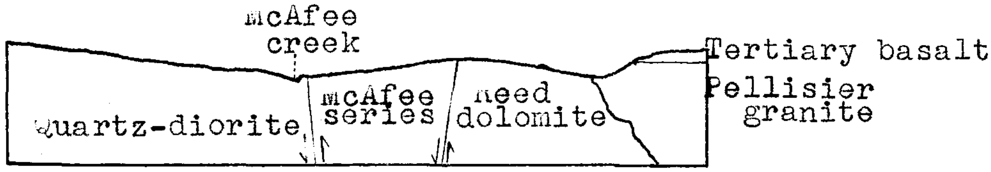


Figure 10. -- Cross section of ridge south of the south fork of McAfee creek from McAfee Meadows on the west to the 11,400 benchmark on the east. (Scale: 2 in. 1 mi.; baseline 10,000 ft.)

Again no data gathered within the area gives the position of these beds in the stratigraphic column, but further south in the region of Campito Meadows, Dr. G.H. Anderson informed the writer that the McAfee series underlie the massive dolomite. This series, therefore, occupies a position intermediate between the dolomite and the Peak and Lone Tree series already described. By correlation with the Reed dolomite described by Kirk and Knopf(H-24) the dolomite to the east of the McAfee series and overlying this series near Campito Meadows, is known to be pre-Cambrian and thus the McAfee series must also be pre-Cambrian. They may possibly correlate with the old sandstone and dolomites described by Kirk and Knopf (H-23). The reason for placing this series above the Peak and Lone Tree series is the conclusion of Knopf already quoted (see page 19).

On the eastern margin of the range occur sediments about 500 feet thick very similar to those just described. These sediments consist of dark black and blusih-black, coarse-grained sandstones overlain by dark quartzites and light fine-grained, rather soft limestones, interbedded with each other. The alternate bands of quartzite and limestone vary in thickness from a fraction of an inch to a few feet. They are intensely folded. On the west they are bounded by an intrusive contact with the igneous complex; on the east they are abruptly cut off by the marginal scarp. Their western contact is offset by the Toler fault and they are again cut off to the south by another fault.

The determination of the age of these beds is very uncertain. They can not be related to any of the other beds in the area. All that is known is that they are pre-intrusion. The rocks may be Paleozoic in age, but since they have no fossils, and there seems to be quite a similarity, both in texture and appearance between these beds and some of the members of the McAfee series, they have

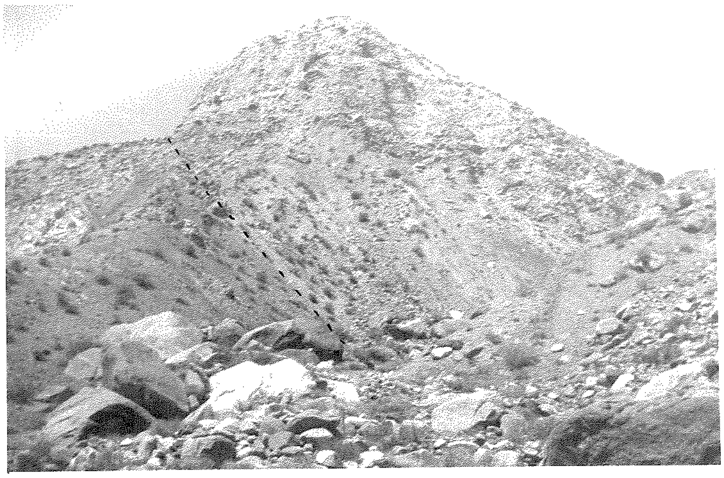


Figure 11. <u>Granite-Sediment Contact</u>
Ridge north of Toler creek, 1½ miles west of range margin. Granite to left, finely bedded quartzite and limestone to right, alluvium at crest of ridge.

been placed in the column as intermediate between the Reed Dolomite and the McAfee series. They may be members of the McAfee series. They may be younger than even the Reed dolomite. It is fully recognized that this placement is practically without foundation, but it is the best that can be done with the evidence in hand.

The youngest of the old sediments is the massive dolomitic marble exposed just east of the McAfee series on the south bank of the south fork of McAfee creek. The dolomite is very coarsly crystalline and on fresh fracture is white in color. It weathers to a tan or cream color, in places decidedly bluish, and gives rise to very characteristic light colored talus slopes. On the west the dolomite is in fault contact with the older McAfee series. To the east the contact with the Pellisier granite is an intrusive one dipping about 55 degrees to the east. Within the area the contact is completely covered with talus, but farther south in the region of the Eva Belle mine, fine-grained contact phases of the granite indicate an intrusive contact. The dolomite does not appear to the north of McAfee creek, being cut off by the granite beneath the valley moraine. No bedding was discernable in this mass, but its thickness is estimated to be at least 2,000 feet.

The dolomite here exposed can be traced directly into the Reed dolomite, with which it is lithologically identical, which is described by Kirk and Knopf (H-24). The placement of these beds in the pre-Cambrian involves a review of the literature of surrounding areas as well as that concerned with the White Mountains. Only a brief outline will be given here which, however, will show the uncertainty of other workers in the exact determination of the age of these beds.

In 1889 C.D. Walcott (B-385) defined the base of the Cambrian as follows:

"At present I draw the basal line of the Cambrian in Utah and Nevada at the bottom of the arenaceous shale carrying the Olenellus faunna."

Spurr in his report of the ore deposits of the Silver Peak quadrangle(N-18) indicates "a great thickness of dolomitic limestone and marble, quartzites and green knotted schists beneath the lowest fossiliferous horizon" of the Lower Cambrian. These he refers to the Cambrian. Turner dealing with the same rocks in his discussion of the geology of the Silver Peak quadrangle in 1909 (O-238) maps them as Cambrian, but admits that they may be pre-Cambrian. Kirk and Knopf (I-23) correlate the basal dolomite of Spurr and Turner with their Reed dolomite and place it definitely in the pre-Cambrian. They base this conclusion on the unconformity which occurs at the base of the Campito sandstone, the lowest known fossiliferous Cambrian. Anderson (A-16) in discussing the meta-sediments of the Northern Inyo Range states,

" The older rocks bear little resemblance to the Cambrian rocks of Westgaard Pass, mapped and discussed by Knopf and Kirk. On the other hand, some of them closely resemble the 'dolomitic limestones and marble, quartzites and green knotted schists' which in the Silver Peak quadrangle, less than 50 miles east, underlie, with apparent conformity, the lowest fossiliferous Cambrian."

Young Sediments: Besides the pre-Cambrian sediments above described, the only sediments exposed in the area are the Quaternary morainal and alluvial material. In the portion of the range which lies in the Bishop quadrangle Kirk and Knopf (I-19) found over 36,000 feet of sediments approximately 25,000 feet of which were Paleozoics representing all of the eras except the Silurian. Here too a section of 6,500 feet of Triassic sediments are described. Spurr (N) and Turner (O) describe Cambrian and Ordovician rocks exposed in the Silver Peak quadrangle 50 miles to the east. Paleozoic and Mesozoic sediments have been described from the Sierra Nevadas a few miles to the west by Turner (P), Lindgreen (M) and others. Is is reasonable, therefore, to conclude that sediments were probably laid down in the White Mountains during Paleozoic and Mesozoic time, but that subsequent erosion has stripped them from the surfaces now exposed in the area.

The quaternary moraines are found at elevations from 8,500 to 9,500 feet in the canyons of both the north and south forks of McAfee creek. These have already been discussed under the section on geomorphology (page 10). They consist of poory consolidated and unstratified material which ranges in size from very fine to large boulders. The boulders have been derived from the upper portions of the range where the glaciers accumulated, and consist of angular and rounded fragments largely made up of the intrusive granites and diorite. Some fragments of the meta sediments were seen, but these were much less abundant. The streams have since cut down through the moraines and exposed cross-sections of them. They are more than 100 feet thick and show no stratification. They are believed to be terminal, though their stepped character may indicate that they are recessional moraines. No detailed study of the moraines was made to determine to which glacial stage they belong.

Quaternary alluvium flanks both sides of the range as giant cones which are among the most striking features of the area. The gravels are composed of materials which have been derived from the interior of the range from the lithologic units upon which the present drainage system is established, indicative of the youth of these deposits. They consist of very coarse hetrogeneous materials some of the larger boulders measuring more than ten feet in width. The gravels are unconsolidated and when examined closely show little if any stratification, although a rather rough and discontinuous layering gives the deposits a stratified appearance when viewed from some distance. The cones form separate and discontinuous features and slope away from the range at an angle of about 6 degrees. Rejuvenation is indicated by the fault scarps and stream terraces developed on the cones. The cones are known to be of at least two ages, the younger having been formed at the expence of the older. The older cones may be in part Tertiary. As no considerable amount of time was spent in the study of the valley alluvium, both ages of gravel have been mapped as a single unit.

Igneous Rocks -- Intrusives: Quantitatively a major portion of the area mapped is composed of igneous rocks, intrusive and extrusive. The intrusives are a part of a large igneous body comparable to the Sierra Pluton. Anderson (A-8) has assigned the therm "Inyo Batholith" to this body which outcrops at intervals along the entire length of the Inyo and White Mountain range. The age of this mass could not be determined definitely. It is known to have intruded the pre-Cambrian sediments in the area and to be overlain by the Tertiary volcanics. Its age is, therefore, only very slightly limited by the evidence from the area mapped. Other writers seem to agree that it is Jurassic or Cretaceous. Anderson (A-8), working in the northern portion of the range says that it is "probably approximately equivalent in age to the Sierra Batholith ---that is, middle or upper Mesozoic". Kirk and Knopf (I-60), working in the southern portion of the range conclude that the "intrusions are clearly post Triassic and are older than deposits of presumably upper Miocene age". They, too, correlate it with the Sierra pluton. Spurr (M-), in discussing the age of the granites and apilites of the Silver Peak Range, concludes that the intrusives of this range as well as those of "various other ranges of Western Nevada are similar in general nature and origin to the granitic rocks of the

Sierra Nevada, and , like them, are of late Jurassic or early Cretaceous age".

In the area mapped, the pluton may be conceived to consist of three major units. Abundant intermediate and apilitic members were also noted, as well as a minor gabbroic phase which intrudes the limestone-quartzite series south and east of Toler creek, but the major units consist of a quartz-diorite and two granites. These may not all be of the same age, but all appear to be members of one large intrusive mass. The quartz-diorite is the oldest and will be discussed first.

The quartz-diorite is found exposed along the crest of the range to the south of White Mountain Peak. It makes an igneous contact with the quartzites to the west and a fault contact with the meta-sediments of the McAfee series. On the north bank of the north branch of McAfee creek it makes an indefinite talus covered contact with the Boundary Peak granite. The quartz-diorite is a coarse grained igneous rock, dark in color, and containing abundant ferromagnesium minerals. The plagioclase is light colored, and hornblende and biotite are the chief ferromagnesium components. Quartz is present in fairly large amounts. Several phases of this rock were seen, some having higher color index than others. The grain size also varied from place to place. Near the north-south ridge at the head of the south fork of McAfee creek the diorite was found to contain considerable epidote and the rock has, as a result, a green color. The intrusive is cut in places by fine grained granitic dikes. The largest of these occupies a considerable portion of the crest between the head of the south fork of McAfee creek and the slopes of White Mountain peak. The dike rock is light in color and its weathered surfaces are white or, more commonly, pink. It is granitic in composition with rather abundant, fine, evenly distributed ferromagnesium minerals. The orthoclase is both pink and white. Along the southern margin of the intrusive just west of the 13,023 benchmark, the dike rock becomes rather coarse grained and contains less ferromagnesium minerals. This phase very closely resembles the Boundary Peak granite to be discussed below. The dike rock is considered to be a fine-grained phase of the Boundary Peak granite and as such dates the quartz-diorite as being the older of the intrusives. On the flat between the two forks of McAfee creek and east of Stone Corral, small patches of basalt were found lying on top of the quartz-diorite, in some places including fragments of the intrusive. These are believed to be part of a late Tertiary flow which poured out onto the surface of the pluton after it had been stripped of its sediments. This indicates that the intrusive is pre-Tertiary. Certain phases of the quartz-diorite appear much like phases of the Pellisier granite, and while no direct evidence was found to indicate that the diorite is not representative of another age of intrusion, still its position and relations to the other intrusives seem to indicate that, while it is older than the granites, it is of approximately the same age; i.e. middle or late Mesozoic.

The granites of the range have been described by Anderson (A-8) and have been named by him the "Boundary Peak Granite" and the "Pellisier Granite". Detailed petrographic descriptions of these granites have been given by him in his paper dealing with the formation of the Pellisier granite which he believes to be the younger of the two.

The Boundary Peak granite as typically described by Anderson (A), is coarse grained, light grey to white in color, with relatively low content of ferromagnesium minerals which occur distributed fairly evenly throughout the rock. He described it as being porphyritic only near its contacts with the sediments. It is close jointed, forming sharp pinnacles and talus slopes of long thin slabs. In the area mapped, the granite exposed on the ridge just southwest of the point where McAfee creek branches, most nearly fits Anderson's description of this granite. The ferromagnesium content here seems to be somewhat higher than that of the typical Boundary Peak and the jointing somewhat broader, giving rise to large blocks in the talus slopes. This mass contacts the quartz-diorite to the west, the contact being hidden by talus. To the south the granite disappears under the glacial moraine, appearing as a small knob on the end of the ridge near the center of the valley, but not appearing to the south of the moraine. Eastward the granite changes in character and grades into the area which has been mapped as igneous complex and will be discussed later.

The Pellisier granite as described by Anderson (A) is quite different from the Boundary Peak in appearance, structure, and composition. As a rule it is coarser grained, darker in color, due both to more abundant ferromagnesium minerals, which in this case are unevenly distributed throughout the rock giving a motteled effect, and to the prevailing bluish-grey tint of its quartz and feldspars. The Pellisier tends to be porphyritic, with the large bluish-grey feldspar phenocrysts, some of which are over an inch in length, being very abundant in many localities. The granite is more massive in character than is the Boundary Peak and is especially characterised by abundant xenoliths. The xenoliths show parallel orientation and appear to have been shistose or argillaceous in original composition. They vary in size and in degree of digestion and give to the intrusive a layered appearance when viewed from some distance. The granite found to the east of the Reed dolomite on the south bank of the south fork of McAfee creek closely resembeled this description, the only major difference being that the xenoliths were not found as abundantly as in the more typical phases. The granite here makes an intrusive contact with the dolomite to the west. On the southern margin of the area the granite is overlain by a large basalt flow forming the crest of the ridge. To the south and east the Pellisier granite grades into the intrusive complex.

A large area, covering most of the eastern third of the area described, has been mapped as an intrusive complex. In this area the granites are for the most part neither typically Boundary Peak not typically Pellisier, although some typical occurrences are to be found. It seems impossible to separate the two granites in this area. Gradational phases of both occur and no separation could be made without a great deal of detailed study, if indeed, separation is possible at all. For the most part it would seem that the granite is a phase of the Boundary Peak. Much of the intrusive is very light in color and the weathered slopes stand out strikingly because of their snow-white color. Some of the cliffs are composed of greatly weathered and disintergrated granite which can easily be dug into with a pick or even by hand, the granite breaking down into very fine talus. The granite here is very low in ferromagnesium content. In other localities a porphyritic phase of the Boundary Peak is met with having larger ferromagnesium content. This phase is characterised by pink phenocrysts similar in size to the bluish-grey phenocrysts of the Pellisier.

The Pellisier also shows several phases and grades into non-porphyritic varieties, varieties having few if any of the characteristics xenoliths, and varieties with low ferromagnesium content. As a rule the most characteristic Pellisier occurs near the contacts of the intrusive mass with the sediments. This supports Anderson's idea of the replacement origin of this granite (A).

It is evident from the preceeding descriptions that the two granites grade into each other. One might consider a certain type to be a phase of the Boundary Peak by tracing it in one direction into typical Boundary Peak, and might, by going in another direction arrive at the conclusion that the same type was a phase of the Pellisier. Under such conditions the separation of the complex would seem to be an impossible task.

The explanation of this complex is beyond the scope of this paper and presents an enormous and fascinating problem. Possible explanations would seem to include; (1) magmatic differentiation; (2) development of secondary magmas; (3) successive intrusion; (4) replacement. The first of these is the obvious one, but seemingly the least applicable. Daly (F-322-333) lists the following as suggested mechanisms for the differentiation of magmas; (1) diffusion of molecules and ions; (2) fractional crystallization; (3) gravitative separation of crystals; (4) filter pressing; (5) crystal fractionation and thermal convection; (6) rest magma versus magma of resorption; (7) liquid immiscibility; (8) pure melting and differentiation; (9) assimilation and differentiation; (10) gases and differentiation. As to which of these processes, if any, apply to this area only a very detailed study could answer.

As to methods of formation of secondary magmas Daly (F-287-318) includes; (1) pure melting; (2) magmatic assimulation; (3) gas fluxing; (4) anatexis. Nothing is known concerning the applicability of these methods.

The last process, that of replacement, involves granitization and albitization. It is this process which Anderson (A) applies to the formation of the Pellisier granite which he believes to have been formed "<u>in situ</u> by the granitization of a series of early

Cambrian or pre-Cambrian sediments and interbedded volcanics -- the Boundary Peak granite being the source of the emanation that took part in the conversion of the sediments to granite". In his paper he discussed the development of this process of albitization and gives a comprehensive bibliography on the subject, as well as applying the process to the formation of the Pellisier granite.

At present the writer is inclined to agree with this theory. Nothing is known concerning the first two methods suggested above. The third method, that of successive intrusion seems to be eliminated by the very gradual change which has been noted to occur between the granite types. The occurrence of the Pellisier, which is always found near the sediments and likewise always near the Boundary Peak, however, seems to fit into the general idea of a replacement origin. Further evidence was noted along the intrusive contact near the mouth of Toler creek where the quartzite xenoliths were seen to grade into the granite suggesting that the granite may have been formed by replacement of the sediments. However, the presence of large areas of granite, otherwise typically Pellisier, having few if any xenoliths, especially along the Reed dolomite contact throws some doubt on the theory. Replacement does, however, seem to be the most feasable explanation at present.

Extrusives: The extrusive igneous rocks exposed in the area are all basalts. Their areal extent is relatively small. Three distinct ages of volcanic activity are represented. The oldest of these is represented by the basalts which are interbedded with the quartzites exposed to the south and west of White Mountain Peak. These have already been discussed in some detail (page 15) and no further discussion of them seems necessary. They are pre-Cambrian.

The lavas which are intermediate in age are exposed at several localities in the area. They are found lying on the surface of the quartz-diorite, especially between the north and south branches of McAfee creek where they occur as small isolated patches. Inclusions of the quartz-diorite and of the fine grained dike rock in the lava, indicate that they are younger than the Mesozoic intrusions. On the southern margin of the area about one and one half miles northeast of Grey Haired Jonny's Corral, a broad patch of these lavas lie on top of the Pellisier granite and form the top of the ridge. Here a white coarse volcanic tuff was found to underlie the lava. The basalts are dark in color, fine-grained, and uniform. They weather to a dull orange-brown. At the last mentioned occurrence they were found to be vesicular near the top of the flow.

Volcanics, also believed to be of intermediate age, lie on the ridge south of Milner Canyon at an elevation of approximately 6,500 feet. They appear to dip gently to the south. These volcanics are quite different from those exposed anywhere else in the area. They consist of a lower meta-agglomerate, composed of large volcanic fragments cemented together by a coarse volcanic cement. The large fragments are dark blue and green, the cement a deep red. The lower portion of this mass is more massive and contains considerable epidote. This massive form ~~may~~ continues along the ridge for some distance above the Lone Tree series and below the Peak series and may represent the feeder for the other deposits. Above the agglomerate is a dark green volcanic which is characterised by abundant calcite porphroblasts. The lack of metamorphism in these volcanics, together with their position as unconformably overlying the ridge sediments, is the basis for placing them with the intermediate group. This is far from absolute, but seems reasonable.

Fragments of the intermediate lavas are to be found in the Quaternary moraines and in the Quaternary alluvium. As already indicated, they are post intrusive and thus their age may be set as post-Mesozoic and pre-Quaternary; i.e. Tertiary. They are to be correlated with the Tertiary basalts described by Kirk and Knopf (I-74) from the southern portion of the range and with those described by Spurr (N-27) and Turner (O-258) from the Silver Peak quadrangle.

The youngest of the extrusives, and indeed, the youngest rocks of the area, except for the recent alluvium, is the basalt which is found to lie upon the Quaternary alluvium near the mouths of Iron and Wildhorse creeks on the eastern margin of the area. These, as would be expected, are extremely fresh and represent very recent volcanic activity. They can also be correlated with similar occurrences described by Kirk and Knopf, Turner, Spurr, and by Anderson (A).

STRUCTURE

<u>General:</u> Whereas the essential structure of the White Mountains is quite simple, the internal structure of the range is exceedingly complex. The White Mountains consist of a tilted horst, the range being an uplifted block bounded by two marginal fault zones on either side of which are the relatively depressed blocks forming Owens Valley to the west and Fish Lake Valley to the east. The present topography is largely due to this horst structure, but within the block itself the structure is much more complicated and is characterised by intense folding, faulting, and igneous activity.

<u>Marginal Faults:</u> The marginal faults are locally buried beneath the great alluvial cones which extend from the canyons out onto the valleys on either side of the range. The evidence of their existance, as derived from the area here described is largely physiographic, and since the physiography of the marginal scarps has already been discussed (page seven) the evidences supporting the existance of the marginal faults need only be briefly reviewed here. The features are for the most part displayed on both the eastern and western margins of the range, but are, locally at least, somewhat better seen on the western front.

The range is bordered by long, steep, straight scarps which trend northwest-southeast. The base of these scarps together with the features which they produce, show remarkable alignment though when studied in detail the scarps are recognized as being echelon in character. The scarps truncate both ridges and canyons, forming in the first instance triangular facets, and in the second leading to the abrupt termination of the V-shaped precipitous canyons, and the formation of great alluvial cones. The scarps truncate the internal range structure cutting obliquely through the sediments exposed on the range margins, distorting them, and exposing along the face of the range a cross-section of the stratigraphic structures. This abrupt truncation shows no relation to rock character or structure as the scarps cut differentially through all of the exposed units ever maintaining the same perfect alignment. The recent fault scarps in the alluvium representing, as they do, vertical movements along the range front parallel the base of the scarps and in all cases in the area studied have their uplifted sides on the mountain side of the faults. Rejuvenation along the range front is further evidenced by stream entrenchment of the cones and the development of stream terraces. The scarps are steepest at the base and low in slope.

For these observed features the only reasonable explanation seems to be that of faulting, as by this process alone can all of the observations be successfully explained. As the features above described are to be noted along both the eastern and western margins of the range, it seems that faulting has occurred along both fronts of the range. This idea, that the range is a horst block, has been suggested by Kirk and Knopf (I-13) who present stratigraphic as well physiographic evidence to support this theory. Anderson (A-6) arrives at the same conclusion as a result of work done in the north end of the range.

The question as to whether the marginal scarps are fault scarps or fault line scarps must next be considered. Again no very conclusive evidence was found in the area mapped. The attitude of the scarps, that of a steep base and low slope, and the presence of the alluvium scarps near the base of the range scarps, indicates that they are most probably fault scarps and that the faults which bound the White Mountain block and along which the displacement took place to produce the mountains, lie along the base of the the marginal scarps.

The position of the range crest together with the more steep attitude of the Western scarp, seems to indicate that the White Mountain block has been tilted to the east; i.e. that there has been greater displacement along the western than along the eastern fault. The alluvium scarps and stream terraces which are better developed on the east, indicate that movements have been more recent on the eastern front, although both north and south of the area mapped there are alluvial scarps along the western front as well. As the faults were themselves buried in the area studied, it was impossible to make any exact location of them or to determine the amount of displacement, attitude, or character of the faults. It seems reasonable to assume, however, that if the faults were to be exposed they would show the characteristics of other Basin and Range faults and as such they would be gently curving in plan and complex in character. They are most likely braided in both plan and section and consist rather of a fault zone than of an individual fault. Judging from other Basin and Range faults which are better known, the dip may be supposed to be rather steep, possibly 50 to 70 degrees. The faults would typically be expected to be normal faults along which the displacement was largely dip slip in which the vertical component took precidence over the horizontal. It has already been shown (page 9) that the displacement along the western fault may be empirically estimated to be in the neighborhood of 9,000 feet. While this is a rough approximation at best, it may be taken as indicative as to the magnitude of the displacement which must have occurred.

The faults must be relatively young features. The youth of the mountains which they have formed, as evidenced by the topography of the range as well as the freshness of the valley alluvium, together with the evidence of recent movement along the range margins shown by the alluvial scarps and stream terraces, testify that they are not only extremely young, but that in all probability movement is still going on along them; i.e. that the mountains are still rising. The faults are considered to be of late Tertiary or early Quaternary age. Anderson arrives at this same conclusion from work done in the northern portion of the range (B-312) as do Kirk and Knopf from work done in the southern end of the mountains (I- 19).

<u>Internal Structure --- General</u>: The internal structure of the range is locally characterised by intensly folded sediments, large igneous masses, intrusive and extrusive, and a large number of faults which vary considerably in both size and displacement. As a rule the internal structures of the range are not represented by topographic features and they are considered to be considerably older than the marginal structures which have produced the present range. The age of these features has not been determined, as no evidence as to their age was found in the area mapped. It is possible that the early stage of folding and faulting which they represent may have produced a mountain range which was subsequently destroyed by erosion, with the production of such old age erosional features as the present range crest, before the initiation of the faulting which raised the present block to form the White Mountains as we know them today. No direct evidence has been found to support this theory, but it seems reasonable that some such history is indicated.

it is probable, and in one case quite certain, that the features are not all of the same age and that there may have been more than one period of diastrophism preceeding the last which has formed the present range.

Folding: For the most part the sediments exposed in the area show evidences of intense folding. Due to the metamorphosed condition of the sediments as well as to the limited portions of each series which are included in the area mapped, it was impossible in many cases to work out any definite structures associated with this flexing. Although exposures are plentiful, attitudes are most difficult to determine with any degree of certainty. The massive character of some of the sediments, notably the buff quartzites of the Peak series and the Reed dolomite, makes the recognition of bedding planes extremely uncertain at best. The shistose character of some of the rocks adds to the difficulty and as planes of schistosity may, and in some cases seem to, cut across the bedding, attitudes taken on such beds are of questionable value. The bedding itself is quite frequently destroyed. This is especially true of the members of the Peak series. A discussion of the folding of these beds will be delayed until the end of this section of the report.

The interbedded quartzites and limestones of the series exposed on the eastern end of the area in the mouth of Toler Creek, have been intensely folded. In this case dips and strikes taken at various localities displayed such marked discordance that in the limited area under observation, no correlation could be made between them to gain a picture of the general structures involved. The whole series has been buckeled into a series of small folds, usually not more than a few feet or a few tens of feet in width. These may be seen on the ridges just south of Toler creek and on the southern slopes of Red Mountain. The folding here may be drag folding associated with the igneous intrusion to the west of the series or with the marginal fault to the east.

In the case of the McAfee series the relationships are more discernable. Here the series has been partially repeated by folding. The series is exposed along the ridge top just south of the south Branch of McAfee creek and as the beds stand vertically one views a cross section of the fold in walking along the ridge from the point where the series contacts the quartz-diorite on the west to the point where it contacts the Reed dolomite some half a mile to the east. The beds are here folded into an isoclinal fold the axis of which strikes north 30° east and is located about feet from the dolomite contact. The beds on either side of the axis strike parallel to it and stand vertically. Of the 1,750 feet of sediments exposed to the west of the axis, only the last 750 feet are repeated to the east, the remainder having been cut off by the fault which has brought the series up against the dolomite.

The Lone Tree series has been folded only to a minor extent. As a rule the beds dip to the east at an angle from 5-15 degrees. A cross section of these beds is exposed on the truncated ends of the ridges north and south of Milner Canyon. They are almost horizontal in attitude, but a minor amount of flexing may be noted which has produced mostly broad gentle folds. This is well exemplified on the ridge just north of Milner Creek where the sediments at a point about three miles to the east of the range margin are bowed into a gentle syncline, the cross-section of which may be seen on the ridge face. Such a structure may be the result of slumping or of distortion

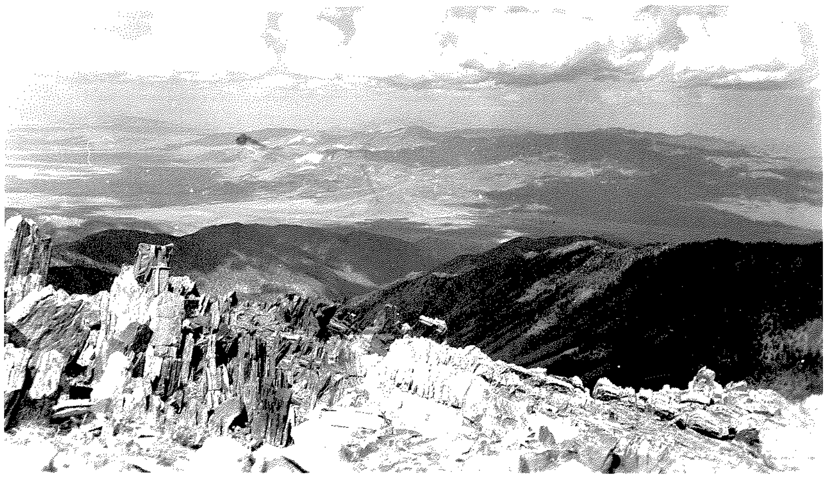


Figure 11. Isoclinal Fold in McAfee Series
Ridge crest north of north fork of McAfee creek $1\frac{1}{2}$ miles east of McAfee Meadows. Fish Lake Valley and Silver Peak Range in distance. Note vertical attitude of beds.

connected with the faults which bound the series on this ridge. The beds appear to be dragged up near the Champion fault where they have a dip of about 10 degrees to the west. On the ridge south of Milner creek, the schists in contact with the lavas near the top of the ridge have been crumpled to some extent and further crumpling in the incompetent members of the series was noted along the ridge front at an elevation of 6,200 feet where the series has been mineralized. This local folding may be due to the Sabies fault which will be discussed later. As a rule the series is not characterised by intense folding. The possible significance of this has already been mentioned. (page 20)

Faulting: The most important internal structural features of the range are the faults. In an area such as this, the faults are exceedingly difficult to locate and to trace. Determinations of attitudes and displacement are usually impossible. This is due not only th the inacessability of some of the localities, and to the fact that many of the key positions are found covered with talus and alluvium, but also because in many cases the faults ~~may~~ extend through the intrusions where relations are most difficult to determine. The high degree of metamorphism of the sediments of the area has so altered them, and made them so variable in composition, that faults in which both sides are composed of the same series may be impossible to distinguish. Faults occur throughout the area, many of them being too small to show on the map. Only those faults in which relationships are well displayed have been included in this report.

Some faults occur in the canyons and strike approximately at right angles to the trend of the range. They may occur in all oo the canyons as has been suggested by Kirk and Knopf (I-), but definite proof of this was not found within the area mapped. In the canyons in which sedimentary rocks were exposed evidences of such transverse faults were found in all cases, and it may be that they are not discernible in the creeks south of Toler creek on the eastern front, since they would here lie wholly in the intrusive complex and could not be located with recourse to a very detailed study of the canyons. The straight courses of many of the creeks along both fronts of the range is suggestive that many of the canyons do follow such transeverse faults. Of these canyon faults observed in the area, the one trending up Milner canyon was best exposed, but a discussion of this fault will be postponed until the end of this section when the structures of the western end of the area will be discussed in detail.

The fault trending up Toler creek, which has been tentatively named the "Toler fault" offsets the granite-sediment contact at the mouth of the creek some 1,000 feet. Since the contact here dips to the east and the offset has resulted in the shifting of the contact on the north side of the creek to the east relative to the contact on the south side of the creek, it would appear that the displacement has resulted in the uplift of the north side of the fault.

In the small unnamed canyon just north of Toler creek, evidence of another canyon fault was found in the abrupt truncation of the sediments which appear on the north side of the canyon, but not on the south. Here the relations seem to indicate that the sediments have been faulted down on the north side of the intrusive.

The evidence for the faults exposed in the western end of the area, in and about Milner canyon, will be taken up in the discussion of this area which appears at the end of this section.

The evidence for the faults exposed on the south side of the south branch of McAfee creek just below McAfee Meadowm is fairly clear. From mapping done further south and from the genaral relationships involved, it seems that the McAfee series here exposed is a fault slice between the dolomite to the east and the quartz-diorite to the west. The series has been partially repeated by an isoclinal fold as has been already described (page 39). The fact that all of the beds are not repeated, and that their contact with the dolomite which is not similarly folded, indicates a fault relationship. The contact itself is covered with float, but the rocks near the contact are intensely sheared. The contact trends northeast-southwest and is, as nearly as could be determined, vertical.

The contact with the quartz-diorite appears also to be a fault though the evidence is more negative than positive. No contact phases of the diorite were noted, no inclusions of the sediments were found in the diorite, and no dikes were found extending into the sediments, eliminating the possibility of an intrusive contact. A fault can be traced with more or less continuity, southwest from this contact across the range and into the mouth of Piute Creek. This fault will be referred to as the "Piute fault". The McAfee series is cut off to the south about a mile north of Piute Mountain and again to the north in the south branch of McAfee creek which they enter from the southwest disappearing under the moraine and alluvium in the canyon, and failing to reemerge to the northeast, being cut off by the intrusive which forms the northern rim of the canyon. Some evidence of the presence of the series on the lower portion of the north canyon wall was found, but the wall is so covered with quartz-diorite float as to make any accurate determination impossible. The dolomite, however, is exposed at the base of the wall, and this together with the presence of float apparently derived from the McAfee series, seems to indicate that the beds do cross the canyon, being cut off further to the northeast. The explanation of this seems to lie in the conclusion that the McAfee series is a slice between the Piute fault to the southwest and a branch of this fault to the northwest. The branch separates from the main fault just north of Piute Mountain and then joins it again under the moraine in the south branch of McAfee creek. The faults both trend to the northeast and appear to be vertical. The main fault may continue on beyond the creek, but in so doing it enters the granite in which it can not be located. The small knob of granite which is exposed just to the west of the moraine and which seems to jut out beyond the normal trend of the granite-diorite contact, may be included between the two faults which would then rejoin in the granite to the northeast.

Igneous Activity: Most of the area is composed of intrusives. These have not only altered and profoundly metamorphosed the sedimentary beds into which they have risen, but in some cases appear to have changed their attitudes causing drag folds etc. For the most part, however, the intrusions have had more influence upon the petrography than upon the structure of the area. It is prehaps the case here, that the structures have had more influence on the intrusions than the intrusions have had upon the structure. The contact effects of the intrusions have already been discussed.

Milner Canyon Area: A discussion of the structure of the western end of the area, in and about Milner Canyon, has been delayed until this point since it has been though best to deal with this region separately. It must be admitted at the outset that the writer knows much less than he would like to know concerning the structures of this portion of the area. It has not been possible to devote sufficient time to work in this part of the range to gain more than a superficial knowledge of the relationships. Enough has been done to show the very complex nature of the region and to make it clear that a great deal of intensive study would be necessary to satisfactorily explain the phenomena observed.

A geologist working in this area is under several handicaps. The region is extremely difficult of access. As may be seen from a glance at the topographic map, the penetration of upper Milner Canyon in itself presents quite a problem. The sediments here exposed are altered and so greatly metamorphosed besides having been subjected to intense diastrophism, that attitudes, structures, and relationships are most difficult to determine. Lastly the problems found in the area under consideration are only a part of the general problems of the entire region. It is not likely that the key to any of these problems lies within the arbitrary boundries of this area. Their solution must depend upon work which must be done both north and south of the area and even such empirical explanations as are to be given below have been determined only through the aid of material gathered outside of the area discussed in this report. Many of the relationships to be suggested are subject to considerable doubt until such time as further field investigation may be carried out.

The observed conditions may be summarized briefly as follows. The Peak series, made up of buff quartzites and interbedded basalt flows, is exposed south and west of White Mountain Peak and north of Milner Canyon appear to stand vertically and strike north-northeast. To the south of the canyon the series maintains the same strike but the beds dip south-southeast at an angle of 32 degrees. These beds south of Milner Canyon may not be the same series as those exposed north of the canyon, however, the similarity in appearance of the quartzites, both on fresh fracture and weathered surface, as well as their occurrence with interbedded basalt flows, seems to the writer to be conclusive enough to warrent their inclusion as members of the Peak series. This series extends farther to the west on the southern than on the northern ridge, overlying the Lone Tree series on the southern ridge. The Lone Tree series, consisting of metamorphosed conglomerates, phyllites, quartzites, and limestones, is exposed to the west of the Peak series on the western ends of the ridges, striking north-south and dipping very gently to the east. The series on the ridge south of the canyon does not appear to be the same as that exposed on the north ridge. Evidences of two faults in the area are conclusive. The first is that forming the contact between the Peak and Lone Tree series on the north ridge of Milner Canyon; the second, the fault trending up Milner Canyon.

The first of these faults is beautifully exposed on the north canyon wall about 500 feet below the lower falls in Milner creek. For convenience in refering to this fault it has been tentatively named the "Champion fault", the name being taken from the Champion mine located in the fault zone in the canyon just north of Milner canyon. The evidences of the fault in Milner canyon are unmistakable and include a finely exposed zone of breccia and gouge which is light in color and stands out against the two contacting series; the buff Peak series to the east, and the grey Lone Tree series to the west. The fault, as here exposed, is vertical and trends slightly west of north. Since the Lone Tree series is younger than

Figure 13. Champion Fault
Ridge north of Milner creek just west of falls. Fault zone light colored, Peak series to right, Lone Tree series to left.

the Peak series, it is evident that the western side of the fault is the downthrown side. The beds of the Peak series near the contact dip steeply to the west; the beds of the Lone Tree series have here been dragged up to a dip of 10 degrees to the west. A small exposure of the Peak series was noted on the ridge just west of the Champion fault. The exposure occurs at the base of the ridge and may represent the old surface upon which the Lone Tree series lies unconformably, but at present this isolated patch of the Peak series is believed to be a fault slice. Further mention of this will be made later.

The Champion fault does not extend across the canyon since the beds on the fault trend on the southern ridge of Milner Canyon are undisturbed. No evidence of the southward continuation of this fault could be found along the south ridge. It is possible that the fault may continue across the ridge, the relationships being obscured by the similarity of the contacting members, since it would be bounded on both sides by members of the Peak series on the south ridge. Further field work may lead to the location of this fault on the south ridge, but at present it is believed that it terminates abruptly in the canyon where it intersects the fault which will be discussed next.

The existance of a transverse fault trending east-west up Milner canyon, although the fault is not so well exposed over such a long distance as the Champion fault, seems none the less unquestionable. This fault will be refered to as the "Milner fault". On the ridge just south of the lower falls, the fault is exposed and the wide zone of gouge, brecciation, and shear is no less striking than that of the Champion fault. Fragments of the adjacent rocks, of the Peak series quartzite to the north, and of a complex hybrid rock to the south, are found scattered throughout this zone. The hybrid rock is believed to be the result of alteration of one of the members of the Peak series by the adjacent quartz-diorite intrusive, and grades from a massive form a few tens of feet from the contact, to a shistose variety near the gouge zone. Both of the adjacent rocks appear to be complexly sheared. The gouge consists of a very fine yellowish clay. The fault appears to be vertical and to trend east-west. It can not be definitely traced by outcrops either to the east or west, but the abrupt change in the strike of the quartzites of the Peak series exposed on either side of the fault trend in the upper canyon, as already described, as well as the differences in the conglomerate series exposed on either side of the lower canyon, are ample evidence that the fault does continue both up and down the canyon. At the head of the canyon the fault enters the quartz-diorite and can not be traced farther. The relationships here represented seem to indicate that the north side of the fault has been raised relative to the south. This will be discussed again later.

The explanation of the attitudes of the Peak series, as exposed both north and south of Milner creek, is a difficult problem. The entire series strikes north-northeast, but to the north of the creek the beds stand vertically, while to the south they have a dip of 32 degrees to the southeast. North of the area near White Mountain Peak, as well as in the vicinity of the Champion fault, the dip is steeply to the west. Since no evidence of faulting, other than the Milner fault already described, was found in this area, it seems best to attempt to explain these relationships by the folding of the series. It is possible that further work in upper Milner canyon may disprove these relationships to be suggested below, but from the evidence now in hand, and the lack of any evidence of faulting in the upper canyon, folding seems to be the most logical explanation.

It would appear that we are here dealing with an asymmetric inclined ~~fold~~ anticline, the axis of which trends north-northeast parallel to the bedding and the axial plane of which dips to the southeast. The northwest limb of the fold stands vertically while the southeastern limb dips 32 degrees to the southeast. The fold is cut on the east by the quartz-diorite intrusion. The Milner fault cuts across the axis of the fold raising the northern portion from which the crest of the fold has been removed by erosion leaving the vertical northwest limb exposed on the slopes of White Mountain Peak and in upper Milner canyon. The higher beds, near the peak, are near the crest of the fold and so dip steeply to the northwest. The beds exposed near the Champion fault, which cuts the fold to the west, are quite some distance from the axis and also dip steeply northwest. To the south of the Milner fault the crest of the fold has not been removed and the southeastern limb, dipping 32 degrees to the southeast, is exposed on the ridge south of the canyon. The form of this fold is suggested in the diagram at the end of this section (figure 7). This explanation involves uplift on the north side of the Milner fault. As already discussed (page 18) the section of the Lone Tree series exposed on the lower portion of the ridge north of Milner canyon appears to be lower in the series than those exposed on the south ridge. This lends support to the theory that the movement along the Milner fault has resulted in the uplift of the north side of the fault and subsequent exposure of a lower section of both Peak and Lone Tree series on the north side of Milner canyon.

The most obscure structure is that of the western part of the ridges north and south of Milner canyon. Here the Peak series extends along the crest of the south ridge to an elevation of 6,700 feet, more than a mile farther to the west than their occurrence on the north ridge. At this elevation they are covered by a thin layer of young volcanics which extends across their contact with the Lone Tree series, exposed to the west of the basalts and continuing on to the range margin. The beds of the Lone Tree series are almost horizontal; they dip at a low angle to the east, and outcrop in the canyon approximately 2 miles east of the range front. The beds of the Peak series dip, as in the upper canyon, 32 degrees to the southeast. The volcanics dip about 6 degrees to the south. From these relationships, shown in figure 14, a depositional contact is impossible since, unless our previous conclusions are at fault, we are here dealing with older beds, the Peak Series, overlying younger, the Lone Tree series. A possible explanation lies in the presence of a thrust fault which has caused the Peak series to ride westward up over the younger beds. The apparent thrust plane is almost falt, dipping only very gently to the east, since the Peak series are exposed only about a hundred feet lower in the canyon than on the ridge crest. The displacement appears to have been to the west. The ridge being covered by float, the thrust plane is not exposed, but the intense crumpeling of some of the finer members of the Lone Tree series along the south side of the ridge near the contact, and more especially at the front of the ridge in the mineralized zone at 6,200 feet, lends support to the existance of the thrust. This fault will be refered to as the "Sabies thrust", the name being taken from the ranch located on the topographic sheet at the head of the ridge south of Milner Canyon upon which the thrust occurs. On the south side of this ridge, between the highest exposure of the Lone Tree series and the lowest exposure of the Peak series, occurs a massive bluish-green rock, possibly an altered volcanic which rose

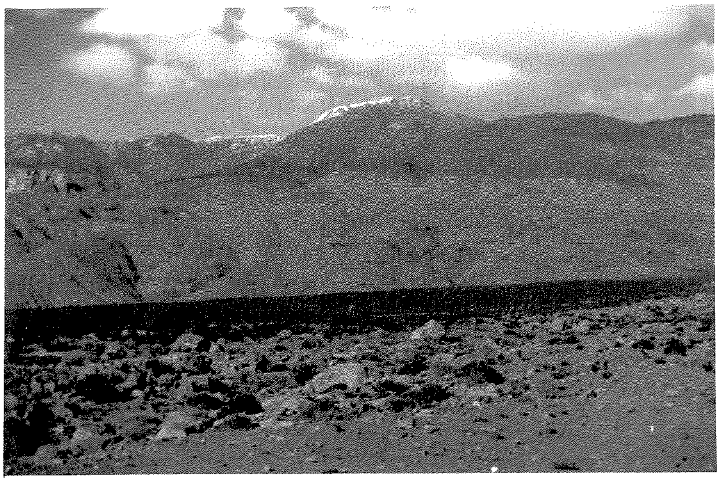


Figure 14. Sabies Fault
Western end of ridge south of Milner canyon from southwest. Light grey Lone Tree series at base, dark Tertiary volcanics and Peak series above. 13,023 benchmark on skyline at center.

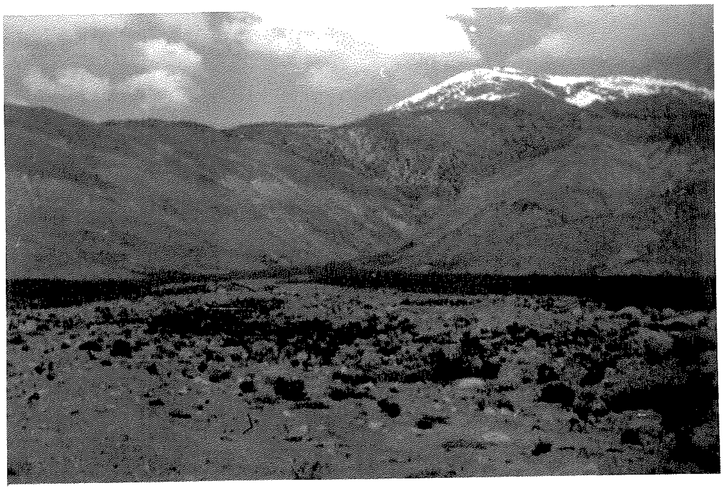


Figure 15. Sabies Fault
South side of ridge south of Milner canyon. Relations as above. 13,023 benchmark on skyline to right.

along the thrust plane and acted as feeter for the young volcanics exposed on the ridge crest. If this bed is present on the north side of the ridge it is covered by float and could not be definitely located. The volcanism, as previously discussed (page 32), is a fairly recent feature, believed to have taken place during Tertiary.

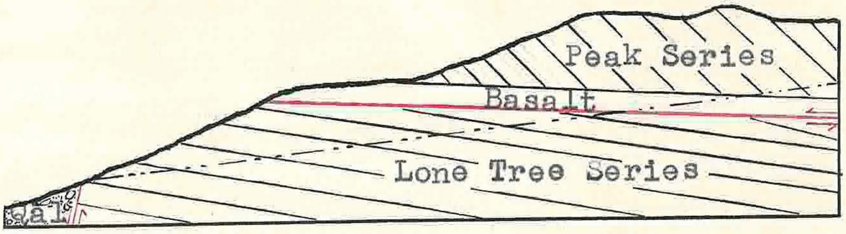


Figure 16.-- Cross section of ridge south of Milner Canyon. (Scale: 2 in. 1 mi.; baseline 4,500 ft.)

No direct evidence of the Sabies fault was found on the ridge north of Milner Canyon. The absence of the Peak series from this ridge may be explained by the Champion and Milner faults already described, or may be due to a difference in the character of the thrust plate. The Milner fault has resulted in the uplift of the northern side of the canyon relative to the southern; this has caused deeper erosion of the northern side and exposure of a much lower section of both the Lone Tree and Peak series. The thrust plate is believed to have been eroded from the top of this ridge, no very conclusive evidence of its presence on the lower ridge having been found. Further mention of this will be made below.

The Champion fault may the exposure of a steepened portion of the Sabies thrust. If the thrust steepens with depth, as it may well do, the exposure of the lower portion of the thrust would have the same appearance as the Champion fault; i.e. the eastern side would have been uplifted relative to the western, bringing the Peak series up against the conglomerates. Very little is known concerning what happens to faults at depth, but the steepening of their planes is fairly well accepted. If the Champion is the steepened lower portion of the Babies, exposed by the uplift of the north side of the Milner fault, it would explain the fact than no continuation of the Champion fault was found on the ridge south of Milner Canyon. While possible, this explanation does not seem reasonable. It involves an enormous amount of vertical displacement on the Milner fault as well as a very abrupt change in the dip of the Babies fault plane, neither of which seem likely. It is then necessary to consider the Champion and Babies faults as separate features.

The Babies thrust may be simply a relatively small branch of the Champion fault, which must then be considered to continue on across the southern ridge. Further field work may locate this southern continuation of the Champion fault, but at present its existance on the southern ridge is not known.

The Champion fault may be older than the Babies which would then have displaced it westward on the southern ridge, possibly beyond the present ridge margin. If this is the case the Babies thrust must be very local, being bounded on the north by the Milner fault. Due to the apparent steepness and amount of vertical displacement on the Milner fault, it does not seem likely that it is merely the margin of a flat thrust.

If the thrust is the older of the two, one would expect to find it exposed on the north ridge of the canyon, unless as already mentioned, it has been removed from the ridge by erosion. The small patch of the Peak series exposed at the base of the north ridge just west of the Champion fault, may be the old quartzite surface, upon which the conglomerates lie unconformably, which has been brought up by the thrust, the overlying conglomerates of the Lone Tree series having been preserved by the depression of the block along the Champion fault. In this case, however, unless the Champion fault termenates abruptly in the canyon, the conglomerates should be exposed on the south ridge above the Peak series, especially since the northern ridge is believed to have undergone deeper erosion as a result of its uplift along the Milner fault.

Another possibility is that the thrust plane is above the Peak series exposed at the base of the north ridge just west of the Champion fault. This theory finds support in the presence of a bed about 20 feet thick, composed of an intensely sheared, very light colored, shistose material which locally, at least, resembles a fault zone of gouge and breccia. This bed continues on across the ridge to the west, dipping gently to the east, and is very similar in attitude and elevation to the Sabies thrust plane on the southern ridge. If this does represent the Sabies fault, the thrust plate is here composed of the Lone Tree series, since no exposure of the Peak series was found above the light schist bed. In this case the Peak series exposed below the thrust plane may be considered to be a fault slice. This abrupt change in the character of the thrust plate which would appear to have the same elevation on both the north and south ridges, does not seem reasonable, although it is possible.

Other explanations involving these three faults, the Milner, Champion, and Sabies, will occur to the reader, but until more evidence is gathered concerning the age relations of these faults, no definite conclusions can be drawn, and it seems unnecessary to discuss them here. The most acceptable theory at present seems to be that the Sabies is the oldest, having been eroded from the north ridge due to its uplift along the Milner fault. The Champion fault, terminating abruptly at its intersection with the Milner, occurred simultaneously with the Milner, causing the block to the east to have been raised higher than that to the west. The thrust is believed to have been eroded from both of these blocks, however, it is possible that further investigation may show that the thrust is present west of the range crest, possibly on the slopes of White Mountain Peak. It is quite certain, however, that the thrust is nowhere present north of the Milner fault in the area mapped. The relations are shown in figure 17 below.

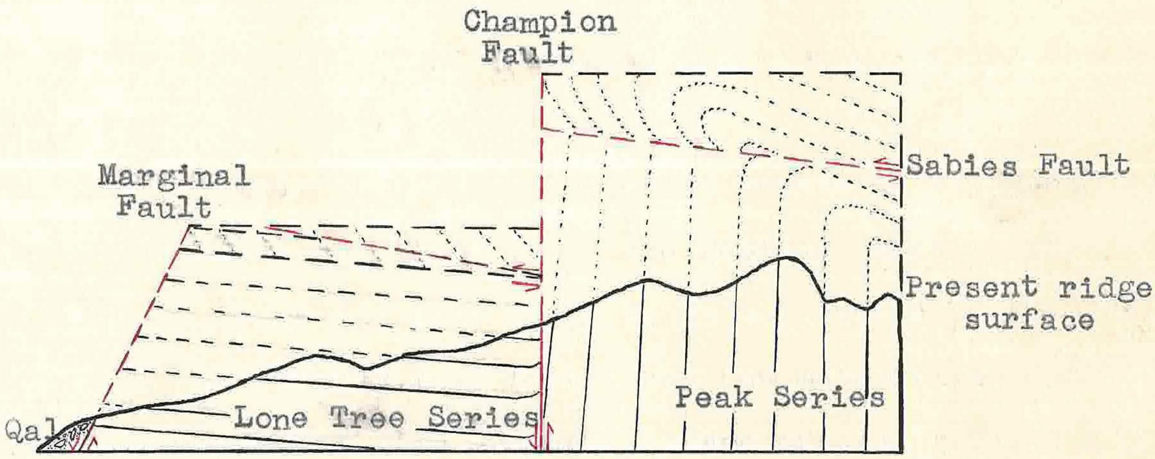


Figure 17.-- Diagrammatic section of ridge north of Milner canyon. Surface of page parallel to plane of Milner fault along which both blocks have been raised. (Scale: 2 in.=1 mi.; baseline 5,000 ft.)

GEOLOGIC HISTORY

The geologic history of the White Mountains as derived from the area studied is essentially that of a typical Basin and Range mountain mass. It compares favorably, for example, with the history given by Gilbert (G) for the Wasatch Range, by Louderback (L) for the Humboldt Range, by Lindgreen,(M), Turner (P), and others for the Sierra Nevadas. From the limited nature of the area mapped, there are of necessity great gaps in the story, but in general the history determined for the portion of the White Mountains herein discussed fits into the general scheme of the history of the Basin and Range Province, of which the White Mountains are a part.

The physiographic history of the White Mountains has been described by Anderson and Maxon (D). The geologic history of a portion of the range has been built up in the course of the preceeding pages. It remains only to collect the material, already discussed separately, to give a clear picture of the whole. In view of the rather complete discussions which have preceeded, it seems unnecessary to go into much detail and the history will be given below in a brief outline form.

Recent	Erosion and development of semi-arid climate--- probably continued movement along marginal faults
	Period of volcanic activity
Pleistocene	Erosion, glaciation, building of alluvial cones with continued marginal faulting and alternation of humid and arid climate leading to complication of cone structure

Early Quaternary & Late Tertiary	Initiation of block faulting and elevation of present range
Late Tertiary	Period of volcanic activity
Middle Tertiary & Early Tertiary	Period of erosion, stripping of pluton and formation of peneplain now preserved as range crest
Late Mesozoic or Early Mesozoic	Intrusion of Inyo Batholith (Pellisier Gr. ? (Boundary Peak Gr. (Quartz-diorite May be simultaneous or separate intrusions

Historical events between pre-Cambrian and Mesozoic unknown
No Paleozoic nor Mesozoic sediments exposed in area
Folding and faulting of pre-Cambrian sediments may have gone on during this time. Diastrophism not dated---- may be pre-Cambrian, Paleozoic, or Mesozoic.

Pre-Cambrian	Deposition of sediments (Reed dolomite (McAfee series (Lone Tree series (Peak series--volcanism Periods of erosion and possibly diastrophism between periods of deposition.

P L A T E S

PLATE I

INDEX MAP

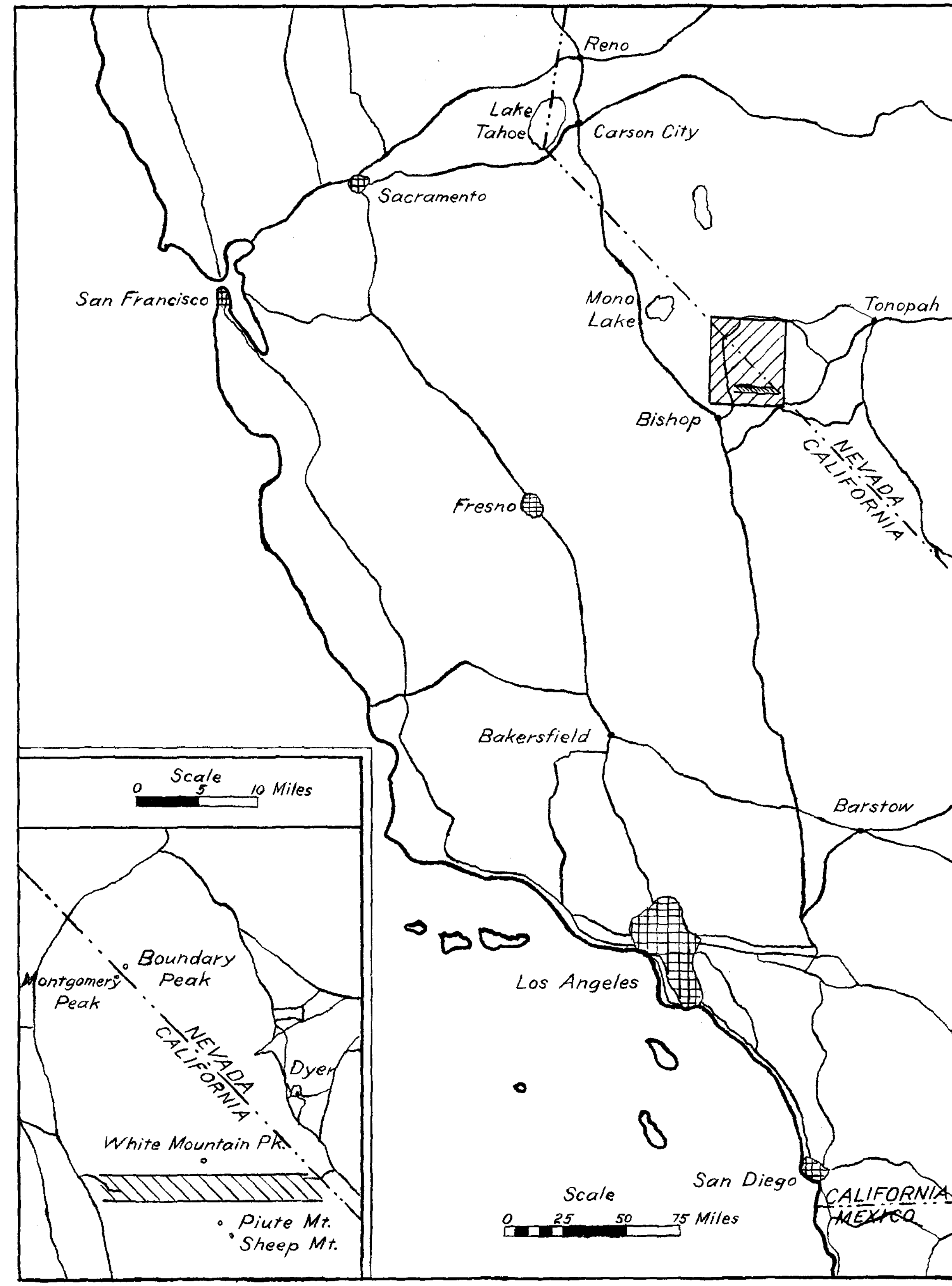
LEGEND

Inset-map of White Mountain Quadrangle

——— Roads

▨ White Mountain Quadrangle

Thesis area



INDEX MAP

PLATE II

STRATIGRAPHIC COLUMN

STRATIGRAPHIC COLUMN

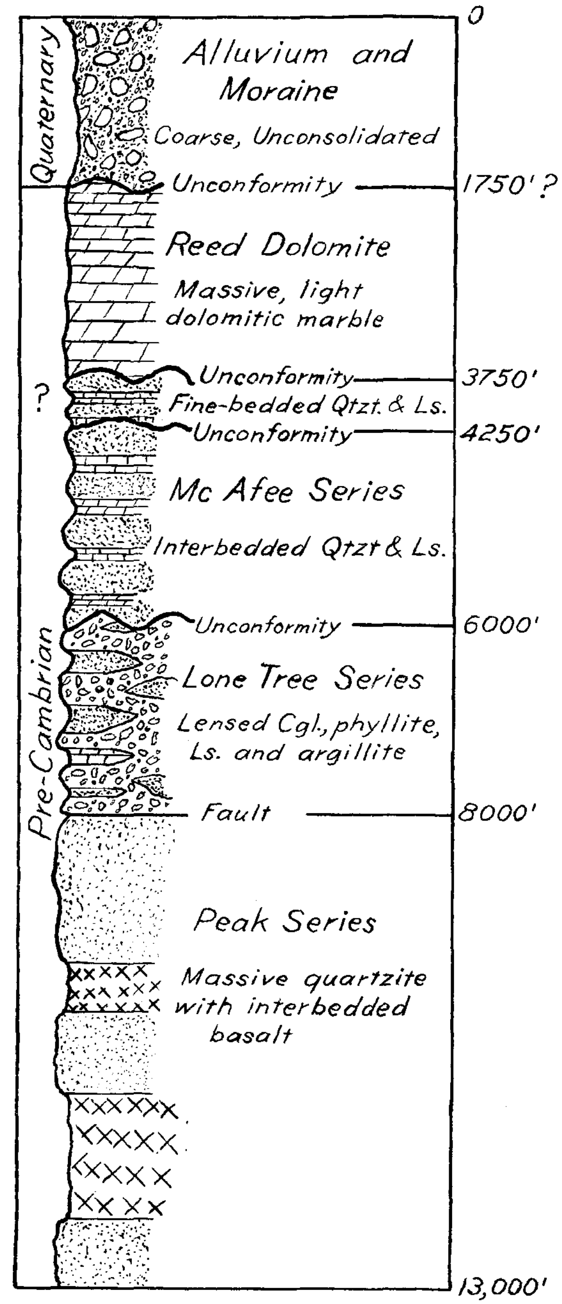


PLATE III

STRUCTURE SECTIONS

LEGEND

SEDIMENTARY ROCKS

Quaternary

Qal — Aluvium (unconsolidated fine & coarse gravels)

Qm — Moraine (unconsolidated glacial till)

Pre-Cambrian

rd — Reed Dolomite (massive, coarse, dolomitic marble)

ql — Finely interbedded quartzite & limestone

ms — McAfee Series (dark quartzites, light limestones & dolomites)

lt — Lone Tree Series (lensed conglomerates, phyllites, argillites, & limestones)

ps — Peak Series (massive buff quartzite & interbedded basalt)

IGNEOUS ROCKS

Recent

Qb — Basalt (young basalt flows)

Quaternary

Tb — Basalt (agglomeratic, massive, and vesiculm basalt)

Middle Mesozoic or Late Mesozoic

ic — Igneous Complex (mixture of Pellisier & Boundary Peak granites)

pg — Pellisier Granite (porphyritic, dark granite)

bp — Boundary Peak Granite (fine-grained, light granite)

qd — Quartz-diorite (coarse, dark, massive quartz-diorite)

———— Contacts

-------- Contacts (uncertain)

Faults

Faults (uncertain)

Fault zone

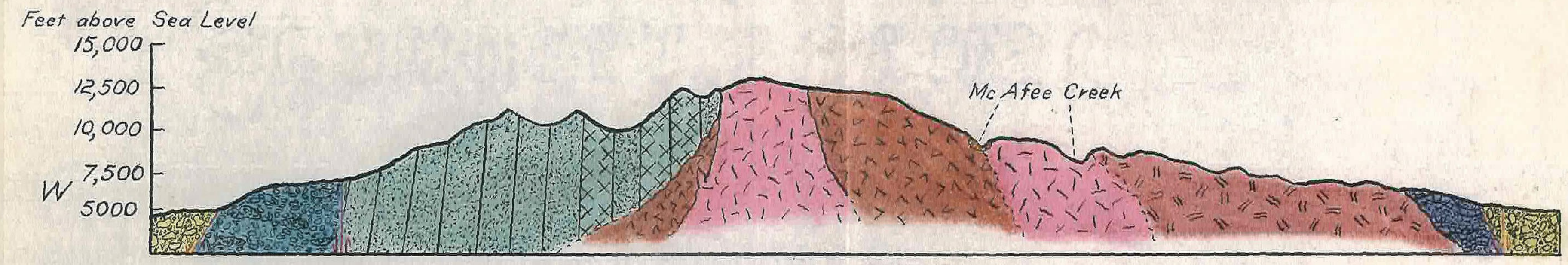
40° Attitude of sediments

PLATE IV

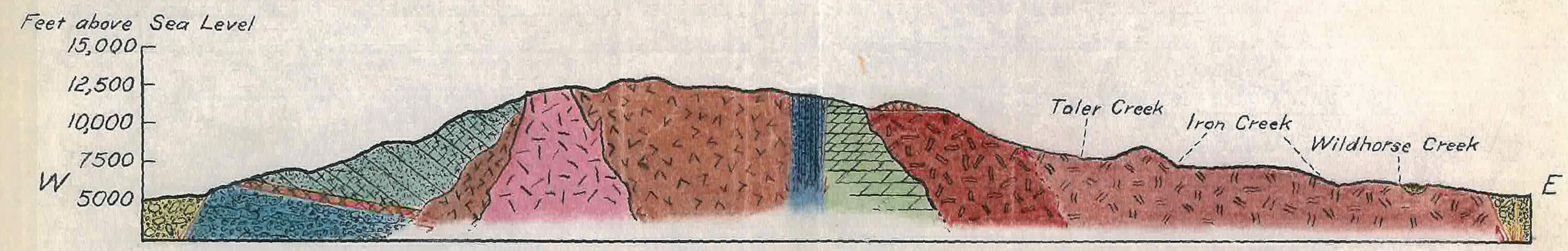
GEOLOGIC MAP OF SECTION ACROSS WHITE MOUNTAINS, CALIFORNIA

(Legend same as plate III)

STRUCTURE SECTIONS



Section A A'



Section BB'

Scale

$\frac{1}{125,000}$