Frontispiece

White Mountain Peak from Fish Lake at Sunrise

GEOLOGY OF THE NORTH HALF OF THE WHITE MOUNTAIN QUADRANGLE CALIFORNIA-NEVADA

by

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Abstract

The White Mountain range, the principal topographic unit of the White Mountain Quadrangle, is an up-faulted block between two relatively depressed areas. It differs from the ordinary basin range block in that it is a tilted horst. The marginal faults of the horst are of unusual complexity.

Physiographically, the range is in the late youthful or early mature stage of the arid cycle of erosion. Glaciation has complicated to some degree the normal development of the cycle. Renewal of uplift by faulting appears to have taken place in recent times.

Upon the crest of the range are remnants of land surfaces of low relief, formed, probably, by erosion before the block faulting which uplifted the range. These surfaces are designated herein as the "Pellisier Erosion Surface" and the "Sub-summit Oldland." It is probable that both were formed in the same cycle of erosion.

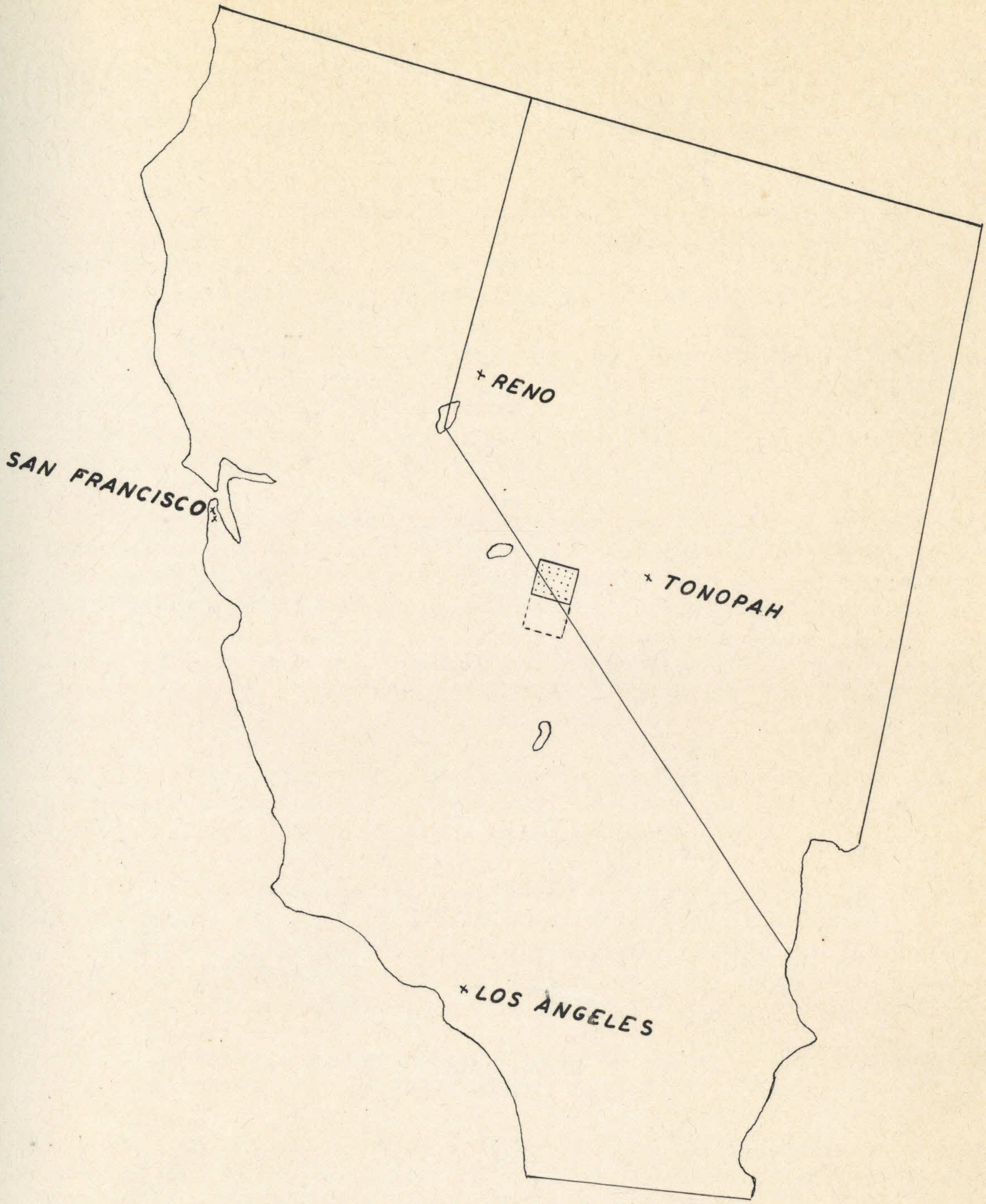
The core of the range is a granite batholith, intrusive into Cambrian or pre-Cambrian sedimentary rocks, chiefly calcareous and argillaceous in composition. For this ancient sedimentary series the name "McNett Formation" is proposed. It is non-fossiferous but on the basis of its lithology it is considered to be the equivalent of a thick series of dolomites and "green knotted schists" which Turner described as underlying the lowest fossiliferous Cambrian in the Silver Peak Quadrangle.

The contacts of the intrusive and the ancient sediments are everywhere characterized by intense contact metamorphism. This is described in some detail in the section on petrography.

Overlying the older rocks is a volcanic series of Tertiary age. These are chiefly rhyolites with some andesites. They include flows and pyroclastics. Vertebrate remains discovered in playa deposits closely associated with the extrusive rocks indicate that the latter were accumulated in part during the upper Miocene and lower Pliocene.

The most recent igneous rocks in the area are Quaternary basalts which cover much of the northern part of the quadrangle.

In the petrography section of this thesis, separately paged and indexed, are to be found descriptions and discussions of certain types of alteration affecting the rocks of the batholith on an enormous scale. These alterations, believed to be of hydrothermal origin, include the albitization of the potash feldspars and the development of a replacement texture closely resembling cataclastic texture but distinguished from the latter by its corrosive pattern and by the formation accompanying it of a large number of minerals not present in the original rock.



INDEX MAP OF CALIFORNIA AND NEVADA
SHOWING LOCATION OF AREA DESCRIBED
IN THIS REPORT

INTRODUCTION

PURPOSE OF THE STUDY.

The field investigations and laboratory studies upon which this report is based were undertaken as a thesis problem for the degree Doctor of Philosophy at the California Institute of Technology. The area investigated was selected because of the varied and important geological features which it exhibits and because of its significant location and relationships. The region possessed an added attractiveness by virtue of the fact that few, if any, studies of a geological nature leading to publication had previously been carried on within it.

FIELD WORK AND ACKNOWLEDGEMENTS:

A brief reconnaissance of the northern half of the White Mountain Quadrangle was made by me in the latter part of the summer of 1929. Field studies were resumed early in July 1930 and were continued through the summer of 1931 and a part of 1932. Altogether about eight months were spent in active field work.

In a region as rugged and as difficult of access as that covered by this report, field work is necessarily very expensive. Because of this fact and because

of the importance of the undertaking, the Division of Geology and Paleontology of the California Institute of Technology rendered financial assistance to the extent of contributing half of the field expenses for the summers of 1930 and 1931. The total amount granted by the Institute, for which I desire to express sincere appreciation, was approximately $530.00. The other half of the expense involved in the field work during these two summers, as well as the whole amounts for the summers of 1929 and 1932, was borne by me.

Many persons have assisted in one way or another in the field and laboratory studies upon which this report is based. To mention them all would make a very long list. Naturally I feel especially grateful to the members of the staff of the Division of Geology and Paleontology of the California Institute of Technology under whose guidance the work was executed. Dr. J. P. Buwalda, Chairman of the Division, Dr. F. L. Randsome, Professor of Economic Geology, and Dr. Ian Campbell, Assistant Professor of Petrography and Petrology, each spent a week in the field. Dr. Rene Engle, Instructor in Mineralogy, made a trip to the area in September of 1931. Mr. Willis P. Popenoe, Curator of Imvertebrate Paleontology, spent several days assisting in a search for fossil remains. I have repeatedly discussed various phases of the problem with all of the staff members mentioned abd also with Dr. Chester Stock, Professor of

Vertebrate Paleontology, and with Dr. William Morris Davis, Professor of Physiographic Geology, and have received much helpful advice and constructive criticism from all of them. Dr. Campbell and Dr. Engel have been especially closely in touch with the laboratory phases of the investigation. Dr. Thomas B. Nolan, Associate Geologist, United States Geological survey, spent several days in the area with me in September, 1930, and offered many helpful suggestions.

During July and August of 1930 Mr. Roland Hodder, a graduate of the Division of Geology and Paleontology of the California Institute of Technology, acted as field assistant. During the first two months of the summer of 1931 similar services were performed by Mr. Andrew Crofut, formerly of the University of Nevada, and by Mr. Royce Martin, my nephew. All of these gentlemen contributed very materially to the success of the undertaking. Certain parts of the work, indeed, could not have been completed at all without their help. Moreover, the conduct of the investigation was rendered very much more pleasant than it might otherwise have been by their cheerful companionship and by their goodnatured assistance in many trying situations.

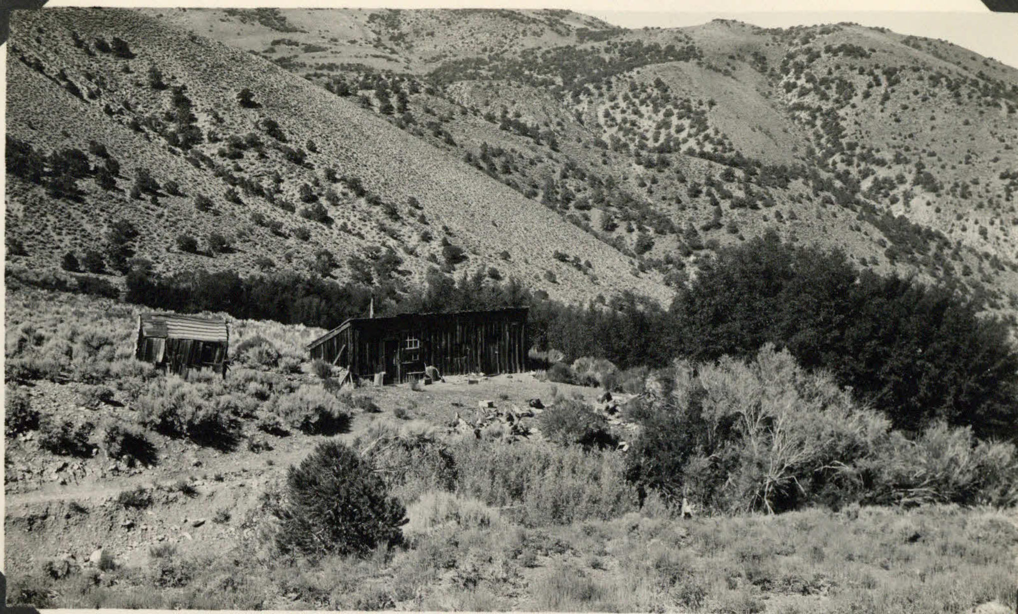
Owners, operators and watchmen of several mining properties gave assistance in many ways. Special mention should be made of J. L. McKinney, Art Gibbs, J. W. Johnson, George Dunnigan of the Red Rock Quicksilver Mine and C. H. Vaughan of the B and B Quicksilver Mine. I was also the

PLATE I

Description of Plate I

A. This miner's cabin, located at an elevation of about 8 000 feet in Queen Canyon, was used as headquarters by the geological party during the summer of 1930. During October of the same year Dr. F.L. Ransome and G.H. Anderson were snowbound for four days in this cabin.

B. Montgomery and Boundary Peaks (right and left respectively) as seen from Truman Meadows northeast of the Pellisier Ranch. The California-Nevada boundary passes through the saddle between the two peaks.



recipient of many kindnesses from the residents of the Chiatovich and McNett ranches, from William Symons of the Cinnamon ranch, from Richard Conway of the Pellisier ranch and from S. W. Tyner, proprieter of the store at Benton Station.[1]

LOCATION AND SIZE OF THE AREA:

The White Mountain Quadrangle lies on the boundary line between California and Nevada, about one-third of the distance from the point where the line leaves Lake Tahoe to the point where it reaches the Colorado River. The northernmost part of the quadrangle lies almost due east of San Francisco and slightly south of west from Tonapah. The Mt. Diablo base line passes about eight miles south of the northern boundary. The portion of the quadrangle studied in preparation for this thesis measures about 27.75 miles in an east-west direction and 17.75 miles north and south. The total area covered, then, is slightly over 492.5 square miles. About 110 square miles lies in the State of California; the remaining 382 square miles is in Nevada.

TRANSPORTATION AND COMMUNICATION:

A narrow gauge railway operated by the Southern Pacific Company between Mina, Nevada, and Keeler, California,

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1. Benton Station should be distinguished from Benton, which lies four miles to the west in the Mt. Morrison Quadrangle.

(Nevada and California Railway) traverses the northern and western portions of the quadrangle. At Owenyo, near the south end of Owens Valley, this railway makes connections with a broad guage line to Los Angeles via Mohave. At Mina it connects with the Tonapah and Goldfield branch of the Southern Pacific. Semi-weekly service is maintained on the narrow gauge between Laws, California, and Mina, Nevada. A mixed passenger and freight train leaves Laws for Mina on Tuesdays and Fridays and makes the return trip on Wednesdays and Saturdays.

Few good roads or trails are to be found in the quadrangle. An automobile road parallels the railroad from Laws to Mina. Within California this road is maintained as a secondary highway and most of this portion is gravelled and oiled. From the Nevada state line to Mina, however, it is not oiled and at times it is much corduroyed and very dusty. At Basalt, Nevada, just north of the northern boundary of the quadrangle, one may turn from this road to a branch leading into Fish Lake Valley. Although the latter receives no systematic attention and consequently is rough and in poor condition, it is usually passable in summer for automobiles. Occasionally it is washed out by cloudbursts. Formerly Fish Lake Valley could be more conveniently reached by a steep but otherwise very good road from Basalt to the B and B Quicksilver Mine, built and maintained by the B and B Company. Since this mine was closed in June, 1931, however, the road has not been kept in good condition.

Description of Plate II

A. Montgomery and Boundary Peaks as seen from the point at which the Benton Station-Montgomery Pass road crosses the California-Nevada boundary. Morris Canyon is in the middle ground.

B. The Benton Range (right distance) and the Sierra Nevada (left distance) as seen from Truman Meadows.

An automobile road from Big Pine, California, to Tonapah, Nevada, crosses the Inyo Mountains at Westgaard Pass, a short distance south of the southern boundary of the White Mountain Quadrangle. This road is usually in very good condition though the part over Westgaard Pass is steep and sometimes very rough. At Oasis Ranch at the southern end of Fish Lake Valley one may turn from this road to a fairly good dirt road, passable for automobiles, leading to Fish Lake Valley points.

Except for the Laws-Mina Road over Montgomery Pass there are no east-west roads of any description crossing the White Mountain Quadrangle. To journey from Benton Station near the western margin of the quadrangle to the Chiatovich ranch in Fish Lake Valley just twenty-two miles due east, one must travel ninety miles over very rough roads. The straight line distance from the Comanche Mine on Blind Spring Hill to the Dyer Ranch in Fish Lake Valley is twenty-four miles but the shortest road distance is more than one hundred miles. Short roads lead from the main highway to the mouths of the principal canyons on the west side of the White Mountain Range and similar ones penetrate short distances into the canyons on the east side. With only one or two exceptions, however, these roads are nearly or quite impassable for automobiles.

Two or three trails exist which may be followed on foot or on horsebacj. None of these, however, cross the main portion of the White Mountain Range. One of the most useful of these trails is one which leads from Queen Canyon, the prominent northwest-southeast trending canyon on the northwest flank of the range, across a ninety-seven hundred and fifty foot pass down into Trail Canyon and thence to Fish Lake Valley. If one has a camp in Trail Canyon he can keep his car in Queen Canyon and by a walk of an hour and a half over this trail he can save a drive of seventy miles to Benton or Bishop for supplies. During a portion of one summer I kept my car and most of my supplies at a cabin near the mouth of Queen Canyon and used pack horses to transport provisions and equipment from this point to camping places in the canyons on the east side of the mountains.

By means of another trail which leads up Indian Creek from the McNett Ranch on the east side of the range (unfortunately there are two creeks bearing this same name in the quadrangle) one may get a pack train up to Pellisier Flats, the high plateau which occupies a large part of the summit region of the White Mountains. This trail affords the only route by which supplies and equipment can be transported for work necessitating an extended stay on the crest of the range anywhere north of White Mountain Peak.

A third useful trail extends from Trail Canyon along the Candelaria Pipe Line to Gold Hit (now deserted) and from there by way of the Tip Top Mine (completely abandoned) to Mt. Montgomery.

PLATE III

Description of Plate III

Deserted Indian Hut near Truman Meadows.

From the Pellisier Ranch a fourth trail leads into the mountainous area which occupies the extreme northwest portion of the quadrangle. It is possible to drive a car as far as Truman Meadows, the only place in this region where water for camping is available but the trip is not to be recommended unless necessity demands it.

Mail communication is slow and uncertain. There is a post office at Benton, four miles to the west of Benton Station, and another at Mt. Montgomery. Mail is received at these two offices twice each week from the north and twice from the south. In Fish Lake Valley the post office of Arlemont, Nevada, is located at the Chiatovich Ranch. Mail is received here by stage three times each week but as most of the mail sent here seems to have a roundabout routing the service is slow. Supplies ordered from Los Angeles were never received in less than two weeks, though the road distance between the two points is something less than three hundred and fifty miles.

The only telegraph office in the area is at Mt. Montgomery, Nevada, in the extreme northern part of the quadrangle. There are no telephone lines anywhere in the quadrangle.

POPULATION:

Although no exact figures are available, a fair estimate places the total population of the northern half of the White Mountain Quadrangle at less than one hundred at the time this report is written and considerably less than twice that number for the entire quadrangle. There are no towns in the area. Benton Station has only a store and a garage. At Mt. Montgomery there is a small store and a railroad station. A post office is located in the store. Another small store and a railroad station are at Queen. A post office is to be found at the Chiatovich Ranch but no store. Gasoline may be purchased at Benton Station, at Queen, at Mt. Montgomery and at the Chiatovich Ranch. During the summer of 1932 prices ranged from 24 cents a gallon at Benton Station to 35 cents a gallon at the Chiatovich Ranch.

The nearest town of importance is Bishop in Owens Valley, thirty-six miles south of Benton Station and fifty miles south of Mr. Montgomery. Most of the ranchers in Fish Lake Valley obtain their supplies in Tonapah, some seventy miles to the east of Mt. Montgomery.

INDUSTRIES:

Stock raising is at present the chief industry of the northern half of the White Mountain Quadrangle. Several thousand head of sheep graze upon the public ranges of the Inyo National Forest. Until recently, however, mining was an important industry. The Comanche Mine south of Benton Station, the Queen Mine in Queen Canyon and the Tip Top Mine south of Sugarloaf Mountain, were all important producers of ores of gold, silver and other minerals a few years ago. More recently a number of quicksilver mines have been profitably operated along the east front of the White Mountains. Among these were the Red Rose, the B and B and the Red Rock. At the time of writing this report, however, no mines in the district are being operated on a productive basis. Each of the mines will be described in detail in the portion of the paper devoted to economic geology.

SURFACE FEATURES:

Many of the features to which attention will be briefly directed in this section have important geologic significance and in such connection will be discussed later in much more detail.

By far the most prominent geographic feature of the area is the White Mountain Range. It trends in a northwest-southeast direction across the quadrangle, the northern end occupying virtually all the central part of the northern half of the quadrangle. The great height and extreme ruggedness of this mountain mass make it a most imposing spectacle and if it were not overshadowed by the still higher and grander Sierra Nevada not far away, the range would undoubtedly be noted for its scenic attractions.

The White Mountains form with the Inyo Range a continuous chain 110 miles long, extending from Montgomery Pass southward to the lower end of Owens Valley. The line of de-

PLATE IV

Description of Plate IV

A. View from the scarp northeast of Morris Canyon. The Pellisier Ranch is in the right middle distance; far beyond are the Sierra Nevada in the vicinity of Mono Lake. The camera is pointed northwest.

B. Boundary Peak from the north, showing pinnacles arising from jointing. The camera is at an elevation of about 10 000 feet.

markation has usually been placed along the road from Big Pine to Saline Valley over Waucoba Pass. On neither structural nor geographic grounds does there seem to be any good reason for thus separating the range into two divisions designated by different names. I heartily concur in the view expressed by Knopf that the entire range should be known by a single name and that the term "Inyo Mountains" is much more distinctive than "White Mountains" and therefore to be preferred.[1] The name "White Mountains" has, however, become so thoroughly established in local usage and in published references that it seems best for the sake of avoiding ambiguity to retain it in this report.

Reference has already been made to the great height and ruggedness of the White Mountains. It is not generally realized that White Mountain Peak in the southern half of the quadrangle has an altitude of 14,242 feet, little less than Mount Whitney, the highest mountain in continental United States. At the northern end of the range, within the area covered by this report, are Mount Montgomery (13,442 feet) and Boundary Peak (13,145 feet). The latter is one of the highest peaks in Nevada.

A large part of the summit region of the range is occupied by a gently undulating plateau, narrow to the north,

1. Knopf, A. - A Geologic Reconnaissance of the Inyo Range and the Eastern Slope of the Southern Sierra Nevada - U.S.G.S. Prof. Paper 110. 1918, p. 17.

broadening to the south of White Mountain Peak. This plateau is highest at its extreme northern end where (at a point about two and a half miles south of Montgomery Pass) it attains an altitude above sea level of 13,545 feet. It slopes southward at an average rate of about 380 feet per mile to a saddle about five miles north of White Mountain Peak where its elevation is 11,200 feet. In this saddle two streams rise within half mile od each other, flow parallel northward for about a mile, separated only by a low ridge and then, making almost right angled bends, turn to flow opposite directions, the one down the east slope, the other down the west slope of the range. The behavior of these streams as well as the existance of the broad saddle in which they originate undoubtedly is governed by structure.

From the saddle mentioned above to White Mountain Peak the plateau rises rapidly. For three or four miles north of that peak it is discontinuous, fragments being preserved on several of the higher summits. It appears likely that the plateau has been broken up into block by transverse faulting in this region, the blocks being successively uplifted to the south. South of White Mountain Peak the plateau again becomes continuous, resumes its southward slope and greatly broadens.

On the east slope of the mountains, just south of the area mapped, the plateau occupies the interstream ridges where it may be clearly observed to extend without interruption transecting the older sedimentary rocks for four or five miles east of the crest of the range. Viewed from the high peaks above, this portion of the plateau, gently undulating, mostly grass covered but with little clumps of timber scattered about, could almost be imagined to be a little fragment of Iowa or southern Ohio transplanted to these western mountains.

In extreme contrast to the modulated character of the plateau just described is the steep, rugged westward-facing front of the range. Bare rocks, high cliffs, precipitous slopes, narrow V-shaped canyons with steeply inclined stream beds here dominate the topography. Falls are abundant and the canyons are choked with brush and debris. To climb to the crest of the range from the western margin, even on foot, is always difficult, usually dangerous and in places impossible. Horses or pack animals cannot be used.

A few figures may be cited to show the steepness of this slope. At the mouth of Rock Creek on the western mountain front in the extreme southern part of the area mapped, the intersection of scarp and fan is at an elevation of 6200 feet. If starting from this point one were to attempt to ascend to the summit plateau by the shortest possible route without regard to obstacles. he would proceed in a northeast direction and, covering a horizontal distance of 16,000 feet, approximately three miles, he would attain the edge of the plateau at an elevation of 13,200 hundred feet - that is, in a horizontal distance of three miles he would have climbed 7,000 feet or at the rate, approximately, of 2300 feet per mile. This is

PLATE V

Description of Plate V

A. Monarch of all he surveys! The mountain sheep stands on a ridge just north of White Mountain Peak. The camera is at an elevation of 14 000 feet.

B. The White Mountains from the east in October. Montgomery and Boundary Peaks are at the right. To the left may be seen the edge of the Pellisier erosion surface.

the steepest part of the mountain front but not very much steeper than any other slope between Rock Creek and Morris Creek. The stream gradients are also very steep, most of them being above 1000 feet and some even 1200 feet to the mile.

The eastern slope of the main mountain mass presents a quite different aspect. The descent from the crest of the range to Fish Lake Valley is longer and more gradual than the one to the west. If one descends the ridge between Chiatovich Creek and Middle Creek from the 13,545 foot point on the edge of the plateau to the mountain base he loses 6500 feet of altitude in about seven miles or about 930 feet to the mile. This is not far from the average for the eastern front. The stream gradients are also less; that of Chatiovich Creek averages about seven hundred feet to the mile. The canyons are broader floored and they contain no water-falls.

The impression must not be gained, however, that the eastern mountain front is ill-defined or even sinuous. On the contrary, from the mouth of the canyon of Middle Creek south, the line of intersection of the mountain slope with the alluvium rising against it is distinct and almost straight.

Northeast of a diagonal line extending from the mouth of Queen Canyon to the mouth of Trail Canyon the topographic character undergoes a marked change. In general there is a loss of regularity observable in many things - in slope, in direction of drainage, in stream pattern and, on the east side, in mountain front. As may be inferred, this is a reflection of the changes both in structure and in the character of the rocks.

Immediately to the west of the White Mountains is a trough-like depression which seems to have received no appellation either on the maps or in local usage. For this depression, which geographically may be considered to be an arm of Owens Valley, the term "Pellisier Valley" is proposed and will be applied provisionally in this thesis.

At its lower extremity Pellisier Valley opens into Owens Valley proper. Throughout its entire length the steep front of the White Mountain forms its eastern wall. Its western border is not so uniform. In its southern part the margin is marked by the ermergence from beneath the valley floor of the tuffs, flows, breccias and comglomerates which form the volcanic tableland to the west. In the northern part of the quadrangle, however, a decided difference in structure becomes apparent. The steep fault scarp of Blind Spring Hill forms a striking western wall intersecting farther north another somewhat less abrupt scarp, trending northeast, which forms the margin of the lava-covered mountainous region covering the extreme northwest corner of the quadrangle.

To the east of the White Mountains is another deep depression, narrow in the south but broadening greatly to the north, known as Fish Lake Valley. The shape of the valley is that of an asymmetric basin. Its bottom slopes steeply from the west, very gradually from north and south to a series of marshes and ponds, collectively known as Fish Lake, which at an elevation of 4,084 feet lies near the eastern border of the quadrangle.

At its northern end the valley is brought to a somewhat abrupt termination by a group of hills, many of which are brilliantly colored and which here and there are carved by erosion into fantastic shapes. To a portion of this group the term "Volcanic Hills" has been applied on the map but as a substitute to cover the entire group the name "Esmeralda Hills" is here proposed and will be provisionally used in this thesis.

CLIMATE:

The climate of the White Mountain Quadrangle is characterized by relatively low precipitation and by both high diurnal and high annual temperature changes. Both precipitation and temperature vary with altitude. Fish Lake Valley is very arid, receiving little snow in winter and almost no rain in summer. Pellisier Valley is somewhat less arid on account of its more favorable position in respect to the mountain range. Both valleys are hot in summer, temperatures above 110 degrees occurring frequently. Winters, however, are usually not extremely cold.

The White Mountains receive less snow in the winter than might be expected in view of their great height. The explanation is to be found in their location to the east of the highest part of the Sierra Nevada. From the southern end of the Inyo Range to the northern end of the White Mountains, however, there is a very marked increase in the amount of precipitation. This is in part due to the decrease in the height of the Sierra Nevada in the same direction. Though far below that of points of corresponding latitude in the Sierra Nevada, the snow fall in the region of Mount Montgomery, for example, is in ordinary years by no means inconsiderable. It is not possible to give definite figures for either precipitation or temperature, however, for no records have ever been kept, so far as could be learned, any where in the area.

During the summer months extremely heavy rains are not unusual in the mountains, at times reaching the proportions of "cloudbursts". These may change the mountain streams into muddy torrents which tear out great channels down the fans and may occasionally wash out roads, bridges and railway tracks. Snow may fall any month in the year on the higher summits and on the crest of the range there are few nights when the temperature does not descend below freezing.

WATER SUPPLY:

South of a line extending from the mouth of Queen Canyon to the mouth of Trail Canyon there is no lack of water for camping purposes, for the watering of stock or for mining uses. Down both slopes of the range rushing streams carry water brought by the storms of winter and summer down into the valleys where it is eagerly appropriated by the ranchers and

PLATE VI

Description of PLATE VI

A. The east front of the White Mountains just north of Indian Creek, at sunrise. The McNett ranch is just beyond the trees in the center of the view.

B. A segment of the Montgomery fault scarp as as seen from the road northeast of Benton Station. Morris Canyon is to the left.

used for irrigation . In general it may be said that the streams of the eastern slope are longer and larger than those of the western one. The water is of excellent quality, clear, cold and usually very soft. It may be drunk without fear of contamination, for at present there are no permanent inhabitants in the canyons and campers are very few.

In other parts of the area water is much less abundant and the problem of securing adequate supplies for camping purposes becomes a serious one for the geologist. In the hilly region in the northeast corner of the map, designated above as the Esmeralda Hills, there are no streams that flow in summer and so far as is known to me there are only two springs. One of these is Sand Spring, shown on the map about half way between Mount Montgomery (the station) and the Chiatovich ranch on the Fish Lake Valley road. The other one, which is of very dubious quality, is to be found on the eastern border of the quadrangle six miles north of the Mount Diablo base line.

In the triangular-shaped area lying between the Mount Diablo base line, the western mountain front and the Fish Lake Valley road, water is exceedingly scarce. The stream shown as flowing into Trail Creek just northwest of Wildhorse Flat is no longer a perennial stream, nor does Trail Creek contain any water in the lower part of its course in summer time. There are few springs and in most of them the water is highly alkaline. There was formerly a good spring at Gold Hit (deserted) but when last visited in the summer of 1931 it was completely dry. A small spring is to be found about a mile north of Sugarloaf Mountain and there is another about a mile southwest of the Tip Top Mine on Mineral County-Esmeralda County boundary line. In Queen Canyon one may find a good spring and also a small stream of water. With the exception of the last named, however, none of the springs in this part of the area can be reached by road or trail.

In the rough lava-covered region in the extreme northwest corner of the quadrangle the only water available for camping purposes is to be found at Truman Meadows. As the name implies, this is a beautiful little mountain meadow with an abundance of excellent water and feed for pack animals. The chief drawback is to be found in the presence of countless hordes of mosquitoes which render the place almost uninhabitable. It may be remarked in passing that nowhere else in the area did I find mosquitoes present in sufficient numbers to trouble me.

A group of springs in the canyon just northwest of Queen Station give a large flow of excellent water, but they have been fenced by the Southern Pacific Company and their flow has been appropriated for its use.

In the valleys water may be obtained at the ranches or from streams that flow down the fans. At the south end of Fish Lake two miles south of the Dyer Ranch is a large pool in which water remains at a temperature of seventy-five or eighty degrees throughout the year.

FOREST COVER:

Plant growth in the White Mountain Quadrangle is very sparse in the lowlands but becomes more dense at intermediate elevations. The crest of the range is bare except for the presence of low shrubs and grasses.

Numerous varieties of sage and of grass are to be found at all altitudes. Between six and nine thousand feet pinon pines (Pinus monophylla) are to be found in great numbers, furnishing edible nuts which the Indians rely on for a large part of their winter food supply. From eight to eleven thousand feet fair stands of foxtail pine (Pinus balfouriana) and lodgepole pine (Pinus contorta) occur. Junipers (Juniper utahensis) are frequently found. Among the larger shrubs mountain or curl-leaf mahogany (Cerocarpus ledifolius) is the principal species.

In the canyon bottoms and in the vicinity of springs are found varieties of willows (Salix, various sp.), of red birch (Betula, sp.) and quaking aspen (Populus tremuloides).

FIELD METHODS:

The mapping of the area was done with the aid of a Brunton compass and an aneroid barometer. Locations were made on an enlargement of the White Mountain topographic sheet of the United States Geological Survey. Wherever possible positions were ascertained by resection from three or more known points, with a check by barometric observations. Frequently, however, especially in deep canyons, the resection method was not practical and reliance had to be placed chiefly upon barometric observations. This does not always yield accurate results, in part because of the difficulty of frequently checking the zero point on the barometer by observation at known elevations and in part because of certain errors in the base map.

In general the White Mountain topographic sheet is accurate and dependable. Some discrepancies exist, however, one or two of which were not noted in time to correct errors in mapping resulting from them. For example, the intersection of Middle Creek with Davis Creek is shown on the topographic sheet at an elevation of 6500 feet which is 900 feet above the elevation given for the McNett Ranch. In walking from the McNett Ranch directly to the point of confluence of these streams in only a little over an hour I observed a decided change in the zero reading of my barometer. At first this was attributed to an actual change in atmospheric pressure, but when afterward it was noticed that there was a corresponding opposite change when the barometer was carried from the second point back to the first, I began to suspect something was wrong. To test this I made a round trip as quickly as possible with the barometer. On returning to my starting point I found little change in the zero reading but the reading at the intermediate point was off approximately four hundred feet. Whether the elevation given at the McNett Ranch is too low or that of the point of intersection of the two streams is too high or if both are incorrect is not known.

I suspect that this or a similar error involves the entire part of the map north of Davis Creek or Middle Creek in respect to the part south of such a dividing line. In three summers of field work it was observed that the zero reading on fixed points in the northern part of the map were almost invariably two to three hundred feet lower than those in the southern part. This remained unsuspected as being the result of error throughout most of the field work for, in a rugged and lofth desert mountain range abrupt changes in atmospheric pressure are common and it is only after much experience in such a region that discrepancies of a constant nature are recognized. For this reason a careful check has not been made to determine if the elevations given for the northern part of the map are indeed too high.

An error of approximately fifty feet is also suspected for the Bench Mark at Fish Lake. The barometer was never found to check the marked elevation when carried directly to it from other known points.

Some of the prominent minor peaks on the crests of the ridges on the eastern mountain slope are also probably incorrectly located. Resection lines from these peaks always failed to pass through a common point of intersection with similar lines drawn from other known points.

PHYSIOGRAPHIC GEOLOGY.

PLATE VII

Montgomery Peak (13, 442 feet) and Boundary
Peak (13, 145 feet) from the northwest.

GENERAL FEATURES.

In its general physiographic features the White Mountain quadrangle is typical of the basin and range province. It consists essentially of an uplifted and tilted fault block between two relatively depressed areas, the whole being in the late youthful or early mature stages of the arid cycle of erosion. Rejuvenation due to renewal of uplift of the mountain block has to some degree interrupted the normal process of the cycle, while further complications have been added by the occurrence of volcanic activity in some portions of the area and by glaciation.

DRAINAGE.

BASE LEVELS:

Pellisier Valley is a part of the Owens Valley drainage basin. The waters which are discharged into it from the neighboring highlands ultimately find their way, if undiverted, to Owens Lake over one hundred miles to the south, which is, therefore, the temporary base level for the drainage area west of the White Mountain divide.

Fish Lake Valley, on the other hand, is an independent drainage basin, collecting and storing the waters discharged into it from the east slopes of the White Mountain range, from the west slopes of the Silver Peak range and from the volcanic highlands at its northern end. The lowest part of the basin within the White Mountain Quadrangle is at Fish Lake, a fresh water marsh which lies close against the base of the most westerly extension of the Silver Peak range. Its location is to be ascribed, in part at least, to the rapid growth of the great fans which have spread out from the base of the great range to the west, but it may also be due to the tilting of the valley floor to the east by downwarping or faulting. Fish Lake forms the temporary base level for the entire portion of the area lying east of the White Mountain crest.

Fish Lake Valley forms an interesting example of a desert basin which has become filled to such a point that it is about to spill over the lowest part of its rim into a lower basin - in this case, the basin occupied by the Columbus Salt Marsh to the north. In other words, an integration of drainage basins is about to occur.[1] Unfortunately exact data are difficult to present because the area to be considered is divided among four topographic sheets - the White Mountains, Silver Peak, Tonapah and Hawthorne sheets - which are on different scales ($\frac{1}{125000}$ for the first two and $\frac{1}{250000}$ for the last two.) Moreover, all elevations of the Silver Peak sheet are seventy-five feet too high.

As has been stated, the lowest point of Fish Lake Valley within the White Mountain Quadrangle is at Fish Lake at the tip of the projection of the Silver Peak range at the

1. Free, U. S. Dept. Agr., includes Fish Lake Valley in the Columbus drainage basin now. See Fenneman, N. M. - Physiography of Western United States, New York, 1931, p. 359.

east side of the area. The bench mark at this point gives the elevation as 4784 feet at the southern end. To the northeast, extending into the northwest part of Silver Peak Quadrangle is an arm of Fish Lake Valley which is occupied at its northern end by a second marsh about ten miles northeast of the first. The bench mark at The Crossing southwest of the Pacific Borax Company Mill (now abandoned) at the southern end of this marsh gives the elevation at the top of a small knoll rising above the valley floor as 4825 feet but this elevation is seventy-five feet too high.

The northern marsh is probably somewhat lower than the southern one, but the total difference in elevation between the two is certainly less than one hundred feet.

From The Crossing north to The Gap in the extreme northwest corner of the Silver Peak Quadrangle the total rise in elevation is also less than one hundred feet. The Gap itself forms the lowest point in the divide between Fish Lake Valley and the basin occupied by Columbus Salt Marsh. Its highest point is between 4700 and 4800 feet. There is a continuous slope downward from The Gap to Columbus Salt Marsh which has an altitude of approximately 4550 feet (bench mark at Columbus, Hawthorne Quadrangle.)

It is evident, therefore, that an increase in elevation of less than one hundred feet - probably less than fifty feet - in the floor of Fish Lake Valley will cause it to drain into Columbus Salt Marsh. The basin occupied by the latter is a comparatively small basin which is separated from the much larger one to the east known as Big Smoky Valley by a divide which is less than three hundred feet above the level of the marsh. In a relatively short time, geologically, unless diastrophic movements intervene, an extensive integration will take place as a result of which drainage from the entire east side of the White Mountain range will eventually reach Big Smoky Valley in Nevada.

STREAMS:

The streams which flow down the western face of the White Mountains are typical of those which drain a steep fault scarp of any tilted mountain block in an arid region - that is, they are fault scarp consequents. They present no features of unusual interest. Their average length from source to mountain front is less than four miles. Most of the perennial ones continue down the fans to join the intermittent axial stream that drains Pellisier Valley, unless sooner diverted for irrigating purposes; a few sink into the fans and disappear a short distance after leaving the mountain front. They flow in deep V-shaped canyons which are commonly choked with debris and in which falls and rapids frequently occur. The gradient is very high. The following table gives figures for the principal streams of the west and northwest slopes:

Stream	Average gradiant in feet per mile from source to mountain front.
Rock Creek	2000
Marble Creek (South Fork)	1730

PLATE VIII

Description of Plate VIII

A. Trail Canyon, formed by one of the consequent streams of the eastern slope. Montgomery and Boundary Peaks are in the left distance.

B. Lower Trail Creek, just above the "elbow", showing entrenchment. In the foreground are Quaternary volcanics. In the middle distance is a section of the Trail Canyon fan. On the sky-line are Quaternary basalts. The camera points almost east.

Montgomery Creek	900
Morris Creek (South Fork)	1200
Queen Creek	750

The streams of the eastern or back slope are also unadjusted to structure. In contrast to the streams of the western slope, they are longer and of less steep gradient; their canyons are wider and more open; falls and rapids are absent; they are commonly of greater volume. The following table gives their slopes:

STREAM	Average gradient in feet per mile from source to mountain front.
Middle Creek	
Davis Creek	790
Chiatovich Creek (North Fork)	700
Indian Creek	670

COMPLICATIONS:

In the entire northern half of the quadrangle Trail Creek is the only stream which appears to have had a history differing in any way from that of a normal consequent stream. It seems to have had an earlier course leading down the large fan which slopes to the southeast from the mouth of its canyon. At present, however, at a point about a mile below the apex of the cone it makes a sharp (nearly ninety degree) bend to the northeast and flows in a deep trench across Wildhorse Hills to Wildhorse Flat. (See Plate Vlll, B) This peculiar behavior seems to be due to the filling of the depression between Wild-horse Hills and the mountain front with alluvial material to

PLATE IX

Description of Plate IX

A. Deeply alluviated lower part of Middle Canyon.

B. Mouth of Davis Canyon, showing wide, flat floor.

such a depth that Trail Creek was able to find a new course for itself through a minor depression in the obstructing hills to the east, taking advantage, no doubt, of the channel of a previously existing northeast flowing stream. In a sense it may even be considered to have been beheaded by the latter.

The phenomenon is discussed more fully elsewhere. (See page)

Fault Scarps.

PLATE X

A part of Montgomery scarp. Rock Creek is at the left, Falls Canyon at the right. The mountain base is at 6 000 feet; the highest point visible is nearly 13 000 feet.

THE WHITE MOUNTAIN SCARPS.

THE WESTERN (MONTGOMERY) SCARP:

The rugged western slope of the White Mountain Range forms one of the steepest and most magnificent mountain scarps in America. Because of its greater remoteness from the chief lines of travel and the greater aridity of the region in which it lies it is not nearly so well known as the scarcely more lofty and steep scarp of the Sierra Nevada which faces it from across the trough-like depression to the west. Never-the less to the spectator who gazes at it from some point of vantage on the slopes of the Benton Range eight or ten miles to the west it presents a view that is both wild and magnificant. To an observer so situated the declivity seems almost a vertical wall, impossible of ascent, broken here and there by deep V-shaped canyons between triangular spur-end facets which are so perfectly aligned as to resemble doorways in the side of a building. (See Plate X)

The steepest and most abrupt part of the scarp is its northern half. Farther south it splits into two portions, a relatively low one to the west and a higher and steeper one a mile or two to the east; at the same time the mountain crest retreats to the east, producing a lengthening of the western slope and a reduction in its angle. North of Falls Canyon, on the other hand, there is but a single scarp and the crest of the range lies close to its western margin.

Some definite figures illustrating the steepness of

PLATE XI

Description of Plate XI

A. Looking south along the Davis scarp from a point just south of Indian Canyon. The camera is at 8 000 feet. Fish Lake Valley is to the left.

B. Looking south along the western slope of the White Mountain-Inyo Range. White Mountain Peak is to the left; Owens Valley is in the right distance. The camera is at 13 000 feet.

the slope may be of interest. The ridge between Falls Canyon and Rock Creek has an average slope of twenty-seven and a half degrees; the base of the mountain here is at 6000 feet, the crest at 12,900. Between Rock Creek and Queen Dicks the slope averages twenty-four degrees. Between Marble Creek and Montgomery Creek from the base to the 11,460 foot peak it is twenty-five degrees.

The above are average figures for the slopes from the base of the range nearly to the crest. Several places may be found at the base of the range where the average slope for 1500 to 2500 feet exceeds twenty-nine degrees.

It may be of interest to compare these slopes with those of the steepest part of the Sierra Nevada Scarp. For the Round Valley Scarp George Taylor gives degrees as maximum angle of slope.[1]

The angle of inclination of a part of the scarp west of Owens Lake Knopf states to be twenty-five degrees but he does not state how much of the slope was included to give this figure.[2]

Southwest of Independence particularly steep and lofty faceted spurs occur, one of which, selected at random, was found to have a slope of twenty-six and a half degrees between the elevations of 6000 feet (base of the range) and

1. Doctor's thesis, Division of Geology and Paleontology, Institute of Technology, 1933, unpublished Mss.
2. Knopf, A. U.S.G.S. Prof. Paper 110, p. 76, 1918.

10,000 feet (top of facet).

The above figures, however, are not strictly comparable to the ones we have quoted for the White Mountain scarp. The latter, it will be remembered, were averages for the entire slope from mountain base nearly to the crest of the range, while those which have just been quoted, on the contrary, are for the lower and therefore steeper parts of the slope. To obtain a better basis for comparison it may be said that from the highest point on the fan west of Lone Pine to the summit of Mount Whitney is five miles horizontally and 8000 feet vertically; the average angle of slope is somewhat less than seventeen degrees.

Not only is the west-facing scarp of the White Mountain range, hereafter designated as the "Montgomery Scarp", steep and rugged but it is also of great height. The maximum relief is in the neighborhood of White Mountain Peak (14,242 feet) which rises very nearly 10,000 feet above a point only eight miles to the west. Farther north the crest of the range lies only three or four miles east of the western base; corresponding differences in elevation along east-west lines are between six and seven thousand feet. For example, east of the Taylor Ranch the horizontal distance from the base of the range at 6500 feet to the highest point on the crest at 13,545 feet is four miles; the difference in elevation is slightly over 7000 feet. (See Fig. XI-B. and Plates XII and XIII, A and B)

Comparing again with the Sierra Nevada slope we find that the maximum relief for minimum distance is between

PLATE XII

Description of Plate XII

A. The Montgomery scarp between Montgomery Canyon (beyond the ridge at the extreme left) and Marble Canyon (extreme right).

B. Another part of the Montgomery scarp, south of A. Marble Canyon is at the extreme left.

Mount Whitney and Lone Pine, where the difference in elevation is 10,774 feet in thirteen miles or between Mount Langley and a point eleven miles east where the difference is 10,332. Figures have been quoted above to show the difference between Mount Whitney and the mountain base, eight thousand feet in five miles.

The above figures not only give some conception of the great height and steepness of the Montgomery scarp but they emphasize how near it is in height and steepness to the great scarp of the Sierra Nevada which is, probably, the most magnificant in the United States.

THE EASTERN (DAVIS) SCARP:

On its eastern side the White Mountain Range terminates in a slope which, though less high and imposing than the one which so impresses the observer on the west, is nevertheless, abrupt and steep enough to be called a scarp.[1] In spite of the fact that three or four of the canyons which

1. The term "scarp" seems to have been derived by aphesis (loss of unaccented prefix) from "escarp" (Fr."escarpe") which originally was a military term applied to the side next the parapet of a ditch surrounding a fort. The word "escarpment" is also derived from a French word "escarpement", which originally meant the ground about a fortified place cut away nearly vertically to prevent hostile approach but by analogy was later extended to designate any steep slope, especially of considerable lateral extent. Blackwelder in his paper on the Recognition of Fault Scarps (Journ. Geol. Vol. 36,1928,p. 293) states that "scarp" is derived by abbreviation from "escarpment" but the development seems really to have proceeded in the opposite direction. Some geologists make a distinction between "scarp" and "escarpment". They employ the former as the more general term, designating any line of steep slope, while they use the latter in a more particular sense to mean a relatively steep slope which follows the line of strike of strata. See also Cotton, Geomorphology of New Zealand, Part 1, 1926,p.6,91.

open out through it at its northern end are wide and flat floored, it is remarkably long and straight. (See Plate XI-A and Plate XIV A and B). As is well known the conditions which prevail at the extreme northern end of the Inyo Range are reversed at the southern end. The eastern scarp, facing Saline Valley, is amazingly high and steep while the western slope is, at least in places, much more gradual. Reasoning in part on this basis, Walcott concluded that the Inyo Range had been uplifted on the east and tilted to the west.[1] Knopf differed from this view, indicating his belief that the range was uplifted along the west front and tilted to the east and that the Saline scarp has been produced by the subsidence of the Saline Valley floor. My studies and observations have led directly to the conclusion that the Inyo Range as a whole is a horst which seems to have received, especially at its northern end, a pronounced tilt to the east. It is possible, however, that such a tilt is more apparent than real.

ORIGIN OF THE WHITE MOUNTAIN SCARPS:

The idea that the steep slopes which bound many of the long narrow mountain ranges in the basin and range province on one or both sides are fault scarps was conceived by Gilbert in 1872-73 and subsequently adopted by Powell in his system of classification of mountains according to their origin. Developed and expanded by such leaders as William Morris Davis, the concept rapidly found favor among students of geology and it has become one of the generally accepted tenets of the

1. Walcott, C.D. - The Post-Pliestocene Elevation of the Inyo Range and the Lake Beds of Waucoba Embayment, Inyo County, Calif. Journ, Geol. Vol. 5, 1897, pp. 340-348.

PLATE XIII

Description of Plate XIII

A. Montgomery scarp north of Queen Canyon (right of center). Note the even slope of the sky-line downward to the left. This is possibly indicative of the former presence of the sub-summit oldland. The peak to the left of the middleline is Sugarloaf Mountain.

B. Closer view of part of the above. Mustang Mountain is just to the left of the middle line.

science. In recent years, however, there has been a tendency in certain quarters to question or modify the theory. J. E. Spurr[1], as is well known, was among the first of the doubters. Later C. R. Keyes argued in favor of general peneplanation following the block faulting and ascribed the creation of the present relief to differential erosion in which wind has played the major part. In brief, Keyes considered that most of the mountain scarps in the basin and range region are fault line scarps rather than true fault scarps.[2] Still more recently Blackwelder, while apparently not denying that true fault scarps probably preponderate in the basin and range province, has expressed the opinion that considering the world at large fault line scarps are much more common than fault scarps, and he stresses, therefore, the necessity for careful discrimination between the two by field geologists.[3]

In view of such differences of opinion as at present exist, therefore, it seems wise - as, in truth, it would be under any circumstances - not to classify the scarps bounding the White Mountains as true fault scarps without carefully considering the evidence. As Blackwelder has so aptly pointed out, the mere existance of a fault along the base of a scarp

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1. Origin and Structure of Desert Ranges - Bull. Geol. Soc. Amer. Vol. 12, 1901, pp. 217-70.
2. Keyes, C.R. - Erosional Origin of the Great Basin Ranges - Jour. Geol. Vol. 17, 1909, pp.31-37; Geological Processes and Geographic Products in the Arid Region. Bull. Geol. Soc. Amer. Vol. 19, 1909, pp. 570-575.(Abst.); Relations of Present Profiles and Geologic Structures of the Desert Ranges, Bull.Geol. Soc. Amer. Vo.l 21, 1910,pp. 543-564; Critical Criteria on Basin-Range Structure, Sci. U.S. Vol. 37, 1913,p. 226; False Fault Scarps of Desert Ranges, Bull. Geol. Soc. Amer. Vol. 26, 1915, p. 65.
3. Blackwelder, E. Recognition of Fault Scarps, Jour. Geol. Vol. 36, 1928,pp. 289-311.

is not sufficient to distinguish a fault scarp from a fault line scarp since a fault would be present at or near the base in either case. Equally indicisive are such criteria as abruptness of slope, triangular faceting, linear aspect of base with alignment of facets, presence of sharp V-shaped canyons or of hanging valleys, the occurrence of springs along the base of the scarp, and an unsymmmetrical appearance of the range in cross profile. Such features are common to both kinds of scarps.

The characters which have just been cited may all be observed in greater or less degree along the White Mountain scarps. Probably most geologists who have viewed the scarps and have considered them true fault scarps have done so chiefly on the basis of such criteria. If, however, we reject the latter as being not sufficiently definite, we by no means thereby destroy the conclusion, for additional evidence is available which leads directly to the same conviction.

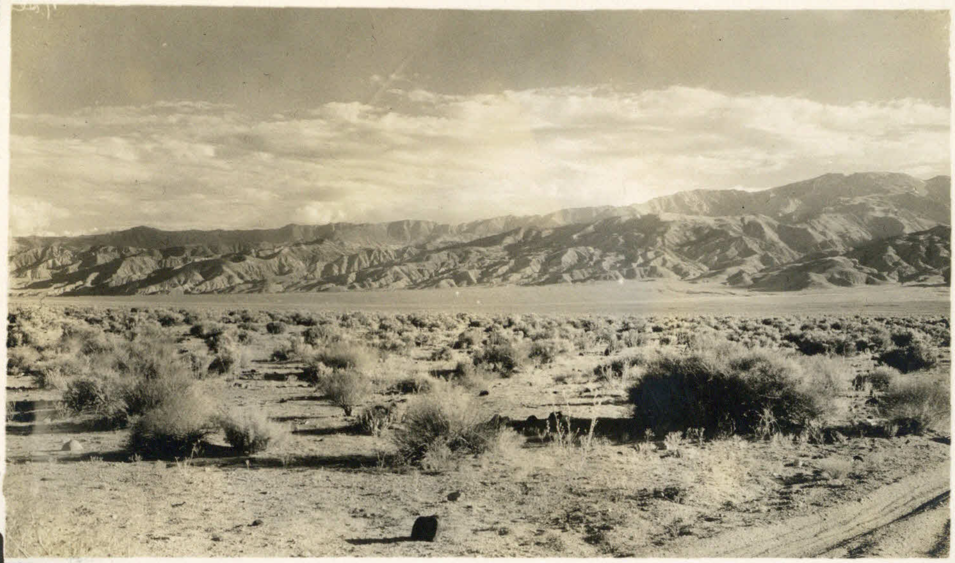
Let us first, however, fairly consider such reasons as may exist for questioning the established conception. One of these is apparent to even the most casual observer. The White Mountain Range is composed in large degree of plutonic rocks, resistant to erosion, while the neighboring lowlands and even the sub-alluvial valley floors are, as has been shown, mostly composed of soft, easily-eroded volcanic tuffs and breccias and of even less resistant playa deposits. It is true that a large part of the lowland areas is at present covered with basalt, a rock which is slow to yield to erosion

PLATE XIV

Description of Plate XIV

A. The eastern scarp of the White Mountain range south of Leidy Creek. White Mountain Peak is at the extreme right. Photograph taken just before sunset.

B. Looking south along the eastern scarp. Leidy Canyon is in the middle distance. The camera is at 9 000 feet.



in an arid climate, but may not much of the difference in relief have been produced before its outflow - as, indeed, the evenness of the surface on which it rests would seem to show? Such consideration certainly suggests the possibility that the range may have an erosional origin.

Upon close examination we find, first of all, that both east and west, the scarps truncate without regard to structure formations of varying degrees of resistance to erosion. Tuffs and breccias of the same character and weakness as constitute the lowlands are present in the mountain block and even in the scarp itself. (See, for example, Plate XIII, A and B. Granitic rocks, limestones, soft schists, shales, slates, basalts, rhyolites, ash beds, loose gravels and metamorphics of great hardness and resistance are all crossed by the scarp without the least deviation..

Not only are the softer rocks to be found in abundance in the mountain block but harder and more resistant ones frequently occur in the lowlands. Thus, for example, in Pellisier Valley about five miles north of the Cinnamon ranch, metamorphics of the same kind as are present in the Montgomery scarp several thousands of feet above its base occur in low hills nearly buried by the alluvium of the fan. Four or five miles farther north in the vicinity of the Taylor ranch it seems probable that the sub-alluvial valley floor is of granite. What evidence is available indicates that in Pellisier Valley the rocks which underlie the alluvium are of the same character as those which compose the mountain range.

Secondly, we find, especially on the east front of the range, Pleistocene or Recent basalts which show positive evidence of having been dislocated by faulting. Often such basalts descend in steps (typical step-faulting) from maximum altitudes of ten thousand feet or more to the base of the scarp, some three thousand feet below. An excellent example occurs on Black Mountain north of Davis Creek. (See for example Plate XL, A) This evidence clearly indicates that the range has been elevated in respect to the valley block several thousand feet since the extrusion of the basalts.

A third type of evidence is to be found in the occurrence of recent fault scarps on both sides of the range. In every case the uplifted side is the mountain side. Frequently the scarps join the main mountain face. These occurrences are described in detail elsewhere. (See page)

A fourth step toward the same conclusion is taken when we consider the strong indication of rejuvenation due to uplift (or subsidence of base level) in the range. Such indications have to do with the intrenchment of the alluvium by the present streams and the presence of terraces along the canyon walls.

The great steepness of the Montgomery scarp is indicative of its origin as a fault scarp. If Pellisier Valley was formed by erosional processes, the rocks worn away were, as has been indicated, probably of the same kind as compose the Montgomery scarp. Under such conditions it is difficult to understand how erosion continuing so long as to produce a valley of such depth could leave a scarp so steep and rugged as this has been shown to be.

It seems unlikely, therefore, that the scarps have been erosional in origin. The mountain block is composed of materials of various kinds and various degrees of resistance to erosion. Similar variations exist in the materials of the lowlands. The idea that the relief was produced before the outpouring of the basalts is shown to be invalid by the presence of similar exposures high up in the mountain block. On the other hand definite evidence is at hand to show that uplift of the mountain block (or corresponding depression of the lowlands) has continued until very recent times and is probably still continuing. Finally there is stratigraphic proof that the scarps are fault scarps.

There still remains, of course, the possibility that the scarps are resequent fault line scarps with renewal of movement in recent times. Such recent movement, however, has been shown by stratigraphic evidence, especially along the Davis scarp, to amount to several thousand feet. The Montgomery scarp shows no pronounced break in profile in the lower three or four thousand feet such as might be expected in case such renewal of movement along a fault line scarp. On the other hand, the distinction tends to disappear between a true fault scarp and a resequent fault line scarp with renewal of movement involving displacements of several thousand feet along its base.

QUEEN FAULT SCARP:

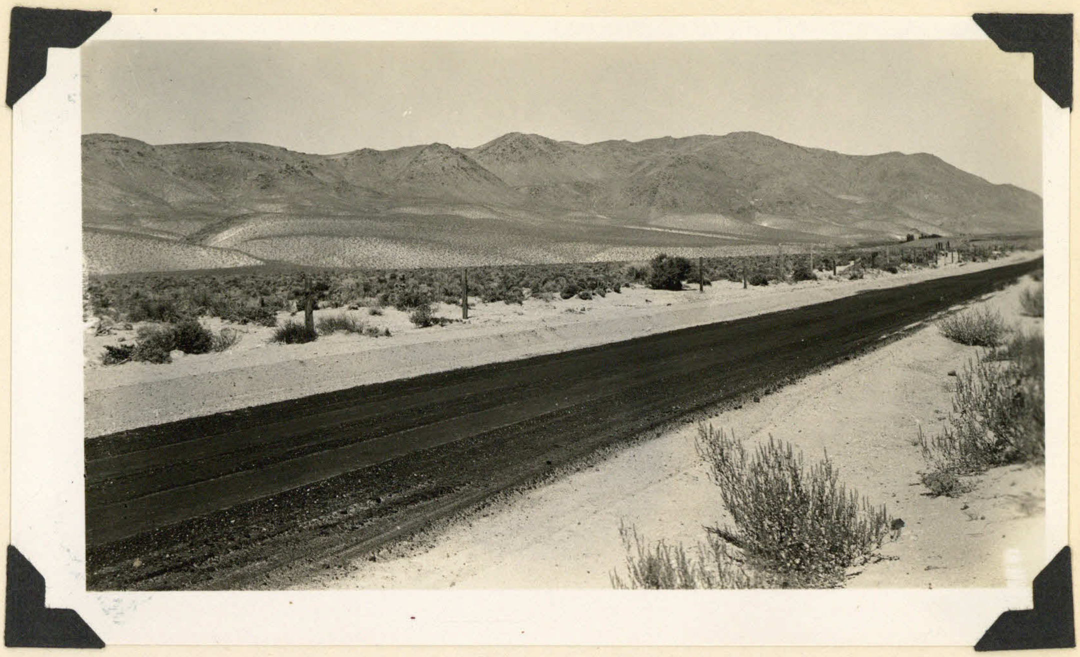
Thus far attention has been given exclusively to the fault scarps which bound the White Mountain Range itself. Other

PLATE XV

Description of Plate XV

A. Looking northeast along the Queen fault zone from the Benton-Montgomery Pass road. The trees at the extreme right are at Queen Station.

B. Near the northwest end of the Davis fault zone. The abrupt slope seen in profile at the upper right is a fault scarp. The dip of the fault, however, is steeper than is indicated by the scarp. The camera points south.



scarps of the same kind are present in the area. One of these is the southeast-facing scarp which trends from the vicinity of the Pellisier Ranch northeast nearly to Mt. Montgomery Station, bounding Pellisier Valley on the northwest. It is relatively low and less abrupt than the ones we have discussed but its character as a fault scarp is no less evident. (See Plate XV. Fig. I and Plate XXXVII. A and B). It transgresses without deviation granites, early or prePaleozoic limestones and slates, soft Tertiary volcanics and Quaternary basalts. For two or three miles northeast of Nichols the major fault plane is in clear view. Along its trend Tertiary volcanics and Quaternary basalts to the southeast lie in vertical or nearly vertical contact against granite, other Tertiary volcanics and ancient limestones and slates. Farther to the southwest the faulting becomes more distributive in character and the scarp is less sharply defined.

COMANCHE SCARP:

From its height and steepness and the rectilinear aspect of its base we may conclude that the northeastern slope of Blind Spring Hill is probably also a fault scarp; there is, however, no definite evidence for or against this view. (See Plate XXIII, B)

At several places between the Taylor Ranch and the mouth of Marble Creek patches of volcanic tuff appear to lie in depressions on the scarp. Such volcanics seem to be identical with others which lie northwest and southwest of Blind Spring Hill and which are undoubtedly of Quaternary - probably late Quaternary Age. If the Blind Spring scarp is a fault scarp, therefore it must have been formed before the volcanic material was deposited - that is, some time in the Quaternary.

AGE AND DEVELOPMENT OF THE FAULT SCARPS:

In determining the age of the fault scarps we must attempt to decide not only when they were formed but whether the movement which gave rise to them was rapid or slow, whether it proceeded without interruption or was irregular with periods of activity alternating with long periods of quiescence. Accurate dating of the scarp in terms of periods or of contemporary events is of more concern to the historical geologist than to the physiographer but the nature of the movement is recorded in the forms.

In recent years there has been a decided tendency to reduce the estimates formerly made of the age of fault scarps. Lindgren[1] believed that faulting along the eastern fault zone of the Sierra Nevada began in the Cretaceous and continued until the late Tertiary or early Quaternary. In his own words "Faulting has occurred irregularly along the eastern fault zones since the Cretaceous period. The subsidences are not uniform. A Cretaceous dislocation along one line may be continued by a late Tertiary fault or extension of this line."

1. Lindgren, W. - The Tertiary Gravels of the Sierra Nevada, of California, U.S.G.S. Prof Paper 73, p. 43, 1911.

It is difficult to agree with Lindgren on this point, since, as Louderback has shown, there appears to be no significant difference in profile between those scarps or portions of scarps which Lindgren considers to be early or pre-Tertiary and those which he regards as late Tertiary in age.[1] It is well known, as stated by Louderback, that " at various times in the history of the Great Basin region the strata were deformed by faulting whose direct effects on the topography have long since been effaced by erosion",[2] but it is apparent from the context of Lindgren's paper that in making the statement quoted above he had in mind the scarps themselves. It is difficult to reconcile Lindgren's view with his specific recognition of the existence of the Sierra "peneplain" which he regarded as of Miocene age. What he does clearly state, however, is that from their very irregularity he considers that these movements cannot have been in any way responsible for the uniform tilting of the western slope. He thinks that the elevation of the Sierra Nevada to its present height was attained by a single uplift which involved the entire Great Basin region, at the close of the Miocene and that the Great Basin was differentiated by the successive subsidence of fault blocks along the eastern margin of the range.[3] This break, he believes, began at the time the main uplift occurred but movements continued until the Recent period.

1. Louderback, G.D. - Period of Scarp Production in the Great Basin, U. C. Pub. Bull. Dept. Geol. Sci. Vol. 15, 1924, pp. 1-45
2. Louerback, G.D. - Morphologic Features of the Basin Range Displacements in the Great Basin, Univ. Calif. Publ. Bull. Dept. Geol. Sci. Vol. 16, p. 4, 1926.
3. Lindgren, Op. Cit. p. 41.

The work of Lawson[1] seems to indicate that for the Southern Sierra region at least, the uplift of the Sierra Nevada took place in two stages separated by a long interval. The first of these Lawson believes occurred at the beginning of the Quaternary, the second in the late Quaternary time. Knopf gives reasons for believing that the first uplift involved the Great Basin region also, concurring to this extent in Lindgren's views, and expresses the conviction that the great eastern scarp could not have been formed until the second stage of uplift. He disagrees with Lawson, however, as to the time at which the uplifts occurred. The first he thinks may have occurred at any time between late Eocene and early Pliocene, while the second or scarp-forming movement did not occur more recently that early Quaternary.[2]

Louderback has deduced the consequences on the outline of a fault scarp of formation by two or more movements separated by a long period of rest. Two types of modification might be expected in the profile of the older surface. These are; (1) a lessening of the slope accompanied by dissection; (2) a recession of the base of the scarp from the fault line. After examining the Sierra Nevada scarps for the presence of such features with negative results he has reached the conclusion that the faulting which produced these scarps was the product of a series of movements closely spaced in time which began

1. Lawson, A.C.- Geomorphogeny of the Upper Kern Basin, Univ. Calif. Publ. Bull. Dept. Geol. Sci. Vol. 3, p. 364, 1904.
2. Knopf. Op. Cit. p. 88.

not earlier than Pliocene and were mostly complete before the late Pleistocene, though some activity has continued down to very recent date.[1]

For the southern portion of the Inyo Range these seems to be no clear evidence either as to the time of formation of the fault scarps or as to the duration of the period of active movement. On the west side the faulting has been distributed over a wide zone and the resultant slope is a gentle one which simulates a scarp of advanced age. Late Teritary or early Quaternary basalts, however, have been dislocated by the faulting.[2]

On the other hand, the Saline Valley scarp presents an appearance of remarkable freshness. Knopf hints, however, that the formation of this scarp may have taken place in two stages by stating that from 1500 feet up to 5000 a given canyon is a narrow rock sluice but that above 5000 feet it is relatively open. His photographs convey the same impression.

When we come to examine the White Mountain scarps we find that they afford fairly definite indication as to the time of their origin. In both the Montgomery and the Davis scarps volcanics which are certainly not earlier than Upper Miocene and are probably of Pliocene age have been dislocated by the faulting. In the Davis scarp as well as in the Queen scarp basalts of Quaternary age have been displaced, frequently by step-faulting, hundred or thousands of feet. The

1. Louderback, G. D.-Period of Scarp Production in the Great Basin. Univ. Calif. Publ. Bull.Dept. Geol. Sci. Vol. 15, 1924, pp. 28-30

2.Knopf, U.S.G.S. Prof. Paper 110, p. 52 and p. 74.

evidence seems quite clear that these scarps are of Quaternary age. It seems equally clear that the successive uplifts in the series that raised the crest of the range to its present elevation were separated from each other by relatively short periods of time. Neither scarp shows by any marked break in its profile that lengthy pauses may have occurred during its formation. The evidence presented by the White Mountain scarps, therefore, seems to substantiate Louderback's conclusion.[1]

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1. Supra p.

Description of Plate XVI

Recent Fault Scarp Crossing the Alluvial Fan at the Mouth of Queen Canyon.

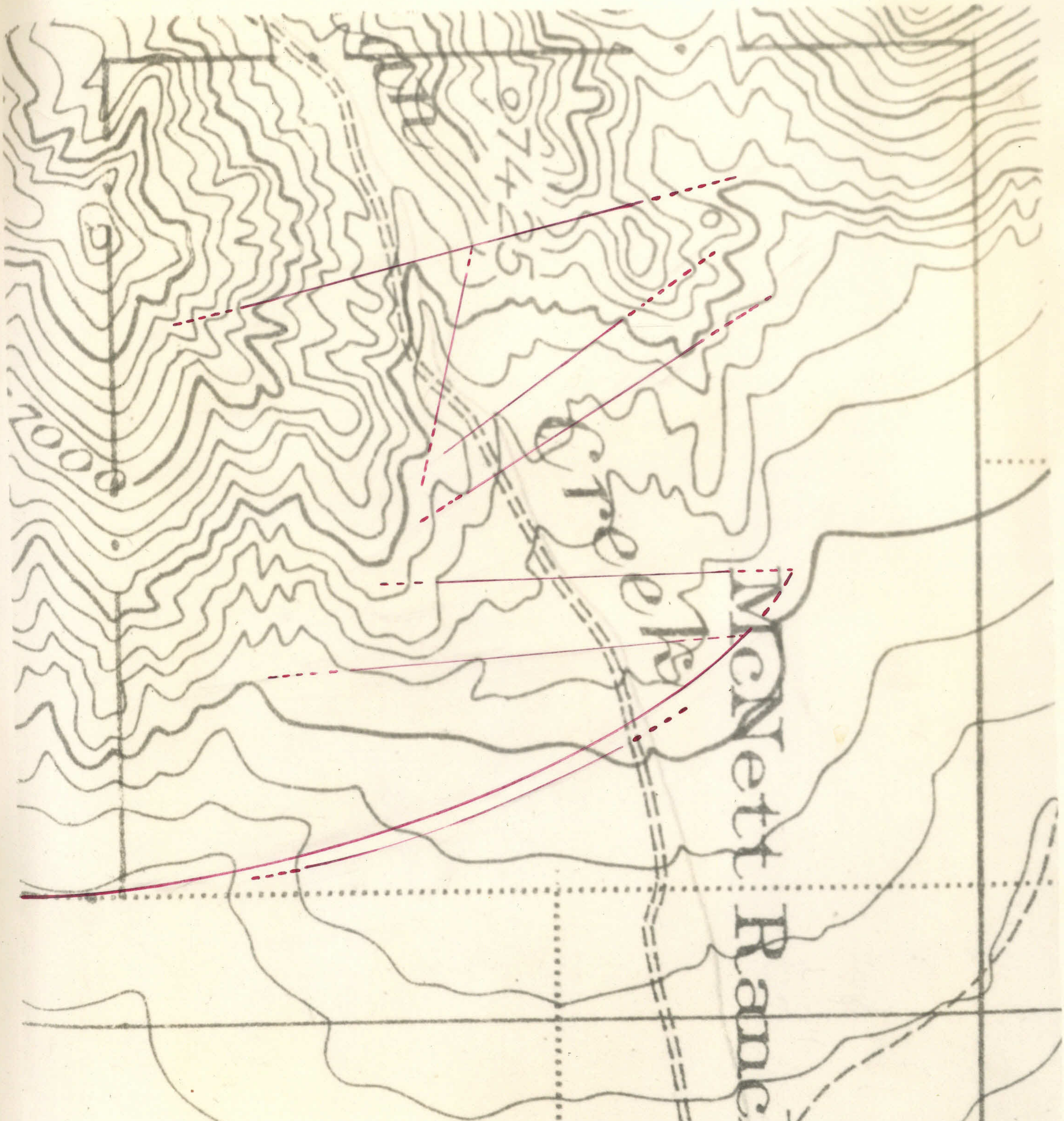
RECENT FAULT SCARPS IN THE ALLUVIAL FANS.

EASTERN MARGIN OF THE RANGE:

Recent faulting has occurred repeatedly along both the eastern and western margins of the White Mountain block, leaving definite records of its movements in scarps which cross the alluvial fans parallel or nearly parallel to the mountain front.

Such scarps are more numerous on the Fish Lake than on the Pellisier Valley side, but in both locations are plainly evident to even the casual observer.

Recent faulting of this type is exhibited in its greatest complexity in the area about the mouth of Indian Creek Canyon (east) between the McNett Ranch and the mountain front. It is probable that displacements have occurred fully as frequently from Indian Canyon north to Trail Canyon, but the rapid accumulation of alluvial material in this region has to a large extent buried the evidence. On the other hand, many of the scarps noted in the vicinity of Indian Creek may be followed long distances to the south. One of these, (indicated



RECENT FAULT SCARPS
AT MOUTH OF INDIAN CREEK
Scale: 1 in. = 1750 feet

on the map as the "McNett" fault) may be traced continuously for a distance of over twenty miles, to beyond the southern border of the White Mountain Quadrangle. It is evident, therefore, that the faulting at Indian Creek may be considered as fairly representative of what has occurred along the entire eastern front of the range. A number of these recent fault scarps are illustrated in Plates XVII to XX inclusive.

The critical observer would probably wish to know at once the reason for the straight line contact which exists between granite and alluvium to the north of Indian Creek at the mouth of the canyon. The answer is plainly evident in the field. The contact is a fault. The fault plane is exposed in cross section in the canyon side, where it is seen to be vertical with the downthrown side to the east. The trend of the fault is about N 15° W. It crosses the ridge to the north of Indian Creek in the saddle to the northeast of the 7425 foot peak. This saddle marks a vertical contact between a rhyolite flow to the northeast and granite to the northwest. (Indicated in Plate XX, A and B) South of the creek along the projection of the line of fault the same rhyolite lies in vertical contact against early or pre-Paleozoic limestone and slates. There is no scarp in the alluvium but the granite itself north of the creek forms a scarp overlooking the alluvium. From the exposure in the north wall of the canyon it is seen that the movement took place along two planes about fifteen feet apart; the space between is a zone of crushed granite.

Crossing Indian Creek at about 6350 feet is a fault

PLATE XVII

Description of Plate XVII

A. Recent faulting south of Indian Creek. The trees in the right middle distance are at the McNett ranch. The dark line paralleling the mountain base beyond the ranch is the scarp.

B. The great bend in the Montgomery fault scarp.

which trends N 75° W. South of the creek it has let down a portion of a basalt flow in a vertical contact against the early sediments to the southwest. Discontinuous segments of a scarp about fifteen feet high can be traced crossing the alluvium, to a junction with the first fault described. The scarp apparently indicates fairly recent renewal of movement on an older fault.

A third fault scarp, also about fifteen feet high, can be seen to trend about N 35° W from the point at which the 6300 foot contour crosses the creek (that is, at about 6350 feet on the road). South of the creek is a low scarp which can be distinctly seen where the fault crosses the basalt. As in the previous case the scarp faces northeast.

A fourth fault, also plainly indicated by a scarp in the alluvium, trends N 33° W from the point at which the 6300 foot contour crosses the Indian Creek road. The scarp in the fan is about ten feet high. North of the creek its continuation is indicated in the fault contact between the Quaternary basalt to the east with the rhyolite to the west. On the north side of the ridge the fault plane is to be seen partially concealed by talus. So far as can be determined from the rather poor exposure, the plane at this point dips at about 50° to the west with the downthrown side to the east. This, of course, would indicate a reverse fault. The fault could not be traced south of the creek.

Two nearly parallel scarps cross the Indian Creek road at elevations of 6261 hundred feet. The former, about fifteen high, south of the road, runs obliquely into the

the mountain face; north of the road it trends due north to the eastward margin of the basalt above mentioned. The second which is from seventy-five to one hundred feet high a short distance south of the road, also joins the mountain face obliquely about one half mile to the south; trending five degrees west of north and becoming somewhat indistinct, it appears to run into the next fault to be described just beyond the ridge north of the creek.

This, the seventh in the complex series of faults, is by far the most important of all the recent alluvial fault scarps which are to be observed in the White Mountain Quadrangle. It is the one which is mentioned above as extending continuously for more than twenty miles to the southeast,(the McNett Fault). Not only on account of its length is it notable; its height also in places is astonishing. For example, southwest of the Molini Ranch (Dyer Post Office) in the southern half of the quadrangle, its total height, covering two closely spaced slices, is not less than five hundred feet. (See Plate XIX, A and B.)
Still farther south it is seen to split into two and later into three branches of which one is wholly in the bedrock of the mountains but two are in the alluvium. The total displacement on the three faults, though not accurately measured, was estimated as at least eleven hundred feet.

Within the portion of the quadrangle mapped the expression of this fault is scarcely less imposing. It is shown as a sinuous line here approaching close to the mountain front, there withdrawing farther down the fan. For most of its course

Plate XVIII

Description of Plate XVIII

A. Fault scarp crossing fan just south of Indian Creek.

B. Extension north of Indian Creek of the fault viewed in Plate XVII, A.

it forms a single scarp with a maximum height of about 150 feet, lowest where it crosses the mouths of canyons, highest in-between. (See Plate XVII, A and B, and Plate XLIII, B. The last is the best general view.) As it ascends the Indian Creek fan its height diminshes until at the crest the scarp is not over fifty feet in height. Crossing the creek at 6050 feet without visible effect on the latter, it swings toward the west and heads directly for the steep lower margin of the large basalt exposure to the north, its height increasing to about one hundred feet at the point where it reaches the basalt. (See Plate XVIII, B). From this point north its course cannot be certainly traced. It may strike into or along the mountain front or its continuation may be represented in the fault scarp which trends N. 10 degrees W. about three-quarters of a mile east of the mountain front.

A striking feature connected with the occurrence of this scarp, confirming our ideas as to its origin and giving us some hint as to the time of its formation, is the degree to which the streams have entrenched themselves below the surface of the alluvium above the fault scarp, both in the fan and in the canyons. Above the great fault scarp the streams flow in deep channels but where they break through this scarp they are rapidly building new fans which are tending to obscure or to lower its apparent height where it crosses the crests of the older cones. At Indian Creek the depth of the trench above the scarp is about seventy-five feet; southwest of the Molini Ranch (Dyer Postoffice) where the fault scarp is much more prominent

PLATE XIX

Description of Plate XIX

A. Recent fault scarp shown in Plate XVII, A but farther south. It is seen best to the right of and beyond the trees in the center of the picture.

B. Closer view of the scarp where it crosses the mouth of Perry Aiken Canyon.

PLATE XIX

A

B

the trench is much deeper. (See Plate XIX, B) Such evidence indicates that the faulting which gave rise to this scarp probably occurred at least several centuries ago. On the other hand, the argument may be advanced that extremely heavy local rains of the type popularly known as "cloudbursts" have occurred in virtually all of the canyons of the east side of the range since settlers first came to Fish Lake Valley. The depth of channel which may be eroded in loose alluvial material in a single such cloudburst and the amount of material which may be carried downstream to be redeposited where the water has an opportunity to spread out are truly astonishing. The time necessary for the effects that have been described, therefore, must not be estimated on the basis of the eroding power of the normal streams.

About one mile south of the point at which the great scarp crosses Indian Creek a second scarp, facing in the opposite direction, diverges from it for a distance and then runs parallel to it until as it ascends the next fan to the south it becomes lower and lower until it finally dies out, not to reappear. The second scarp is approximately fifty to seventy-five feet lower than the first, which is here about 150 feet high. Between the two is a depressed area about 250 feet wide with a floor which is flat in cross section but which slopes from north and south to the low point between the fan of Indian Creek and that of the next (unnamed) canyon to the south. At this point the second (westward-facing) scarp is breached to permit drainage down the slope eastward. Likewise at the point of divergence of the two scarps the eastward-facing scarp has been broken through with the formation of a deep narrow transverse gorge.

G.K. Gilbert has described small grabens between oppositely-facing alluvial fault scarps in connection with his studies of recent faulting along the front of the Wasatch Mountains in Utah.[1] Other examples are well-known, as, for example, along the 1872 earthquake fault south of Lone Pine in Owens Valley. I am not inclined to regard the depression just described, however, as a graben nor the westward-facing scarp as a fault scarp. The phenomenon is quite clearly either entirely or in large part the work of running water which, after breaking through the true scarp, ran down the slope along its base, originally guided, perhaps, by a slight back slope in the fan brought about by faulting. On the other hand, it is possible that there may have been at the outset a small depression between the two scarps, the westward-facing one being much lower than the other; in this case subsequent erosion deepened the channel and enhanced the apparent height of both scarps.

About two hundred feet in front of the McNett scarp just south of the Indian Creek road is a parallel eastward-facing scarp, not over twenty-five feet high. It cannot be traced north of the road; to the south it dies out after half or three-quarters of a mile.

Late in the afternoon when the shadows are long, throwing all slopes into strong relief, a number of low scarps can be seen crossing the fan at varying intervals for two or three miles below the McNett Ranch. These scarps are only two or three feet

1. Gilbert, U.S.G.S. Prof. Paper 153, 1928, pp.

PLATE XX

Description of Plate XX.

A. Alluvial terraces at the mouth of Indian Canyon. A recent fault scarp breaks the continuity of the terraces at the right.

B. Closer view of part of the above, showing more clearly the recent fault scarp.

high and are not likely to be noticed except from a distance. They may be fault scarps but it is more likely that they are related in some way to the creep of alluvial material down the slope. They may be fronts of lobes of mud flows. (See p. this thesis.)

Between Indian and Trail Canyons occur many other alluvial fault scarps which would attract the attention of a careful observer. Limitations of time have not permitted the tracing and mapping of all of these. They are somewhat less numerous and less complex than those which have been described and most of them are lower, but they are of the same general type. One of the most prominent parallels the mountain base just south of the mouth of Davis Canyon, but before it crosses the creek it swings sharply toward the north and shortly dies out. All of the scarps which have been noted are steep, approximating in slope the angle of repose in loose alluvium.

A prominent series of high fault scarps cross the eastern end of Black Mountain, trending for the most part about N. 35 degrees W. These are partly in an older alluvium, partly in Quaternary basalt. They are of a somewhat different type and probably are much older than those just discussed; they are described elsewhere in this thesis.

Across Fish Lake Valley northeast of the Dyer Ranch beyond the eastern boundary of the White Mountain quadrangle is a remarkable fault scarp in the alluvium. Since it lies wholly in the Silver Peak Quadrangle it is mentioned here only because of its place in the general pattern. An accompanying photograph serves to illustrate its characteristic features. (Plate XXI.)

PLATE XXI

PLATE XXI

Recent fault scarp at eastern margin of Fish Lake Valley. The scarp is partly in alluvium, partly in bedrock. Note excellent example of fault scarp mountain face at middle right.

PLATE XXI

FAULT SCARP ACROSS QUEEN CANYON FAN:

Highly significant in its bearing upon certain structural features of the White Mountain Range is the fault scarp which interrupts the continuity of the fan just below the mouth of Queen Canyon. It is to be noted that at this point an abrupt break occurs in the Montgomery fault scarp, the part to the south having been offset a full mile to the northwest.

For half a mile southwest of Queen Creek the great escarpment of the Montgomery fault zone has been eroded away and its trace covered over with detritus from the canyon in a rapidly expanding fan. The mountain front at this point is in dolomitic limestones and in rather soft metamorphic rocks (Knotenschiefer) derived from shales. At the mouth of the next important canyon to the south, approximately one mile distant from the Queen Canyon road, the mountain base becomes once more a fairly straight and well-defined line.

Diverging from what appears to be the main fault scarp a few hundred feet to the south of the house which is located at the mouth of the canyon is a recent scarp with a general northwest trend. For the first quarter of a mile of its course it displaces the surface of the fan; (See Plate XXIII,A) a little farther to the northeast the scarp is in volcanic material (tuff) and marks the boundary between this material and the alluvium. Curving slightly toward the north, the scarp again enters alluvium and, diverging more strongly from the present bedrock slope, crosses the Queen Canyon road at an elevation of about 6800 feet, trending about N 15° E. An eight of a mile north of the road it assumes a more easterly direction and continues approximately N 26° E obliquely across the fan until it reaches the channel in which the stream issuing from Queen Canyon now flows, where it abruptly terminates. (Refer to Plate XVI and Plate XXII)

At the point where the scarp diverges from the mountain front it is not over ten or fifteen feet high, but its height increases as it proceeds northwest until north of the Queen Canyon road it is seventy-five to one hundred feet high. The scarp faces northwest.

DISSYMMETRY OF QUEEN CANYON CONE.

The alluvial cone at the mouth of Queen Canyon is decidedly unsymmetrical. It is, in fact, a composite cone, consisting of a younger and an older part. The latter has been uplifted by the faulting which formed the scarp described above. It forms the western half of the composite fan above the scarp. In consequence of the uplift, the stream issuing from Queen Canyon has deeply incised itself below the surface of this older part of the fan. To the north and east of the older alluvium and extending nearly to the mountain face is a depression in which the material being derived from the destruction of the older part of the fan is being deposited. This and the alluvium deposited below the scarp form the younger part of the fan. These relations are quite well shown in Plate XXII, A.

It should also be noted that the alluvial material in the cone above the recent fault scarp is not of great depth. Just below the mouth of the canyon Tertiary colcanics rise in low hills above the alluvium. Farther down, these Tertiary volcanics and the early or pre-Paleozoic sediments which together

PLATE XXII

Description of Plate XXII

A. Recent fault scarp in alluvium across the Queen Canyon fan, viewed from the north. The camera is at an elevation of 7500 feet north of Nichols station and about 5½ miles from the scarp. Note particularly the dissection of the older cone above the scarp.

B. The same scarp viewed from the northwest. The trees and houses at the lower right are at Queen Station. The offset in the Montgomery fault scarp at Queen Canyon is well shown.

PLATE XXII

A

B

form the basement on which the alluvium rests are exposed both in the ravine followed by the road and in the stream channel to the east of it. These exposures indicate that even as far down as 6900 feet the maximum depth of the detritus south of the stream is not over fifty or sixty feet. This is fully a mile down the slope from the apex of the cone.

These conditions are not yet fully explained. Whether the older alluvium to the west is separated from the younger alluvium in the depression to the east by a fault against which the transverse fault-forming scarp terminates is not certain. I strongly suspect that this is the case, but I must admit the possibility that the recent fault simply dies out to the northeast. It seems highly probable to me, however, that the recent scarp closely approximates the line of the main fault which delineated the mountain front south of Queen Canyon before erosion bevelled off the sharp northward-pointing angle which otherwise would exist there.

SCARPS SOUTH OF QUEEN CANYON:

South of Queen Canyon comparatively few faults which displace the present alluvial surface occur within the area mapped and all are less prominent than the more important ones which have been described.[1]

1. In the south half of the quadrangle, however, several recent fault scarps may be seen in the alluvium at the foot of the western mountain slope.

PLATE XXIII

Description of Plate XXIII

A. Detail of faulting at mouth of first large canyon southwest of Queen Canyon. The fault passes near the small tree to the right and appears to join the mountain front just above the center of the view.

B. Looking south from the Truman Meadows region. To the left in the middle distance is a segment of the Montgomery scarp. Just above and to the right of the center is Blind Spring Hill, bounded on the east by the Comanche fault scarp. Between the two is the Montgomery canyon fan.

A short distance north of the mouth of Marble Canyon is a prominent scarp which has a general but rather irregular northward trend about three quarters of a mile west of the mountain base. It may be plainly seen from the Laws-Benton Station road. This, however, is not a fault scarp although it might be mistaken for one. On the contrary, it marks the front of a landslide which has descended from the canyon next the north of Marble Canyon. The uneven, hummocky appearance of the surface above the scarp helps to indicate its true character.

Just north of the mouth of the canyon above Queen Dicks is a fragment of an alluvial fault scarp. A pear-shaped remnant of older alluvium whose surface is virtually continuous with the top of an alluvial terrace within the canyon extends westward about a quarter of a mile away from the mountain front. There it terminates in an abrupt slope a hubdred feet high. The width of the remnant is not over three or four hundred feet but its top is almost level. (See Plate XXIV, A)

South of the creek there is no remnant to correspond. The terrace within the canyon, however, is matched by one on the south wall. This terrace is cut off exactly flush with the rock face of the mountain, so that a roughly triangular cross section of the alluvial material is exposed.

On the north side of the creek where the older alluvium emerges from the canyon its surface is deeply notched and from this notch a stream channel leads down from the angle between the older alluvium and the mountain face to the base of the latter and thence westward.

This feature is somewhat difficult to interpret. It appears probable, however, that a north-south fault at the lower margin of the remnant of alluvium north of the creek raised the level of the fan and elevated the mountains to the east about the present hright of the scarp. The stream flowing down the steep mountain slope quickly entrenched itself in the upper or old part of the fan and, swinging to the south, undercut and rapidly destroyed the alluvial remnant in that direction as far back as the mountain face; the remnant to the north of the creek, however, being in a direction up the slope of the strong Marble Creek fan, was less readily destroyed. It will, however, ultimately yield to the combined effort of the drainage which is deepening and widening the channel in the angle with the mountain front and that which, coming down the slope from north and northeast, tends to cut it away.

Remnants of older alluvium are also to be observed on either side of the mouth of Marble Canyon, stranded two or three hundred feet above the present fan level on the mountain face. These are accordant with alluvial terraces lying against the canyon walls within the canyon. One of these remnants is illustrated in Plate XXIV, B.

ALLUVIAL ACCUMULATIONS.

GENERAL FEATURES:

Along both margins of the White Mountain are detrital slopes formed by the partial coalescence of alluvial cones having their apices within the canyons which supply the material for their construction. Those on the west are relatively short and steep; those on the east longer and of more gentle gradient. Close to the mountain front a depression normal to the scarp marks the junction of adjoining cones bounded on both sides by slopes which rise steeply to the mouths of the canyons.

The higest amd most imposing of the cones west of the range is the one which has its apex at the mouth of Montgomery Canyon, the largest and deepest of those canyons which drain to the west. From apex to outer margin this cone is about three and a half miles wide. In that distance its surface slopes from 7000 feet to 5400 feet or at an average rate of 457 feet to the mile. This is approximately 8.6% or nearly 5^{o}. The Marble Creek cone is two and three-fourths miles wide with an average slope of about $4\frac{1}{2}^{o}$.

On the eastern slope the largest is the great cone formed by the coalescence of the cones of Trail Canyon, Dry Canyon and Middle Canyon. Its extreme width, measured from the mouth of Trail Canyon southeastward to the outer limit of coarse material is not less than eight and a half miles. Its apex is at 7500 feet, its outer margin is at about 5500; its extreme height, therefore, is 2000 feet. The average slope of its surface is about $2\frac{1}{2}^{\circ}$.

The above figures, it should be noted, are for average slopes. The maximum slopes are much higher. The alluvial surface has in general a profile which is concave upward, with steepest slopes near the mountain front and flatter ones near the margin.

With these figures we may compare those given by Knopf for the alluvial cones of the east flank of the Sierra Nevada. These, he says, are from one to seven miles wide and rise 1000 to 2500 feet above the valley, with slopes that average between six and seven degrees.[1] The cones of the southern portion of the Inyo Range, however, are more complex and direct comparison is not possible.

The rapid growth of the White Mountain cones has forced the intermittent axial stream which drains Pellisier Valley to the extreme western and northwestern side of the valley. On the Fish Lake Valley side the same effect may be observed in the position of Fish Lake and of the series of fresh water marshes which extend to the northeast.

COMPLEXITY OF THE CONES:

Knopf has recognized and mapped alluvial cones of two ages along the flanks of the southern portion of the Inyo Range, especially on the west side.[2] The younger cones have been derived, he thinks, almost entirely from the erosion and

1. Knopf. U.S.G.S. Prof. Paper 110, 1918, p. 53.
2. Ibid, pp. 54-57. Remnants of still older alluvial material have been observed on the precipitous ridges between the gulches as high as 2000 feet above the floor of Saline Valley on the east side, but these are not extensive.

partial destruction of the older. The apices of these older cones lie well within the canyons from which they were derived. They have been dissected to depths as great as five hundred feet. Knopf ascribes this dissection of the older alluvium in part to a former climatic change in the direction of increasing humidity but he also recognizes the probable influence of renewed uplift of the range by faulting. The upbuilding of the younger cones is now practically at a stand-still, in the opinion of Knopf, as a result of increasing aridity in recent times. Alluviation of the canyons by the pouring-in of detritus from the steep lateral tributaries is the chief process now at work.

In the northern part of the range the alluvial deposits are fully as complex as those described by Knopf in the southern Inyo Range. Not only are the present cones composite in character, consisting of younger and older parts, as in the case of the Queen Canyon fan, but remnants of still older detrital accumulations are to be found in terraces lying high up against the present canyon walls and in deposits underlying Quaternary basalts on the interstream ridges and even near the summits of some of the higher peaks. Such remnants give valuable information respecting the later history of the range.

Reference to the geological map will show that three ages of Quaternary alluvium have been differentiated. The earliest is that deposited before the extrusion of the Quaternary basalts. The second division includes those gravels accumulated after the extrusion of the basalts and before the formation of

PLATE XXIV

Description of Plate XXIV

A. Older alluvium at the mouth of the canyon at Queen Dicks. Note the alluvium on the scarp south of the canyon at the extreme right of the picture.

B. Older alluvium at the mouth of Marble Canyon. There is an exactly similar occurrence to the north of the canyon, off the picture to the left. The alluvium also extends up the canyon at an accordant level.

the most important of the recent fault scarps which break the continuity of the present fans. In the third division are placed all the more recent alluvial deposits.

This classification represents a very liberal generalization. In detail the conditions are much more complex. Much important information concerning the later history of the range could be obtained by more detailed study and mapping of the alluvial deposits.

In general it may be said that the complexity of the present cones is more evident on the eastern than on the western side of the range. This is because renewal of faulting along the eastern front and in the vicinity of Queen Canyon has occurred somewhat more recently than in the western segment extending from Morris Canyon to Rock Canyon. The difference is more apparent, however, than real. Reference to a geologic map will in fact disclose the presence of several remnants of pre-recent faulting alluvium along the western front. In several of the western canyons, also alluvial terraces doubtless formerly accordant with the levels of the fans occur at heights of one hundred to two hundred feet above the present floors. These terraces tend to become less conspicuous in the canyons farther to the northeast. In Queen Canyon the former presence of such a terrace is indicated by the occurrence of a comparatively few large sub-angular granite boulders scattered along the schist of the northeast canyon wall up to a level about one hundred feet above the stream. Both within and at the mouths of the canyons on the east side of the range, however, these terraces are very striking. (See Plate XXVI, A and B)

On the east side of the range the pre-basalt alluvium near the mouths of Trail Canyon, Dry Canyon, Middle Canyon and Davis Canyon lies with its upper surface three hundred to nine hundred feet above the surface of the present fans. It lies across the bevelled edges of bedded Tertiary volcanics (flows and tuffs) and underlies Quaternary basalts. (Refer to Plate XXV, A and B, Plate XXXVIII, A and B and Plate XXXIX) Similar but thinner accumulations of debris occur underlying basalt on some of the higher summits farther to the northwest, as, for example, on Mustang Mountain at an elevation of about 10,300 feet. A line tangent to the farthest west exposures of these higher levels would be nearly a straight line with a direction about N 35° W which is closely parallel to the direction of the mountain front southeast of Trail Canyon.

Faulting has undoubtedly been responsible for raising these gravels to their present positions. I consider it highly probable that the line along which these exposures lie marks the approximate position of the mountain front at the end of the first period of faulting which delineated the eastern margin of the range. This first movement took place along the Davis zone. Later movements to the south also occurred along the Davis zone, but at the north end of the range these later movements appear to have occurred in part along the Pinchot and Sand Spring faults and involved all of the area to the southwest of these structural lines.

PLATE XXV

Description of Plate XXV

A. Older alluvium underlying Quaternary basalt at an elevation of 7800 feet at the northeast end of Black Mountain, 800 feet above the present level of the fans. The scarp of one of the Black Mountain step faults is at the left in the distance.

B. Detail of the above, showing character of the alluvium. Note the rounded and sub-angular granite boulders.

PLATE XXV

A

B

The alluvial material which forms the present floors of the canyons extends up into them for distances of two to three miles. Above these floors, as has been indicated, sets of terraces occur in all of the canyons. The terraces are best exhibited in the central portion of Middle Canyon and at the entrance to Indian Canyon. At these localities as many as five may be observed, varying in height from ten to two hundred feet above the present valley floor. The highest of these can be traced to the base of the morainal material in Middle Canyon and is considered to be equivalent to the pre-basalt alluvium in Black Mountain, as well as to the fifth terrace at the mouth of Indian Creek. Fragments of terraces at various levels can be observed in the other canyons of the eastern slope but in none of them does the complete set occur at a given point. (See also page of this thesis) Corresponding terraces exist not only along the main streams but even in the smaller tributary canyons. (Refer to Plate XXVI, A and B.)

A closely related circumstance which merits discussion is the fact that on both the eastern and western slopes the streams are flowing in channels which are from ten to a hundred feet below the present canyon bottoms and the accordant level of the fans. Such channelling extends for variable distances up the canyons and down the alluvial slopes. Rock Creek has entrenched itself to a depth of twenty-five feet at the mouth of its canyon, Marble Creek approximately ten feet, Montgomery Creek twenty to twenty-five feet, Morris Creek thirty-five to fifty feet. The present stream which emerges from Queen Canyon is too feeble to have much eroding power but although it flows virtually on the surface of the alluvium in the canyon, below the mouth of the canyon it flows in a channel which is seventy-five to one hundred feet below the surface of the fan. In all except the case of Queen Canyon the entrenchment gradually diminishes both up the canyons and down the fans.

On the east side of the range an exactly similar condition occurs. Trail Creek, Middle Creek and Davis Creek all flow in trenches of this character, varying in depth from thirty feet at the mouth of Middle Canyon to seventy-five or more for Davis and Trail Creeks at corresponding points. In each of these cases (except Trail Creek, which has an special explanation) the stream continues to flow in a deep channel down the fan for a distance of about a mile beyond the mountain front, when a sudden steepening of the slope of the fan brings the alluvial surface nearer the surface of the stream. A second steepening of this kind takes place a short distance below the first, below which the creek flows virtually on the surface of the fan.

The same situation holds true for Indian Creek below the mouth of the canyon. Above this point a special condition exists. Beginning where the first tributary enters the main canyon from the south at an elevation of 7000 feet the stream flows at the base of a steep southward facing longitudinal escarpment in alluvium forty to fifty feet high. From the south the canyon floor slopes down gradually to the base of this escarpment from a height on the south side somewhat lower than the maximum height against the north wall. The following sketch indicates the gen-

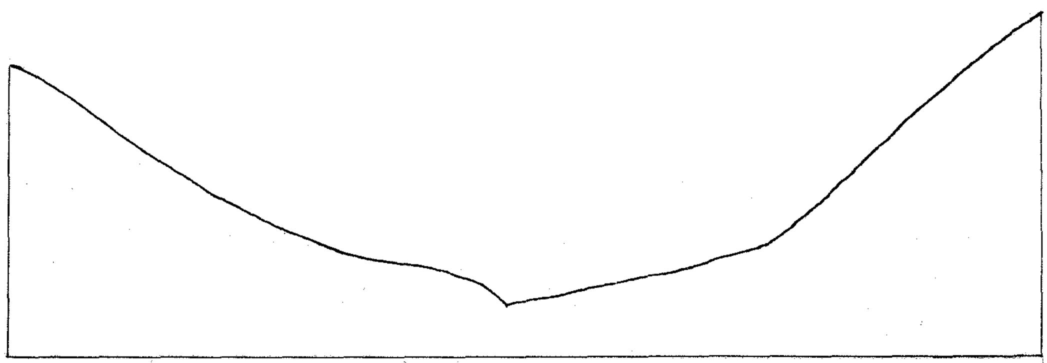
PLATE XXVI

Description of Plate XXVI

A. Stream terraces to the north of Indian Creek. Front of Davis Mountain in the upper left. Indian Creek flows fifty feet below the level of the fan in the foreground.

B. Alluvial terrace within Indian canyon at an elevation of 6800 feet. Indian Creek flows at the base of the scarp.

eral cross sectional profile of the canyon:



This arrangement continues to about a quarter of a mile above the mouth of the canyon where a scarp on the south gradually rises to match the one to the north, forming the trench typical of the streams farther north.

Various observers have interpreted the feature last described as the typographic expression of a longitudinal fault. I am inclined to consider it as an erosional feature. The stream formerly flowed close to the south canyon wall, whither it was crowded by the larger amount of debris which slid or rolled into the canyon from the higher mountain (Davis Mountain) to the north. Later, in response to the same influences which caused the creeks farther north to incise themselves velow the valley floors (i,e,, uplift by faulting) it also began to deepen its channel. Assisted, possibly, by an increase in volume it becan to migrate toward the north side of the canyon by a lateral corrasion, cutting downward as it went, thus forming the steep scarp which is now so conspicuous.

As noted above, Knopf[1] has considered the entrench-

1.Knopf, A. - U.S.G.S. Prof. Paper 110, 1918,pp. 56-57.

ment and destruction of the old fans at the southern part of the Inyo Rangeto be due to change in climate toward greater humidity with some assistance from uplift due to faulting. At the northern end of the range the formation of the present channels by the eastward flowing streams is more probably due primarily to uplift by faulting. This is indicated by the fact that on the mountain side of the recent fault scarps the streams are entrenched in the alluvium while down slope from the scarps they emerge from their trenches to flow on the surface of the fan. The valley floors into which the streams have incised themselves are continuous with the fans above the scarps. (Refer to Plate Xix, B) It is probable that uplift is similarly responsible for the entrenchment which has occurred on the west side and also at least for the earlier down-cutting which led to the formation of the terraces that have been noted. As suggested in the case of Indian Creek, however, increased volume of streams due to oncoming of a more humid climate (or, what amounts to almost the same thing, a coolor climate) may have assisted. If uplift occurred as a result of faulting, even in relatively small degree, it seems reasonable to suppose that precipitation at the crest of the range might be somewhat increased and average temperatures somewhat lowered. The former would directly result in increasing the volume of the streams, the latter would indirectly lead to the same end by decreasing the evaporation. If anyone is inclined to doubt the importance of the latter, let him observe the very marked changes in volume which occur in streams similar to those which flow down the eastern slopes of the Inyo Range, between early morning and noon of a warm summer day and the corresponding reverse changes between late afternoon and the following morning.

ALLUVIAL DEBRIS ON INTERSTREAM RIDGES:

The occurrence of gravels underlying basalt flows on various interstream divides at the eastern front of the range high above the present valley floors has been described and discussed. On the precipitous western slope detrital material in every way like that which is now present in the upper part of the alluvial fans occurs lying on the granite of the interstream ridges at elevations up to four hundred or five hundred feet above the present base of the range. Some of the larger localities south of Marble Creek are shown on the map. These are regarded as fragments of cones left stranded on the mountain face by recent renewal of movement in the Montgomery fault zone. It is possible that they may be remnants of older cones which have been almost completely destroyed by erosion. Even if this is the case, however, the clear evidence for recent faulting observable elsewhere on the margins of the mountain block strongly inclines the observer to regard renewed uplift of the range as the most probable cause of the increased energy of the streams.

COMPOSITION OF THE ALLUVIAL CONES:

The alluvial material derived from the White Mountain block consists chiefly of coarse grained detritus. The composition varies greatly laterally, however, especially close to the mountain front, according to the character of rock exposed in the canyon from which most of the material was derived. Fragments of various kinds of lavas, limestones, slates and different metamorphics may be observed. Fragments which tend to remain long and flat, such as thin bedded slates, limestones and lavas more rarely reach the outer edge of the fans.

An interesting and striking feature, noted elsewhere by many observers, is the large size and mumber of boulders which occur on the surface of the cones at considerable distances from their apparent source. Knopf notes the presence of a granite block over fifty feet in length partially embedded in the gravels of the alluvial cone about two miles from the mouth of the canyon of George Creek on the east slope of the Sierra. Other boulders, some 18 x 6 x 8 feet, lie practically at the edge of the fan four or five miles from the canyons from which the debris was derived.[1]

On the alluvial slopes on both sides of the White Mountain range similar occurrences have been noted. The largest boulder measured was part way up the steep marginal slope of the pear-shaped residual mass of older alluvium north of the mouth of the canyon at Queen Dicks. This great boulder, which lay half a mile from the canyon mouth, was forty-six feet long and twenty-six feet wide. Its exposed height was fourteen feet but it was partially buried. The minimum weight of the mass was calculated to be no less than eighteen hundred tons.

1. Knopf, A. U. S. G. S. Prof. Paper 110, p. 53.

Two or three boulders exceeding twenty-four feet in diameter were measured to the north of Davis Creek more than two miles east of the mountain front. Great numbers three and four feet across are to be observed as far as five miles from the mouths of the canyons from which they must have been transported.

Blackwelder[1] has attributed the transportation of such huge granite boulders as well as the more numerous smaller ones which make up the alluvial cones to mudflows. Such mudflows are considered to be a viscous paste composed of water and finely divided material which becomes slippery when wet. There is little or no excess water, for such excess would lessen the viscosity and reduce the carrying power. The whole mass behaves like a lava flow. Great boulders skid long distances down gentle slopes as the combined result of the impelling effect of the flow and the lessened resistance due to lubrication. Variations in thickness and viscosity of the flows produce corresponding variations in the distance attained and the size of the material carried. The thick and very bouldery flows come to rest more quickly and build the upper part of the fan; the thinner ones may reach the margin of the playa.

That the mudflow is a very efficient agent of transportation on the alluvial fans there can be no doubt, although one may question the degree of viscosity necessary or commonly present.

In the summer of 1931 I had the fortune to be at the

1. Blackwelder,- Mudflow as a Geologic Agent in Semi-arid Mountains - Bull. Geol. Soc. of Amer. Vol. 39, pp 465-483, 1928.

head of the Trail Canyon fan in a very heavy rain approaching cloudburst proportions. The downpour had continued for perhaps fifteen minutes with only ordinary surface runoff when large areas of detrital material on the somewhat steeper slopes at the margins of the fans began to move down grade. The movement began as a series of rivulets of mud which constantly widened and developed tributaries until in the course of a very few minutes an area an acre or more in extent was in motion carrying with it all surface materials, including boulders a foor or more in diameter. The boulders, however, were not floated along like a log in a stream but were rolled and tumbled about with a roar that could be heard above the other noises of the storm. In a short time channels were formed into which rushed the water which had been accumulating in the depressions upon the relatively level space on top of the fan. Such channels rapidly coalesced, broadened and deepened and with remarkable rapidity the entire mass was swept in a newly formed trench down a long slope to the deep channel of the permanent stream and carried away.

It seems probable that Blackwelder in stressing the importance of the mudflow in the transportation of huge boulders and minimizing that of other agents has overemphasized the former. The surface of the alluvial cones appears smooth from a distance but if one walks across one in a direction parallel to the mountain front he is at once impressed with the very large number of channels in braided pattern varying in depth from three or four feet to twenty-five feet or more which spread out down the slope from the head of the fan. During cloudbursts new channels of this sort are often formed; the permanent stream may even be suddenly shifted to a different part of the fan. Great torrents of water pour at high velocities down such channels and smaller volumes may continue to run for days or even weeks after the cloudburst. Such floods must certainly be very effective in moving material and extending and aggrading the fan. They may be considered to be mudflows in so far as any moving body of water heavily charged with material in suspension and sweeping quantities of heavier water along the bottom may be so designated; they are, however, probably quite outside of Blackwelder's use of the term.

DEPTH OF ALLUVIUM IN THE FANS.

GENERAL DISCUSSION:

Accurate knowledge of the depth of the alluvial material in the fans as well as of its character at different depths would yield much valuable information in regard to both the structure and the geologic history of the White Mountain region. Unfortunately information on this point is almost completely lacking. Neither oil nor water wells have been drilled to depth in the valley nor have any extensive excavations been undertaken for road building nor other purposes.

On the basis of such observations as we can make we may conclude, first, that considerable variations in alluvial thickness occur which are undoubtedly related to structural conditions; second, that the average depth of detritus may be much less than might be supposed from the apparent size of the cones and of the canyons from which they have been derived; third, that there appears to be in general a very considerable depth of the alluvium near the mountain front on both sides of the range which may even amount to an actual increase in depth as the front is approached. The last is a condition to be expected along the base of the fault scarp of a fault block mountain range in an arid region so long as that base remains virtually at the fault line, especially if there has been some rotation of the down-faulted block; it is one of the criteria suggested for distinguishing a true fault from a fault line scarp.[1] In the case of the margin of the back slope, on the contrary, we should expect to find the alluvium thinning out to feather edge toward the mountain as erosion proceeds, as would also be the case on the opposite front in the later stage of arid erosion.[2] If, however, the range should be a horst or even a tilted horst with a great amount of displacement on one side and a relatively

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1. Willis, R.-"Physiography of the Calif. Coast Ranges", Bull. Geol. Soc. Amer. Vol. 36, pp. 643-78, 1925; Blackwelder," Recognition of Fault Scarps", Journ. Geol. Vol 36, pp. 289-311, 1928.
2. Lawson, "Epigene Profiles of the Desert", Univ. Calif. Publ. Bull. Dept. Geol. Sci. Vol. 14, (1915) pp. 23-48; Blackwelder, "Origin of the Piedmont Plains of the Great Basin", Geol. Soc. Amer. Bull. Vol. 40 (1929); Bryan, Kirk, "Erosion and Sedimentation in the Papago Country, Arizona, U.S.G.S. Bull. 730, pp. 53-65, 1922; Paige, Sidney, "Rock-cut Surfaces in the Desert Ranges", Journ. Geol. Vol. 20, pp. 442-450, 1912; Davis, W. M. "The Geographic Cycle in an Arid Climate", Journ. Geol. Vol. 13, 1905, pp. 381-407.

small amount on the other, as appears to be the case with the White Mountain range (see page) it is conceivable that the alluvium would attain considerable depths close to the margin of the black slope.[1]

IMPORTANCE OF THE QUESTION:

If we inquire under what conditions the base of the mountain front will approximately coincide with the fault at the margin of the block we will find, as alternatives, that the original uplift or depression has taken place in very recent time, (that is, that the mountain block is in an early stage of the first cycle of erosion) or, that renewed uplift of the mountain block (or, of course, corresponding downthrow of the depressed block) has occurred in a correspondingly recent period.[2]

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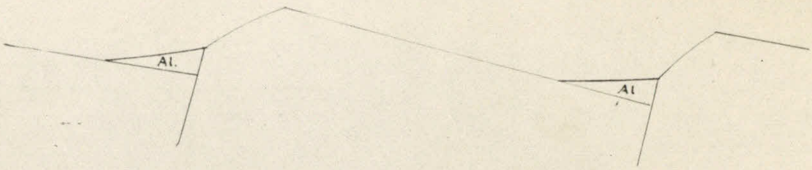
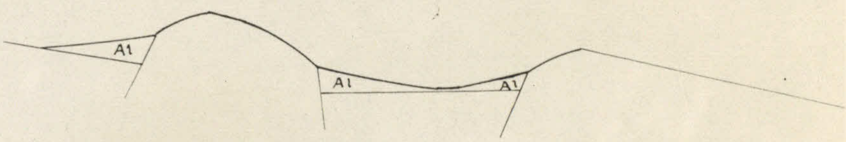
1. The question may be raised whether the principles governing the degradation of mountain ranges in an arid cycle of erosion may apple to the White Mountains. Certain features, such as the development of rock-cut pediments have been observed to occur chiefly in the Great Basin south of Latitude 38°, which marks the northern boundary of the White Mountain Quadrangle. But such differences do exist between the northern and southern parts of the basin region are apparently not related to differences in aridity but to differences in degree of diastrophic activity. Davis, (Geol. "Cycle in an Arid Climate," Journ. Geol. Vol. 13, 1905, pp. 381-407) has summarized the essential features of an arid climate as follows:So small rainfall that plant growth is scanty, that no basins of initial deformation are filled to overflowing, that no large trunk rivers are formed and hence that drainage does not reach the sea. Ground water is reduced to a minimum and weathering therefore is limited to the surface and is more physical than chemical. Streams are generally shorter than their slopes and act as discontinuously at their lower as at their upper ends. The scarcity of plant growth leaves the surface relatively free to the attack of the winds and to the intermittent water." Such conditions are certainly existent in the whole of the White Mountain Quadrangle.
2. It is assumed, of course, in both these cases that the scarps are true fault scarps and that the mountain block is in the first cycle of erosion. If the scarps, on the other hand, are fault line



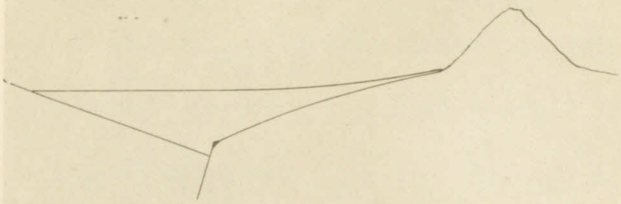
ALLUVIUM ON BORDERS OF TILTED FAULT BLOCK

(A)



ALLUVIUM ON BORDERS OF A HORST

(B)



ALLUVIUM ON MARGINS OF A QUIESCENT BLOCK

IN AN ADVANCED STAGE OF DEGRADATION

(c)

The accompanying diagrams illustrate typical development of alluvial material, (a) on the margins of a simple tilted fault block, (b) on the margins of a horst, with recurrent movements taking place along the fault planes in each case, and (c) on the margins of a quietescent block in the advanced stage of degradation.

Blackwelder has advanced the opinion that alluvial fans probably cannot be made under static conditions but are built only where normal gradients have been changed by faulting, warping, lateral erosion and the like. Fans made in response to climatic change are probably common but very thin. Thick fans probably can be deposited only in a region of active diastrophic movements.[1] Rock cut pediments, he believes, are the type of plain normally developed during quiescent periods. Such pediments are not rare but have escaped recognition.

If then we have, as we suppose, comparatively thick accumulations of detritus against both flanks of the range

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scarps, either resequent or obsequent, the essential condition is that the mountain block shall be in a very early stage of the second cycle of erosion. Even in such case it seems somewhat doubtful whether the base of the mountain front would, except in rare cases, correspond as closely with the marginal fault as a true fault scarp would do on account of the fact that inevitable differences in resistance to erosiom in the materials of one or the blocks would be sure to give rise to irregularities in the outline of the base of the scarp which might depart quite widely from the fault line in the time necessary for the scarp to develop by differential erosion.

1. Blackwelder, - Origin of Piedmont Plains - Abstract. Bull. Geol. Soc. Amer. Vol. 40, 1929, pp. 168-169.

we have confirmatory evidence for regarding the White Mountain range as a tilted horst which has been recently either uplifted or re-elevated. If we could also obtain difinite figures as to the actual depth of alluvium at different points as well as more precise knowledge of the materials which form the valley floors we would be able to make much more positive statements about the structure and the geologic history of the region than we would care to venture here.

DIP OF SUB-ALLUVIAL STRATA:

We come now to the basis for our ideas concerning the depth of the alluvium in the White Mountain cones and the amount of material which they contain. As the first bit of evidence we have the attitude of the stratified deposits which occur west of Pellisier Valley in the southern half of the quadrangle. These deposits are chiefly volcanic tuffs and conglomerates apparently of Quaternary age. Surveyed from a distance sufficient to give a general view of their behavior, these beds are seen to dip gently (perhaps ten degrees) eastward where they disappear under the material of the alluvial fans at the western edge of the valley. The average distance from the mountain front of the line along which these deposits dip under the alluvium is between two and three miles. The surface of the fan slopes westward about five hundred feet per mile. If the eastward dip of the volcanic beds continues constant, the depth of the alluvium along the mountain front in this vicinity may be calculated to be about 2500 feet, more or less, depending on the height of the particular fan which may be chosen.

Farther north, within the limits of the northern half of the quadrangle, small patches of similar volcanic material lie upon the plutonic rock of the eastward slope of Blind Spring Hill. Still farther north in a region just beyond the border of the White Mountain Quadrangle west and southwest of the Pellisier Ranch, volcanic material of the same kind overlying Quaternary basalts are also seen to possess a gentle though somewhat steeper eastward dip. It would be very unsafe, however, to attempt to project these dips as far as the margin of the range, although there is reason to believe that these Quaternary volcanics may immediately underlie the alluvium of the valley floor.[1]

EVIDENCE OF STREAM CHANNELS:

Channels eroded by the streams in the fans indicate minimum figures for the depth of the alluvium where they occur, but rarely do they disclose the total depth. Thus, at the mouth of Morris Canyon the alluvium is seen to be at least one

1. This theory has some confirmation in the occurrence of the low hills trending east-west across Pellisier Valley about three miles north of Benton Station. These hills are covered with granite alluvium but in several places outcrops of basalt project above the alluvial surface, giving the hint that other volcanic materials lie not far below the surface of the alluvium. The line of hills appears to be of structural origin, forming in reality a low southward-facing scarp which may denote the presence of a fault or of a fold depressing the valley floor to the south.

hundred feet in thickness but the base is not exposed.

At the mouth of Queen Canyon on the other hand, the stream has eorded through the alluvium into the bedrock. Here the depth of the detritus is not great. As has been pointed out, however, this is a special case dependent upon structural conditions which have been discussed. To restate the case briefly, it may be said that a sub-alluvial platform bounded by a fault or by faults at its outer margin appears to extend northwest for about a mile from the apex of the cone.

Turning to the east side of the range, we find that all of the streams have entrenched themselves in the alluvial material at the mouths of their canyons to a depth of seventy-five feet or more and are still in alluvium. Deep alluvium continues up the canyons for distances of two or three miles above their mouths. In Chiatovich Canyon, for example, the depth of the detritus as indicated by the depth of the creek channel is certainly not less than twenty-five feet or thirty feet two miles above the mountain front.

Trail Creek, flowing along the edge of the fan where it lies against the volcanic material of the hills to the north, has entrenched itself and exposed a section of the fan which is two hundred feet or more thick just west of the point at which the creek makes its great bend first to the south and then to northeast. (Refer to Plate VIII,B)

It is significant that the detrital materials exposed in all the stream channels below the mountain front, from Trail Creek south to Indian Creek, are composed almost exclusively of granite pebbles and boulders originating high up in the range, yet large exposures of basalt occur (overlying the Tertiary volcanics) just to the north and south of the mouths of each of the canyons concerned. Blocks of basalt that have rolled down from these exposures are abundant on the surface of the fans between the streams but they are almost completely absent from the materials composing the fans directly below the canyons. The inference to be drawn is that the basaltic blocks must lie in alluvium below the present depth of the channels, for streams, forming channels by headward erosion on the newly-formed scarp of a mountain block, would first attack the rocks present at the margin and deposit detritus composed of it. Later, as the stream extends itself by headward erosion, the materials obtained from the mountain front would be covered over by materials transported from somewhat farther up in the range and these, in turn, by others from still higher. All detritus now seen on the fan was derived after the canyons had attained their full length. Hence we may conclude that the alluvium extends to considerable depths below the present stream beds.

EVIDENCE DERIVED FROM FAULT SCARPS:

A third line of evidence bears on the alluvial depths - namely, that presented by the recent fault scarps. The McNett fault which trends parallel to the mountain front from Indian Creek to the southern end of Fish Lake has somewhat less than a mile south of Indian Creek and a quarter of a mile east of the mountain front, a height, due to the combined effects of displacement and erosion along its base, of nearly 150 feet. Southwest of the Molini Ranch at Dyer, the scarp at a distance of a half mile from the range has a total height, divided between two steps, which was estimated to be between 350 and 500 feet. In both cases the scarps are wholly in alluvium and in both, therefore, the alluvial depth must be at least as great as the height of the scarp.

A closely related kind of evidence is presented at the entrance to Marble Canyon on the Pellisier Valley side of the mountains. Here alluvial terraces may be observed lying against the canyon wall on either side of the stream. These terraces are exposed in cross section at the mouth of the canyon, where they have been cut off flush with the rock face of the mountain. Their height above the present level of the fan at this point is about 300 feet. The present position of these terraces is considered to be due to uplift along a fault lying close to the base of the range. The top of the terrace was formerly on or nearly on a level with the surface of the fan.[1] If this interpretation is correct, the thickness of alluvium at the mouth of Marble Canyon must be at least as great as the height of the terraces.

COMPLICATING FACTORS:

In spite of the probable great depth of alluvium near the mountain front, however, it is likely that the cones actually contain less material than their apparent size would suggest. This is in large part due to pre-faulting relief in

1. The fan may have been somewhat aggraded since the movement took place.

the sub-alluvial floor. That such irregularities exist is indicated by the fact that at several places hills and ridges belonging to the floor may be seen to project up through the alluvium. Such occurrences are to be found about three miles north of the Cinnamon Ranch in the southern half of the Quadrangle where low hills consisting in some cases of volcanic material, in others of early or pre-Paleozoic sedimentary rocks may be seen surrounded by detritus from the mountain block - diminutive " Inselgebirge". A short distance northeast and east of the entrance to Middle Canyon east of the range small hills of Tertiary volcanic material and of Quaternary basalt, are likewise to be seen rising fifty to a hundred feet above the level of the fan. In other cases the presence of low hills consisting apparently of alluvium but probably of basement material covered with a thin veneer of alluvium are to be observed, as, for example, the prominent northwest-southeast line of hills south of the Pellisier ranch.

Structural as well as topographic conditions will, of course, have a considerable bearing upon the depth of the alluvium. In a direction perpendiculat to the trend of the mountain front the profile section may be shown in the following diagram.

Various modifications or combinations may occur.

It seems logical to believe that the volcanic accumulations which are exposed in the hills west of Wildhorse Flat may continue under a relatively thin covering of alluvium (possibly several hundred feet) to the mountain front in the segment extending from Trail Canyon to Davis Canyon and possibly much farther south, descending more and more deeply beneath the surface of the alluvium with increasing distance from Trail Canyon. The reasons for this belief will be set forth in more detail in the section on structural geology. If this supposition is correct, the sub-alluvial floor rises toward Train Canyon both from the east and from the southeast and the alluvium, although it probably has a depth of several hundred feet in the angle enclosed between Wildhorse Hills and the mountain front, has a thickness still greatly less than the 2000 feet difference in elevation between apex and margin.

ROCK-CUT PEDIMENTS:

Northeast of Sand Spring and some five or six miles north of the Chiatovich Ranch are slopes which both on the map and in the field resemble those of alluvial fans. Others of similar nature are to be seen in the extreme northeast corner of the quadrangle east and southeast of the 7417 foot mountain. These slopes are covered with a thin accumulation of alluvium. In many small draws and gullies cut rock surfaces are disclosed. The surface alluvium is not over four or five feet in thickness. Underlying the detrital material are well-stratified volcanics consisting chiefly of tuffs, ash-beds and playa deposits dipping to the southeast at angles somewhat variable but in general exceeding the slope of the surface by several degrees. East of Sand Spring these rocks descend gradually under the feather edge of the valley alluvium.

SUB-ALLUVIAL BASEMENT ROCKS.

Brief mention has been made of the various types of rocks composing the foundation on which the alluvium of the valleys rests. Extended discussion of this question would be out of place in a section devoted to physiography but because of its bearing on the question (discussed elsewhere) of whether the scarps which bound the White Mountain range are true fault scarps or fault line scarps we may devote a short paragraph to the subject.

In various places in both of the valleys which bound the range sections of the basement rocks are exposed to view. On the basis of such observations fairly good inferences can be made as to what lies under the debris. In Pellisier Valley south of the southern end of Blind Spring Hill the alluvium appears to rest on Quaternary bedded volcanics which, in turn, overlie ancient dolomitic limestones, schists and slates. Farther north as far as Benton Station the alluvium probably rests either directly on plutonic rocks such as are exposed in Blind Spring Hill or on Quaternary volcanics which in turn rest on the plutonics. Still farther north the basement apparently consists of Tertiary volcanics and Quaternary basalts. At the northern end of Fish Lake Valley the sub-alluvial floor is unquestionably of Tertiary volcanics (acidic to intermediate flows, breccias, tuffs, ash-beds and playa deposits and Quaternary basalts and tuffs). South of the McNett Ranch the basement rocks are largely ancient sediments, metamorphics including dolomitic limestones, slates and schists. Plutonics intrusive into these may also occur.

NOTE ON THE USE OF WORDS "FAN" AND "CONE":

In the foregoing section the words "alluvial fan" and "alluvial cone" have been applied indiscriminately to the accumulations of detrital material which descend from the mouths of the canyons to the valley floors. The choice of the two terms seems to be largely a matter of individual preference. Blackwelder habitually uses "fan", Knopf as invariably uses "cone". I have employed both terms in order to avoid as far as possible the tiresome repetition of words and phrases so difficult to escape in such discussions as are recorded in these pages.

Cotton[1] has the following to say about the use of these words:

> "Gilbert has suggested that the term 'alluvial cone' be restricted to the steeper forms, those less steep being termed 'alluvial fans'. The term 'fan' was used as early as 1864 in New Zealand by Haast. He restricted it, however, to the sub-aerial parts of the confluent deltas - in part, probably, true fans - forming the Canterbury Plain and introduced the name 'half-cone' for the majority of what are now termed 'fans', because of their greater steepness."

In my opinion, the use of the term 'fan' tends to direct attention to the surface shape of the feature; the use of the word 'cone' on the other hand, represents an attempt to emphasize the three-dimensional nature of the accumulations.

1. Cotton, C.A. - Geomorphology of New Zealand, -Part 1, p.199, Footnote 1926, Ed.

But it should be realized that for such a purpose the word 'cone', though perhaps the best that can be applied, is by no means descriptive of the true shape of the alluvial mass, which is, in many cases at least, thinnest at the outer margin and thickest at the apex in vertical section. For most cases not even the term 'half cone' would be accurate.

ALLUVIATED CANYONS.

Attention should now be directed to the wide, level floors in the canyons of Davis Creek and Middle Creek near their mouths. In the case od Middle Creek this condition prevails for a distance of more than three miles upstream from the the eastern mountain front; in Davis Canyon it is nearly as extensive. (See Plate IX, A and B)

At first glance one might be inclined to suspect that glaciation was responsible for this valley form. But there is no evidence that glaciers were ever present here. The canyon walls are not oversteepened, the spurs are not truncated, there are no moraines. The width and flatness of the floors is quite evidently due to the accumulation of alluvial debris to unknown but probably very considerable depths. Projection downward of the slopes of the canyon walls just above the Old Davis Ranch indicates a probable depth of detritus in the middle of the canyon of four hundred feet. That this depth is very considerable is shown by the fact that the creek, close to the base of Black Mountain on the north side of the valley, has incised itself to a depth of seventy-five feet or more without cutting through the alluvium.

The detritus which is present in the lower parts of these canyons probably is in part glacial outwash material. Much of it, however, has been accumulated since the close of the last glacial epoch. The present surface does not represent the surface of the maximum accumulation. That surface, by projection of the slope of the highest terraces of the valley trains and by other evidence, is shown to be some five hundred feet above the present surface. On the other hand it does not represent the lowest level accomplished by the streams since glacial times in their work of sweeping out the debris accumulated in the canyons while the ice was present. In short there seems to be good reason to believe that thecanyons were first filled to considerable depths with alluvium, then partially cleaned out but that since the time of maximum deepening there has been a partial refilling. Such refilling has been made necessary by the growth of the great fan which extends from the mouth of Trail Canyon southeastward along the mountain front. The waste from Trail Canyon, from Dry Canyon and to a lesser degree from Middle Canyon, was restrained from spreading in normal fashion to the east and southeast by the barrier of volcanic hills to the west of Wildhorse Flat (which for convenience will henceforth be referred to as "Wildhorse Hills"), and was thus forced to build southward. As this fan grew onward it began blocking the mouths of Middle Canyon and Davis Canyon so that the streams occupying the latter were forced to aggrade their beds and hence to deposit thick accumulations of alluvium in the lower parts of their canyons. That at least part of this process has taken place since the close of the Pleistocene is indicated by the fact that the Quaternary basalts which form the crests of Wildhorse Hills have been partially buried by the detritus of the Trail Canyon composite fan. These basalts elsewhere overlie what are probably Pleistocene gravels and for this and other reasons are to be considered of recent origin. Hence there is good reason for believing that at least a part of the filling up of the canyons of Middle and Davis Creek has taken place since the end of glaciation.

Eventually the depression which existed between Wildhorse Hills and the mountain front became filled up to such an point that the stream issuing from Trail Canyon was able to find for itself a new channel leading in a northeast direction across Wildhorse Hills to the vicinity of Pinto Hill. It promptly availed itself of this channel which, formed across such soft and easily eroded volcanic rocks as tiffs and breccias, was easily and rapidly deepened. In pace with such deepening, Trail Creek intrenched itself in its old alluvial fan and at present just above the right angled bend where it changes its course sharply from southeast to northeast, the stream is two hundred feet below the surface. (See Plate V111, B)

The defection of Trail Creek slowed up though it did not stop the building of the fan. Meanwhile, renewal of faulting occured along the mountain front, re-elevating the canyons and rejuvenating the streams. Partly because of slower growth of the barrier fan but more directly as a result of the re-elevation Middle Creek and Davis Creek began once more to deepen their channels and to begin anew the task of sweeping the accumulated detritus from their canyons.

PLATE XXVII

Description of Plate XXVII

The Pellisier Erosion Surface. The camera is pointed southeast from an elevation of 13, 500 feet. White Mountain Peak is to the right. To the left is an arm of South Chiatovich Cirque.

THE OLDLANDS.

THE PELLISIER EROSION SURFACE:

In the introductory part of this thesis is to be found an empirical description of a land surface of relatively low relief which extends almost without interruption along the crest of the range from a short distance south of Montgomery Peak to the southern boundary of the quadrangle. To the portion of this surface which lies in the northern half of the White Mountain Quadrangle the designation "Pellisier Flats" has been applied on the topographic sheet. It seems better, however, in discussing this land form from the physiographic point of view to refer to it as the "Pellisier Erosion Surface." (Refer to Plate XXVII, Plate XXVIII, A, and Plate XXX, A and B)

At the outset the fa ct should be recognized that no adequate conception of the physiographic development of this erosion surface can be attained by considering only the part represented in the northern half of the White Mountain Quadrangle. Indeed a full understanding cannot be arrived at even by extending the studies to the southern part of the quadrangle. Farther south in the Inyo Range are surfaces of subdued relief, old age valleys and similar physiographic features, now at high elevations, which doubtless are closely connected in origin with the forms which are about to be described. (See Plate XXVIII, B) The evidence available along the entire extent of this long and interesting mountain range should, if carefully studied and described, yield us much valuable information concerning the physiographic history of this entire region.

The Pellisier Erosion surface as it is exhibited in the northern half of the quadrangle is for the greater part of its length not over a half mile wide, though in one place it attains a width of about two miles. It is, however, very much elongated in a dirrection approximately parallel to the trend of the mountains. As has been stated, it occupies the very crest of the range; its high points are the highest peaks of the Inyo chain. Very probably it formerly extended northward to some point beyond the present Montgomery Peak, but this northernmost portion has been destroyed by the combined effects of glacial and normal erosion. Within the northern half of the quadrangle the surface has a gradual but very definite southward slope which is very nearly the same as the southward slope of the western base of the range. The highest point on the Pellisier surface is the peak near its northern end, about two and a half miles south of Montgomery Peak, where it reaches an elevation of 13,545 feet above sea level. A corresponding point five and a half miles farther south, about a mile south of the area mapped, is 12,746 feet high. Thus the surface is seen to have a southward slope between these two points of 800 feet, or nearly 150 feet to the mile.

A glance at the topographic sheet is all that is necessary to establish the fact that the Pellisier erosion surface is a surface of low relief. In a region characterized by its steep and rugged topography it is conspicuous on the map because of the wide spacing of the contour lines. Nevertheless to arrive at satisfactory figures to express quantitatively its relief is somewhat difficult because in this region so near is it to final destruction that the erosional agencies of the new cycle have already begun their attack upon it. It is not easy to determine how much relief was inherited from the old cycle and how much must be credited to the new. Many of the streams which flow down the steep, youthful canyons of the western slope arise upon the Pellisier surface. The headwaters of such streams without question must have deepened to some degree the old valleys in which they flow.

At its eastern end the Pellisier surface is of granite but immediately south of the area mapped it truncates steeply dipping sedimentary rocks of early or pre-Paleozoic age, while still farter south it suts across intrusives and sediments. The sub-summit oldland likewise truncates the bedding of early or pre-Paleozoic slates and limestones in the region lying just south of the upper part of Indian Creek Canyon.

In an accompanying diagram is shown a longitudinal profile of the Pellisier surface from its northern end to the southern boundary of the area mapped. A second diagram shows a cross (east-west) profile about seven miles north of White Mountain Peak in the southern half of the quadrangle, while a third shows another cross profile taken about four miles south of the same peak.

It will be seen that for three miles south of the northern end of the Pellisier surface the differences in elevation nowhere exceed 200 feet to a mile. Just south of this is a southward slope about a half mile long which averages slightly less than 800 feet to the mile. This declivity may represent a structural feature of later origin than the formation of the surface. From its foot to the southern boundary of the mapped area the relief is again measured by maximum slopes of two hundred feet to the mile.[1]

Just south of the headwaters of the southern branch Of Chiatovich Creek the Pellisier erosion surface widens in a northeast-southwest direction. A profile constructed along a two mile line marked X-X on the topographic sheet should show a maximum relief of one hundred and fifty feet for the western half of the line but a northeasterly slope of five hundred feet to the mile for the other half. Still farther south, along the line marked Y-Y on the topographic sheet the maximum relief is measured by a slope of 350 feet to the mile or less than four degrees.

These figures appear to warrant consideration of the Pellisier erosion surface as one of subdued relief although perhaps the term "peneplain" may not be applicable.[2]

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1. Relief is a measure of the "roughness" of a surface but this obviously depends upon maximum difference of elevation within a given area, as, for example, a square mile, or upon degree of slope.
2. The term "Oldland" has been suggested to designate such a surface. Maxson, J.H. - Geology of the Western Siskiyou Mts.- Doctor's Thesis, Calif. Institute of Technology, 1931.

PLATE XXVIII

Description of Plate XXVIII

A. The even sky-line at the right of the picture is the edge of the Pellisier Erosion Surface as seen from the east. The transitional slope between the Pellisier surface and the sub-summit oldland may be seen at the left. From left to right of the view is five or six miles.

B. The Pellisier Erosion Surface as seen to the south from White Mountain Peak.

PLATE XXVIII

A

B

Farther south in the region a short distance north of White Mountain Peak small fragments of the Pellisier surface are scattered along the crest of the range, varying in altitude from 12,700 feet to 13,700 feet. White Mountain Peak itself, at an elevation of 14,242 feet is a fragment of the old surface, upfaulted on the north and tilted south.

South of White Mountain Peak the Pellisier surface broadens considerably and continues along the crest at elevations ranging between 12,500 and 13,000 feet, as far south as Sheep Mountain,(12,487 feet) two miles north of the southern boundary of the quadrangle.

THE SUB-SUMMIT OLDLAND:

The western rim of Indian Creek cirque - that is, the line of intersection between the westernmost wall of the cirque and the Pellisier Flats - is a remarkably sharp, straight line, trending slightly to the west of south. The southward projection of this line is continued in a rather steep easterly slope which seems to mark a boundary between the high plateau area belonging to the Pellisier erosion surface to the west and another more extensive surface of low relief to the east, which for convenience will be temporarily designated as the "Sub-summit Oldland".

The latter slope has an inclination of about 1400 feet to the mile. The elevations at the western margin vary between 12,500 and 12,700 feet. Those to the east are about one thousand feet less. (See Plate XXIX, A, and Plate XXXI, A and B)

The maximum relief of the sub-summit Oldland is about the same as that of the Pellisier surface. Cabin Creek and its tributaties, which flow across it, have doubtless somewhat deepened their valleys and accentuated the relief inherited from the earlier cycle of erosion. The surface has a general slope to the east of about 350 feet to the mile.

About three miles northeast of White Mountain Peak, separated from the fragments of the Pellisier surface along the crest of a fairly steep slope, lies a small almost level surface at an elevation of about 11,500 feet. This may be a relict of the sub-summit oldland.

Beginning northeast of Grey-haired Johnny's Corral and running irregularly south and southwestward is another rather steep scarp, 1000 to 2000 feet high, which separates the high plateau (Pellisier surface) on the west from a lower surface (designated on the map as Tres Plumas Flat) to he east. This flat, which is probably representative of the sub-summit oldland, slopes southeastward north of Cottonwood Creek at an average rate of about 450 feet per mile to a low point at 8000 feet in the southeast corner of the quadrangle. Cottonwood Creek and its tributaties, as well as the north fork of Crooked Creek, flow at the bottom of deep trench-like canyons as much as a thousand feet deep which they have incised into the old age surface. North of Cottonwood Creek the oldland is fairly continuous, though in places dislocated. South of that stream, however, it has been dissected to such a

PLATE XXIX

Description of Plate XXIX

A. Looking north across a part of Davis Cirque. The Pellisier Erosion Surface is just visible above the snow banks to the left. Fragments of the sub-summit oldland may be seen on the inter-stream ridges to the right.

B. Headwater erosion proceeding along a fault. The depression marks the trace of the fault.

PLATE XXIX

A

B

degree in the new cycle of erosion that its former oresence is indicated only by accordant crests of the inter-canyon ridges and summits.

Just to the north of Post Meadows on Indian Creek is a conspicuously flat-topped mountain known as Davis Mountain, step-faulted by northwest trending faults at its northern end. A flow of Quaternary basalt, fifty to a hundred feet thick, forms its summit. The surface upon which the basalt flowed, now exposed in section on the Indian Creek side, appears to have been nearly flat. At the southwest end of the mountain, contact metamorphic rocks underlie the basalt. In the central part granite is the basement rock. Farther northeast the basalt rests upon the ancient sediments. At the extreme northeast end it extends evenly across the upturned edges of rather steeply tilted Tertiary volcanics. The basalt, in short, appears to lie upon an oldland which may be considered to correspond with the sub-summit oldland. (Plate LII,A)

RELATION OF THE EROSION SURFACES:

It appears likely, from the evidence available, that tere were formerly two plateau levels extending continuously or nearly continuously along virtually the entire length of that portion of the Inyo Range included in the White Mountain Quadrangle. The higher of the two, the Pellisier Erosion Surface, has an apparent southward slope of, roughly, 1000 feet in twenty miles. The average elevation of its summits is not far from 13,000 feet. The sub-summit oldland slopes gently

PLATE XXX

Description of Plate XXX

A. Topography south of Indian Creek. A part of the sub-summit oldland is seen on the ridge in the upper right.

B. Looking north from a point about four miles north of White Mountain Peak. The Pellisier Erosion surface is seen in the distance. The Montgomery scarp is to the left.

southeast at an angle which is somewhat greater than that of the southward slope of the Pellisier surface. The two surfaces may, therefore, have been identical at the northern end.

Two possibilities are now to be considered. Either there are two surfaces of low relief or the lower one is a downwarped or downfaulted portion of the Pellisier surface. If the first alternative is correct, there still remains a question of whether they were produced in the same cycle or in different cycles of erosion.

Fortunately a good section across the line of escarpment is exposed in the cirques at the head of Indian Canyon (east slope) and Davis Canyon. So far as could be determined neither faulting nor folding have occurred along this line. It does here approximate a surface of contact between slates of Paleozoic or pre-Paleozoic age and plutonics intrusive into them, but only a short distance farther south the slope is underlain by slates.

Since this evidence leads to the rejection of the structural hypothesis, the conclusion must be adopted that there are two subdued surfaces, both of which can be shown to be the products of errosional processes, connected with each other by transitional slopes. To account for the presence of these two surfaces one has a choice of several explanations. The first of these is that the two surfaces represent two co-existing peneplains (old age surfaces) formed in different cycles of erosion. A second is that the higher surface forms the unreduced highlands of the sub-summit oldland and that both

PLATE XXXI

Description of Plate XXXI

A. Part of the sub-summit oldland at an elevation of 11 000 feet south of Cabin Creek.

B. Another view of the sub-summit oldland. Cabin Creek nearly on the vertical center line. At the extreme right is part of the north wall of Leidy Canyon. At the extreme left is part of the south wall of Indian Cirque. Fish Lake Valley is in the hazy distance.

therefore, are products of the same cycle of erosion. A third hypothesis, which is perhaps only another way of expressing the second, is that the sub-summit oldland is a portion of the floor of a wide old age valley eroded into the Pellisier surface and properly to be considered a part of it.

It would be difficult to choose from among these explanations on the basis of the evidence available in the White Mountain Quadrangle. It does not, however, as a matter of general principle seem reasonable to suppose that even a relatively small fragment of a peneplain, or old age surface, could continue to exist during the whole of the enormous time required for the uplift, dissection and reduction to low relief of a contiguous surface. Some workers, nevertheless, have advocated the existence of as many as three co-existing peneplains for the Front Range of the Rocky Mountains in Colorado, several have admitted two while one has claimed as many as five.[1]

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1. Chamberlain- Building of the Colorado Rockies- Journal of Geology 27; 158-162, 1919.
Davis, W.M.- The Colorado Front Range - Assoc. Amer. Geogr. Ann., Vol. 1, pp 48-64, 1911.
Lee, W.T. - Peneplains of the Front Range at Rocky Mountain National Park, Colorado, U.S.G.S. Bull. 730, 1922.
See also:
Ball, Sidney H. - Geol. of the Georgetown Quadrangle, Colorado, U.S.G.S. Prof. Paper 63, pp. 30-34, 1906.
Blackwelder, E.- Cenozoic History of the Laramie Region, Wyoming, Journ. Geol. Vol. 17, 1909.
Darton, N.H. U.S.G.S. folio 173, 1910.
Fenneman, N.M. Geology of the Boulder Dist.,Colo. U.S.G.S. Bull. 265, 1905.
Lovering, T.S.-Geologic History of the Front Range,Proc. Colo. Sci. Soc. Vol. 12, No. 4, 1929.

Lindgren thinks that in the northern Sierra Nevada flat-topped ridges belonging to a Cretaceous Peneplain rise above a middle or late Tertiary oldland.[1] It may be possible, therefore, that the end-products of two or more cycles of erosion may exist in near proximity to each other. As for the occurrences in the White Mountains, however, I prefer to regard the sub-summit oldland as having been formed at approximately the same time as the Pellisier erosion surface, being possibly a remnant of a late mature or old age valley eroded below the general level of the Pellisier erosion surface.

The question may be raised whether the erosion surfaces which have been described may not be of the type called "primary peneplains" ("Primarrumpf) by Penck (See Sauer, Carl: Land Forms in the Peninsular Range of Calif. U.C. Pub. in Geol. Vol. 3, No. 4, 1929, p. 212.) This hypothesis is rejected for the following reasons:

1) On neither the Pellisier erosion surface nor the sub-summit oldland are the accumulations of detrital material to be found in such amounts as would be collected in the formation of a "primary peneplain".

2) Between the southern boundary of the area mapped and White Mountain Peak the Pellisier erosion surface has apparently been displaced by a number of faults transverse to the trend of the range. The age of these faults in resepct to the time of uplift of the mountain block is not definitely known

1. Lindgren, W. - The Tertiary Gravels of the Sierra Nevada of Calif. U.S.G.S. Prof. Paper 73, 1911, p. 39.

but Kirk (Knopf and Kirk, U.S.G.S. Prof. Paper 110, 1918, p.27) thinks that many of the transverse faults of the Inyo Range are considerably older than the latest great displacement along the sides of the range.

3) The burial of what is probably a part of the sub-summit oldland by basalts, as on Davis Mountain, indicates that this surface was formed at a time before movements took place which elevated the range three or four thousand feet.

COMPARISON WITH THE SIERRA NEVADA PENEPLAINS:

The existance of remnants of one or more old age surfaces in the Sierra Nevada has been recognized by geologists for many years. G.K. Gilbert was the first to call attention to the existence of the so-called "Sierra peneplain" which underlies the Tertiary lava flows on the west slope of the morthern Sierra.[1]

Later, Lindgren, studying the auriferous gravels of the gold belt, emphasized the existence of this erosion surface, which, however, he denied could be properly described as a peneplain on account of its considerable relief.[2]

Lindgren further noted that many of the ridges and peaks which arise above the general level of the Sierra "peneplain" are flat-topped and of accordant levels. These he considered to belong to a peneplain formed in an earlier cycle of erosion.

1. Gilbert, G.K.- Science, Vol. 1,1883, pp. 194-195.
2. Lindgren, Waldemar, - Tertiary Gravels of the Sierra Nevada, Calif., U.S.G.S. Prof. Paper 73, 1911, pp. 37-39.
3. Lindgren, W., Op. cit. pp. 39-44; Lindgren, Journ.Geol. 4, 1896, p. 894.

Meanwhile Professor Andrew C. Lawson had been conducting his notable studies of the geomorphogeny of the region about the headwaters of the Kern River in the southern Sierra Nevada.[1] In the course of these studies he noted and described three hypsometric zones which he designated as the High Mountain zone, the High Valley zone and the Canyon zone. The High Mountain zone he subdivided into the Summit Upland and the Subsummit Plateau, both of which appear to represent earlier surfaces of low relief. The summits of Mount Langley, Mount Whitney and Mount Barnard are fragments of the Summit Upland, while various flat-topped ridges and lofty masses at elevations 2000 to 2500 feet lower are considered to belong to the Subsummit Plateau. In the vicinity of Mount Whitney the two levels are discontinuous but on Diamond Mesa, just north of Mount Tyndall, they are seen to be connected by flowing transitional slopes. Farther south the higher surface disappears and the Subsummit Plateau becomes literally the summit upland. From the Mount Whitney region south to Mulkey Meadows, a distance of twenty miles, the Subsummit Plateau slopes avout 2000 feet or an average of one hundred feet to the mile.

Lawson considered that the Summit Upland was a durface of differential degradation controlled by the contact sur face of the batholitic mass with the softer schists which it inintruded. Knopf, however, has shown that the batholitic roof

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1. Lawson, A.C.- Geomorphogeny of the Upper Kern Basin. Univ. Calif., Bull. Dept. Geol. Sci. Vol. 3, 1904, pp. 292-376.

PLATE XXXII

Description of Plate XXXII

A. Fragment of basalt-covered plateau north of Trail Canyon. The camera points southeast.

B. Basalt plateau north of the Queen fault scarp.

is an extremely uneven surface and that the surface of the Summit Upland transgresses schist and granite alike without discrimination.[1] He therefore considers Lawson's hypothesis to be inadmissible and explains the Summit Upland as being "merely the unreduced interstream areas of the surface of erosion represented by the Subsummit Plateau; the two surface features are confluent and were formed during the same period of erosion." [2] As to the Subsummit Plateau, Lawson correlates this with the Sierra peneplain farther north.

The High Valley zone or Chagoopa Plateau of Lawson consists of residual portions of broad valleys with gently sloping walls whose lower levels are one or two thousand feet below the surface of the Subsummit Plateau. Included in this High Valley System are many of the wide, grassy meadows which today occur on the west slope of the Sierra. In places there is a tendency for the different valleys in the High Valley systems to coalesce to form local peneplains of a younger stage than that represented by the Subsummit Plateau and the Summit Upland. Some of these valleys on the eastern slope are, according to Knopf, abruptly truncated by the steep eastern fault scarp of the Sierra Nevada.[3]

In the bottoms of the valleys of the High Valley zone deep V-shaped canyons were incised by the streams which flowed in them in a subsequent period of uplift. Many of the

1. Knopf, A. Geologic Reconnaissance of the Inyo Rangeand of the the Eastern Slope of the Southern Sierra Nevada, Calif. U.S.G.S. Prof. Paper 110, 1918, p. 83.
2. Op. cit.
3. Knopf. Op. cit. p. 85.

canyons were later modified in part by glaciation. Such was the canyon of the Kern River. These canyons form the Canyon zone of Lawson.

To the northwest, Matthes has observed similar conditions along the course of the Merced River.[1] Traces of the Sierra Peneplain are here preserved in the accordance of summit levels (The Yosemite Upland). Below the level of this ancient surface are remnants of two systems of old age valleys, the one within the other, formed in subsequent periods of erosion. Deeply entrenching the inner valley is the narrow V-shaped pre-glacial gorge of the Merced, deepened and widened along part of its course into the Yosemite.

In the region northeast of Lake Tahoe, Reid noted a number of flat summits and ridges which he considered to be remnants of a peneplain. This, he believed, should be correlated with the older erosional surface described by Lindgren.[2]

Still further north in the Northern Cascade Mountains other peneplains have been described.[3] Daly, however, denied that such a peneplain was present in the Cascades and in a well known paper referred the accordance of summit levels to other causes.[4]

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1. Matthes, F. - Geologic History of the Yosemite Valley, U.S. G.S. Prof. Paper 160, 1930, pp.
2. Reid, J.A. - The Geomorphogeny of the Sierra Nevada Northeast of Tahoe, Univ. Calif. Pub. Bull. Dept. Geol. Sci. Vol. 6, 1911, pp. 109-110.
3. Russell, I.C. - U.S.G.S. 20th An.Rept. Pt. 2, 1899,p. 144: Willis,Bailey, U.S.G.S. Prof. Paper 19, p. 48, 1903. Smith and Calkins, "Reconnaissance Across the Cascade Range Near the 49th parallel, U.S.G.S. Bull. 235, 1904, p. 86.
4. Daly, R.A. - Can Geol. Surv. Mem. 38, 1912.

AGE OF THE PELLISIER EROSION SURFACE:

In the White Mountains the Pellisier erosion surface appears to bevel in places the upturned edges of volcanic rocks belonging to the Esmeraldo Formation of Tertiary age. This formation was formerly assigned to the Upper Miocene and a portion of it, as evidenced by horse remains which I have discovered in the Fish Lake Valley[1] occurrences, undoubtedly belongs to that period. On the other hand I consider it probable that the upper part of the series belongs to the Pliocene. This belief is based on the fact that in parts of the area, as in the northeast quarter of the quadrangle, the stratified volcanics appear to form an uninterrupted succession to the base of the Quaternary basalts which they conformably underlie. The opinion seems to be substantuated by the most lately expressed opinions of the vertebrate paleontologists.[2] It is not entirely clear to which part of the section the beds bevelled by the Pellisier surface should be referred but from the evidence at hand it is improbable that the Pellisier erosion surface is earlier than Uppermost Miocene or Lower Pliocene. Its Upper age limit is definitely fixed by Quaternary lavas which at various points near the eastern margin of the range lie unconformably upon it.

CORRELATION:

The attempt to correlate erosion surfaces, being

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1. See page 226
2. Stirton, R.A. - Science, Vol. 76, 1932, p. 60.

based mainly upon deduction without possibility of corroboration, usually leads to dubious results. The following discussion, therefore, is intended to be suggestive rather than conclusive.

The similarity between the summit topography of the White Mountain-Inyo Range and that of the Sierra Nevada west of Owens Valley is striking. The relation of the Pellisier erosion surface to the sub-summit oldland closely resembles that of the Summit Upland to the Sub-summit Plateau or of the latter to the High Valley zone of the Sierra. The comparison if extended to altitude, slope, degree of relief and other features becomes increasingly impressive. If it is true that the summit region of the White Mountains as described here does not exhibit all of the features which may be seen in the Sierra, as, for example, extensive High Valley and Canyon zones, the reason may be found, at least in part, in the much narrower width of the White Mountain block and in the comparatively small size of the area carefully examined. Areas of similar extent indeed, may readily be found along the crest of the Sierra Nevada in which not all of physiographic features described by Lawson are exhibited. Brief preliminary observations indicate that further studies south of the region covered by this report will disclose even more pronounced similarites in the physiography of the two ranges.

It is quite possible that the Pellisier erosion surface may be the correlative of the Sub-summit Plateau of Lawson and that the Sub-summit Oldland may correspond to the Chagoopa Plateau. If this hypothesis is correct, the equivalent of the Summit Upland is not found in the White Mountains. According to Knopf (U.S.G.S. Prof. Paper 110, 1918, pp. 82-83) this is the case in the vicinity of Mulkey Meadows and southward in the Sierra Nevada.

Lawson has correlated the Subsummit Plateau with the Sierra peneplain but this correlation seems somewhat doubtful, according to Knopf, on account of the greater relief of the latter.[1] Matthes assigns the Sierra Peneplain to the Miocene,[2] as does also Diller.[3] Lawson in his various papers considers it to be Pliocene. Lindgren [4] is content to consider it early Tertiary. If Lawson is correct in his correlation and if Matthes and Diller are also correct in dating the Sierra Peneplain, it sould seem that the Subsummit Plateau is of somewhat earlier date than the Pellisier erosion surface. It must be admitted, however, that this chain of evidence is decidedly weak.

On the other hand, it should be noted that there is some doubt about the age of the Pellisier erosion surface, inasmuch as it has not yet been possible to exactly date the beds of the Esmeralda series which the surface bevels. Moreover, as has been stated, Lawson's correlation is also in some doubt. In spite of these uncertainties it seems ressonable to tentatively correlate the Pellisier surface with the surface at the crest of the Sierra Nevada in view of the remarkable similarity between the summit topography of the two ranges.

Baker, it should be noted, correlates the Ricardo peneplain which bevels the Rosamond series of probable early

1. Op. Cit. pp. 83-84.
2. Op. cit. p.
3. U.S.G.S. 14th An. Rept. p.
4. U.S.G.S. Prof. Paper 73, p.

Pliocene age, with the Chagoopa Plateau of High Valley zone of Lawson.[1] This also would tend to push the formation of the Subsummit Plateau back into the Miocene. But as Knopf points out,[2] there is some weakness in the chair of correlation:

> "inasmuch as the Ricardo erosion surface is correlated with the summit upland represented by broadtopped mountains in the vicinity of Walker Pass, and this summit upland is in turn correlated with the high level floor of the Kern. But the ancient floor of the Kern lies some two thousand feet below the Subsummit Plateau and the Summit Upland which together constitute the summit topography of the Sierra Nevada."

Matthes considers that the older of the two old age valleys represented in the Merced River region was formed in the Miocene, while he assigns the latter one to the Pliocene.

The peneplain which Reid has reconstructed for the region northeast of Lake Tahoe[3] he considers to be equivalent to the older peneplain recognized by Lindgren which the latter believed to be Cretaceous in age.

Maxson[4] assigns the peneplains of the Crescent City region to the Pliocene and argues for the existence of a Pliocene peneplain of general extent throughout the western region.

The Cascade peneplain has been referred to the Pliocene.[5]

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1. Baker, C.L. - Univ. Calif. Publ. Bull. Dept. Geol. Sci. Vol. 7, 1912, pp. 137-139.
2. U.S.G.S. Prof. Paper 110, 1918, p. 87.
3. Reid, Op. cit., pp. 109-110.
4. Op. cit., p. 62.
5. Willis, B. - U.S.G.S. Prof. Paper 19, 1903, p. 69; Russell, I.C. - U.S.G.S. An. Rept. Part 2, p. 144.

It is evident, nevertheless, that our knowledge of western peneplains is still too incomplete to make safe any attempts at generalizations, either in respect to age, correlation or extent. That surfaces of moderate to low relief were quite common in the middle or late Tertiary, however, there can be no doubt.

William Morris Davis has pointed out that in general the structural and physiographic development of the ranges of the Great Basin has taken place in three stages. In the first stage mountains were formed by the folding of the sediments. These Davis designates as the "King Mountains". In the next stage extensive peneplains were formed. To the old age surface which so frequently truncates the folded sediments of the King Mountains, Davis has applied the general term "Powell Surface." In the third and last stage block faulting and uplift occurred. The forces of erosion began again their levelling process. The basin ranges as we now know them are the result. These Davis calls the "Gilbert Mountains." In general they are in the youthful or early mature stage of the second cycle of erosion. Upon their crests are frequently preserved remnants of the old Powell surface. Thus we see how well the White Mountains fit into the general scheme.

SUMMARY OF THE SECTION ON GLACIATION:

Evidence for the former presence of glaciers in the White Mountains is to be found in several of the canyons on the east slope of the northern part of the range. Glaciation does not appear to have occurred on the western side except possibly in the canyon of Morris Creek. This is to be explained not by differences in precipitation but by a more rapid melting of the snow on the southwestern slope.

The glaciers were probably all short. Recognizable morainal material is nowhere found below an elevation of 8200 feet. Nevertheless glacial ice was an important and effective agent in sculpturing the details of the White Mountain Range.

Evidence has been found for at least two epochs of glaciation. In the earlier one cirques were formed in the upper parts of the canyons of Indian Creek (east), Davis Creek, North and South Chiatovich Creeks and Middle Creek. In the second and less important stage ice returned only to the cirques of Davis Canyon, North and South Chiatovich Canyon and to a part of the cirque of Middle Canyon. These, for various reasons, were the most favorable locations for glaciers. In this stage the cirques were rejuvenated and morainal material deposited.

Blackwelder's criteria for the glacial stages of the Sierra Nevada and the basin ranges, when applied to the White Mountain occurrences seem, in spite of certain discrepancies, to indicate that glaciers were active here in Tahoe and Tioga times.

GLACIATION.

INTRODUCTION:

Glaciers formerly occupied many of the canyons of the east slope of the White Mountain Range. At least two, perhaps three of the glacial stages recognized in the Sierra Nevada are represented.

Proof that glaciers existed in the White Mountains consists of well-defined cirques, moraines, remnants of terraces belonging to glacial valley trains, U-shaped canyons and oversteepened valley walls, roches moutonnees, polished and striated rock surfaces and, in one or two instances, very small glacial lakes or tarns. Certain glacial phenomena, as hanging valleys and diverted streams, were not noted.

On the northeast side of White Mountain Peak, at the head of the middle branch of the North Fork of Perry Aiken Creek, is a well preserved cirque with much morainal material. This, however, is in the southern half of the quadrangle and will not be described. I have observed no evidences of glaciation elsewhere in the southern portion of the White Mountain Range.

INDIAN CREEK:

The large semi-circular amphitheater which forms the head of Indian Creek Canyon (east) is probably a cirque, much modified but still clearly possessing the characteristic shape.

PLATE XXXIII

Description of Plate XXXIII

A. Looking up Indian Canyon from an elevation of about 9 000 feet, showing morainal material in middle distance.

B. Looking up South Chiatovich Canyon from an elevation of 11 000 feet, showing glacial topography partially obscured by talus and landslide material.

It is the largest cirque in the range. Its extreme breadth, northwest to southeast, is about three miles and its maximum depth, valley floor to rim, is 3300 feet. The steepest slope of the cirque walls is not less than thirty-four percent, which is equivalent to thirty-one degrees. The rocks which compose the walls are complex, consisting in part of intrusives of granodioritic composition, in part of Paleozoic or pre-Paleozoic sediments, and in still greater part of a contact metamorphic complex which includes rocks of a great variety of composition and textures.

An accumulation of material with a steep frontal slope and a hummocky surface is found in Indian Canyon above an elevation of 9000 feet. This material is in part of glacial origin. Much of it, however, has been deposited as the result of landslides and of talus accumulation since the departure of the ice. The proportions of these various kinds of materials are not easy to estimate for the discrimination of glacial from non-glacial detritus in such cases is difficult. The accumulations as a whole are in a rather advanced stage of dissection. Plate XXXIII-A, illustrates this material.

Large talus cones lying at various points against the cirque walls indicate a considerable age for the cirque.

The comparatively wide, flat floor of the upper part of Indian Canyon is further evidence of glaciation. Partial filling of the canyon by detrital material carried out by streams issuing from the front of the short glacier is thought to be responsible for this condition. A longer glacier may have occupied the lower part of the canyon in more remote times but I have not recognized any evidence of its presence in the form of morainal material or of marked oversteepening of the lower parts of the canyon walls.

The short tributary canyon which joins the main canyon from the northwest at Post Meadows has a similar wide flat floor. This represents detritus accumulated as the tributary canyon aggraded its floor to keep pace with the aggradation in the main canyon.

DAVIS AND CHIATOVICH CIRQUES:

The cirques which are to be found at the headwaters of Davis Creek and of the two branches of Chiatovich Creek are more nearly perfect in form and fresher in appearance than any others observed, while the moraines in the canyon below are correspondingly more complete and less affected by erosion. Grooved and polished rock surfaces, rarely observed in the Indian Creek cirque, are somewhat more abundant here. Talus cones and landslide material form much smaller accumulations th than in the case we have just discussed. "Glacial stairs" form a noticeable feature of the topography. Above the moraines the canyons have the characteristic U-shape and oversteepened walls. Truncated spurs and hanging valleys are rare or absent but this is because the glaciated parts of the canyons had not formed lateral tributaries before the coming of the ice.

The morainal material is typical in character. It has a hummocky surface, its down-valley slopes are steep and it is composed of sub-angular boulders unsorted as to size and material, sometimes exhibiting glacial striae. The largest boulder measured lies on the surface of the moraine at an elevation of 8800 feet in Davis Canyon, It is of coarse-grained Pellisier granite, very little weathered. It is oval in shape and twenty feet wide by twenty-four feet long, projecting ten feet above the surface of the moraine. Many others were observed nearly as large.

In Davis Canyon material unquestionably of glacial origin extends down the canyon as far as 8200 feet. (Plate XXXV A and B) In the other two cases discussed in this paragraph the lowest accumulations of glacial debris clearly recognizable as such occur at elevations of 8600 to 9000 feet, or about where the old California-Nevada boundary line crosses the creeks in question. In Davis Canyon the moraine front is not steep and the change from morainal material to stream alluvium is neither sharp nor readily determined. Undoubtedly Davis Creek in the process of grading its bed since glacial times has removed much material from the moraine and has redeposited it where the abrupt change in the slope from moraine front to canyon floor occurred. In the two branches of Chiatovich Creek, however, the front of the moraine is much more sharply defined. The steepest and best preserved moraine front of the three is the one in the canyon of the north branch of Chiatovich Creek. It is more than 600 feet high with a slope of about thirty degrees. This is probably a terminal, though there is a possibility that it may be in part a lateral moraine. In the case of the south fork of Chiatovich Creek, the moraine front is as high but

PLATE XXXIV

Description of Plate XXXIV

A. Moraine near 10 000 foot contour in South Chiatovich Canyon. Behind the moraine is a small glacial lake or tarn.

B. Secondary moraine, probably recessional, at an elevation of about 10 000 feet in North Chiatovich Canyon. The entire foreground is morainal material.

much less steep.

In descending the fronts of the moraines the streams have in all cases incised themselves deeply into the detrital material. The maximum depth of such channels is attained in North Chiatovich Creek and in Davis Creek, where it is as much as two hundred feet. In the case of the latter stream the entrenchment extends for two miles with gradually diminishing depth toward the head of the canyon. Usually the streams follow rather closely the line of contact between morainal material and the valley wall.

Both terminal and lateral moraines occur and probably also the so-called "ground moraine". The laterals are rather low and not continuous, for the walls of the cirques and of the glaciated part of the canyon are in general too steep to permit the retention of much morainal material on the slopes. Much of the material that formerly was present in the laterals appears to have slid down from the two sides of the narrow canyon and to have become distributed over its floor, so that a transverse cross section of such part of a canyon exhibits a moraine surface from wall to wall which is somewhat concave upward. It is difficult in such a case to distinguish lateral moraines from ground ground moraines. The only usable criterion is based on the assumption that the boulders of the ground moraine would be somewhat more angular than those of laterals, but this is not reliable. Much of the material present in both cases has been transported so short a distance that the degree of angularity is high. The situation is complicated, moreover, by the fact that a considerable amount of material has been deposited on the canyon floor as the result of processes closely related to those involved in the accumulation of talus cones, that is, by the loosening and rolling down of blocks from high up on the oversteepened walls. It is often very difficult to distinguish materials accumulated in this manner from those deposited by glaciers near their source.

A lateral morainal ridge parallels the north side of Davis Canyon below the point at which the 10,000 foot contour crosses the creek. It is separated from the canyon wall by an undrained narrow depression fifty to seventy-five feet deep into which fine alluvial material has been washed.

On the south side of the canyon is a similar ridge over a hundred feet high which blocks the mouths of two rather large tributary canyons within a mile west of Boundary Marker 62 on the Nevada-California line. The small streams from these canyons have now succeeded in cutting a deep narrow gorge through the morainal material through which they flow into Davis Creek.

Both of these lateral ridges lie upon the surface of the morainal material which fills the canyon to an apparent depth of several hundred feet. They may be perched laterals.

Several small, probably medial, moraines occur. The most easily recognized of these is the one forming the nose of the ridge which separates the north and south branches of Chiatovich Creek.

Secondary terminal moraines occur upon the surfaces of each of the principal terminals which have just been described. These are especially well exhibited on the north fork of Chiatovich Creek. (Plate XXXIV - B and Plate XXXVI - B). Here a secondary moraine, approximately fifty feet in height, lies superimposed upon the principal one about a quarter of a mile above the lower margin of the latter. Continuing up stream another quarter of a mile one is confronted with a second morainal scarp with a height of about 150 feet trending transversely across the canyon at the 9900 foot contour. To be directly correlated with these are similar features on South Chiatovich and Davis Creeks. In the former the secondary terminals occur at 9300 and 9800 feet. (Plate XXXIV - A)

I was at first inclined to consider these secondary moraines as recessional in character. This conclusion seemed to be substantiated by an examination of the materials composing the two sets of moraines, which disclosed no apparent significant difference in the degree of weathering exhibited in the boulders included in them nor in the numbers of boulders to be found on their respective surfaces. But Blackwelder gives the average height of the terminal moraines of the Tioga stage on the eastern slope of the Sierras as twenty-five feet with few over seventy-five.[1] In view of this it seems doubtful whether a terminal moraine of the height of one hundred and fifty feet should be considered a recessional although, as Blackwelder himself admits,[2] the relations between the Tioga and the preceding

1. Blackwelder, E.- Glaciation in the Sierra Nevada and Basin Ranges. Bull. Geol.Soc.Amer. Vol. 43, Part 2, 1931, -. 884.
2. Op. cit. p. 887.

PLATE XXXV

Description of Plate XXXV

A. Moraine in Davis Canyon. To the right of the center of the view is a morainal ridge blocking the mouth of a tributary canyon from the southwest.

B. Another view of the morainal material in Davis Canyon. Looking down the canyon from an elevation of about 10 500 feet.

glacial stage are so close that some observers have preferred to regard them as one stage with two advances separated by a retreat. Moreover, it is readily apparent that the height of a terminal moraine will be somewhat dependant not only upon the size of the glacier and the length of its life but also upon its topographic setting. A glacier in a deep narrow canyon would receive much more material upon each unit of its surface by the rolling down of material from the canyon walls and it would therefore deposit more material in a given time at its terminus. The different sets of moraines above described deserve more careful and detailed study with a view to determining their true character than I have had time to devote to them.

The boulders and pebbles composing the moraines just described, as well as those which occur in the Middle Creek moraine, have been derived from intrusive igneous rocks of prevailingly intermediate composition - that is, quartz monzonite to granodiorite. The chief differences are in texture. Most of the rocks are medium to coarse grained but a few are rather fine-grained and compact. Boulders and pebbles of aplite make up about ten percent of the whole. Very few show grooves, striae or polish, yet most of the material has a comparatively fresh appearance. None of it, certainly, is deeply decomposed although there is a certain degree of staining and discoloration.

Several "treads" of a glacial stairway occur in all three canyons but these are better exhibited in the canyon of North Fork of Chiatovich Creek than in either of the others.

Examples are to be found at 10,500 feet in this canyon, The first step is over 200 feet high, the second over 300. Another, 400 feet high occurs at the same elevation in Davis Canyon, where the bare rocks plainly exhibit striations and polishing.

Glacial sculpture has produced hanging cirques or corries in all three of the canyons described in this section. These are most noticeable in the canyon at the head of North Chiatovich Creek. A glance at the topographic sheet will disclose their location. The largest lies just north of the 13,500 Bench Mark on Pellisier Flats. The bottom of this corrie is not more than 500 or 600 feet below the rim of the Pellisier Flats but it is at least 800 or 900 feet above the floor of the main cirque.

MIDDLE CREEK AND TRAIL CANYONS:

It is probable that the entire upper part of Middle Canyon was formerly a cirque but the northern portion has been so much modified by erosion that any former cirque-like features have been largely destrpyed. These are now clearly recognizable only in the area lying to the northeast of the 13, 545 triangulation station on Pellisier Flats.

The Middle Canyon moraine has been greatly disected and large portions of it have been covered by talus and by landslide material. Nevertheless, its original character, particularly in the southern part, can still be discerned.

As in Davis Canyon and in both Chiatovich Canyons. the streams tributary to Middle Creek have deeply incised the moraines. The trenches thus formed are deeper than in the cases above described, especially in the northern portion of the old cirque, where they may reach 200 feet. Moreover, they are not limited to the terminal part of the moraine but extend back with gradually diminishing depth for more than three quarters of a mile from the margin of the latter.

In Trail Canyon no glacial debris of any kind was observed. Although the canyon head bears some resemblence to a cirque the likeness is less striking than in the cases that have been described. There is no clear evidence that a glacier ever occupied any portion of Trail Canyon. (Plate VIII-A)

GLACIAL OUTWASH MATERIAL AND VALLEY TRAINS:

Downstream from the fronts of the moraines in Middle and Chiatovich Canyons are alluvial terraces which may be remnants of glacial valley trains. Such terraces are especially well exhibited in Middle Canyon, where five sets occur. The highest can be traced directly up the canyon to the moraine front which it joins at the base of its slope. In Chiatovich Canyon only one set of terraces is clearly defined.

The terraces of Middle Creek vary in height above the present valley floor from about ten feet for the lowest to about two hundred feet for the highest in the middle portion of the canyons. The formation of these terraces is probably more directly connected with uplift resulting from faulting along the eastern front of the mountains than with the decreased load of the streams after the retreat of the ice. Nevertheless, the uppermost terrace level may represent the depth to which the valley was filled with debris deposited by the overloaded streams as they issued from the front of the glaciers. Near the mouths of their canyons Davis Creek and Middle Creek now flow in channels the bottoms of which are from fifty to seventy-five feet below the valley floors. The total down-cutting of these streams, measured by the difference in elevation at the mouths of the canyons between the present stream level and the uppermost terrace level projected to the canyon mouth, may be ascribed to various changes in conditions which have taken place since glacial times. This difference in elevation is not far from 600 feet.

At various points along the eastern margin of the mountains occur thick accumulations of alluvium overlain by Quaternary basalts. Such an occurrence is strikingly exposed at the eastern extermity of Black Mountain between Davis Creek and Middle Creek. Another forms most of the ridge which separates lower Trail Canyon from Dry Canyon. In both cases the gravels unconformably overlie volcanics of Upper Miocene or, more probably, of Pliocene age. In both cases the surface of the alluvium lies at an elevation of 500 ot 600 feet above the adjacent valley floors, with the basalt-alluvium contact dipping approximately ten degrees northeast. The maximum exposed thickness of these gravels is not less than 500 ot 600 feet.

The material is loose and composed exclusively of granitic rocks of the same type as those whose fragments make up the glacial moraines. Upon the geologic occurrence of these deposits as well as upon their unconsolidated character, is based the inference that the material is of Quaternary age and that it may represent Pleistocene accumulation. Since the elevation of the alluvial surface accords closely with the figures obtained by projecting to the mouths of the canyons the slope of the uppermost of the sets of terraces observed below the moraines in Middle Creek Canyon they may represent the approximately maximum level of the glacial outwash material.

EXTENT OF THE GLACIATION:

The glaciers which at one time existed in the northern half of the White Mountain Quadrangle were confined to a comparatively narrow belt trending northwest and southeast just east of the present crest of the range. No evidence of glaciation was observed on the west side of the range, with the possible exception of Morris Canyon. All the glaciers were short. The maximum lenght of those of which traces still remain was probably less than four miles. Earlier ice may have extended farther down the valleys but no clues to their presence below the latest terminal moraines have been found.

Most of the northeast trending canyons on the east side of the range have cross-sections approaching the typical U-shape of the glacial canyon. (See Plate IX, A and B) This is especially noticeable in the Chiatovich-Davis Creek system at the head of which the earlier presence of glaciers can be so clearly demonstrated. The mistake must not be made, however, of attributing the shape of the lower parts of these canyons to the work of ice. As is shown in more detail elsewhere the condition is to be referred to an entirely different cause.

The importance of glaciation in the White Mountains, however, should not be underestimated. In spite of their slight extent and of the relatively restricted area to which their activities were confined they played an important part in the formation of the topography of the higher altitudes of the range. If the effects of glacial sculpture are confined to the upper third of the canyons on the east side of the range, the amount of widening and deepening accomplished by the ice was nevertheless large. The cirques are among the most conspicuous physiographic features of the mountains. It was in attacking and reducing the old age land surface of the summit region, however, that the glaciers did their most significant work. It seems very probable that in pre-glacial times this surface, now represented in the Pellisier Flats, was much more extensive than it now is, not only descending along broad interstream divides nearly to the eastern mountain front as it does south of Indian Creek, but extending also to the north at least as far as the Mount Montgomery-Boundary Peak region. The intercanyon portions have certainly been almost completely destroyed by the enlargement of the cirques, while the same process also encroached greatly upon the Pellisier Flat region. It seems probable that the destruction of a former northern extension of the plateau and likewise the formation of the "saddle" south of Mount Montgomery are in large part to be credited to the glaciers.

The effects of the glaciation upon drainage has been almost neligible. Only one or two lakes of glacial origin are to be found in the area and these are of small size. One, less than a quarter of a mile across, nestles behind a dam of morainal material in the upper part of the canyon of the south branch of Chiatovich Creek. Another, even smaller, is to be found near the head of the same cirque at an elevation of 12,300 feet.

At the foot of the slope which marks the front of the moraine of North Chiatovich Creek are large springs which supply most of the water that in summer forms the stream. Similar, though smaller. springs are to be found at the base of the other moraine fronts. A very large proportion of the precipitation which descends upon the moraine or on the slopes above as well as the water derived from melting snow in the cirques sinks into the porous material to reappear where the granite floor of the valley emerges from beneath detritus.

PLATE XXXVI

Description of Plate XXXVI

A. Looking northwest from a point about one mile northeast of boundary marker 64 on the California-Nevada boundary. A part of the sub-summit oldland may be seen on top of the ridge in the center of the view. Above and to the right of the center is a southeast-trending valley belonging to an older cycle of erosion, now left as a hanging valley by the more rapid down-cutting of the consequent stream which formed Indian Canyon. This valley can be traced four miles northwest from Post Meadow on Indian Creek.

B. Morainal material in North Chiatovich Canyon.

AGE OF THE GLACIAL REMAINS.

BLACKWELDER'S CRITERIA FOR GLACIAL STAGES:

Blackwelder in his recent paper on Pleistocene glaciation in the Sierra Nevada and Basin Ranges [1] recognizes four stages of glaciation in the Sierra Nevada, which are, in stratigraphic order,

4 Tioga Stage

3 Tahoe Stage

2 Sherwin Stage

1 McGee Stage.

It is not improbable, he believes, that a fifth stage may eventually be differentiated which present evidence suggests will lie between the Sherwin and the Tahoe stages.

In his discussion of criteria for the detremination of the age of a given set of glacial phenomena Blackwelder attempts to select from the various kinds of evidence available those which are most applicable to glaciation in an arid climate. Of these the most important are summarized below;

1. If more than one set of moraines occur, those of each of the several stages were less extensive than those of the next preceding. This difference is especially marked in the case of the moraine of the Tioga stage as compared with those of the Tahoe. In a particular valley the moraines nearest the head are youngest, those farthest out are commonly the oldest.

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1. Blackwelder, E. Bull. Geol. Soc. Amer. Vol. 42, part 2, 1931.

2. The advance of the talus cones, especially in the cirques, may be of value in differentiating the last two stages but is useless for earlier times because the earlier cirques have been destroyed by erosion. Moreover, the differences in lithology must be considered. Within the same limitations the older cirques are less craggy and have more soil and more vegetation upon their slopes than the younger ones.

3. Preservation of polished and striated rock surfaces may be a useful criterion if applied with caution. Dense siliceous rocks preserve striae and polish much longer than granite or marble.

4. The depth of valleys cut by axial creeks in the glacial floor is an important criterion but differences in gradients and lithology as well as in sizes of streams must be considered.

5. The extent to which the terminal moraine has been destroyed by the axial stream is significant. Generally the Tioga moraines have been merely notched and the axial creeks are still above grade, while the Tahoe moraines have been more or less breached and the frontal part entirely consumed.

6. The wastage of moraines by weathering, wind and rain-rills tends to leave rocky knolls standing out from their surfaces, which are rather common in areas of Sherwin till but lacking in younger moraines. This condition is noted in the moraine of Indian Canyon, described below.

7. The destruction of lakes has made little progress since the Tioga stage but since Tahoe time has been nearly completed.

8. Weathering of boulders in the till is one of the most useful of the criteria if those of similar rock types are compared. The boulders may be classified as (a) almost unweathered, (b) notably decayed on the surface but still solid, (c) greatly weathered, cavernous or rotten. In the case of granodiorite boulders, a ratio of 90-10-0 would surely indicate Tioga age, one of 30-6-10 would be typical of the Tahoe while one of 0-30-70 would be found only in the older tills.

9. The frequency of boulders on the undisturbed till surface is a useful criterion. In general the younger moraines are more bouldery than the older ones.

1o. The height of the post glacial stream terraces is a recently suggested criterion which is only now coming into use.

In a more detailed discussion of the characteristics of the various glacial stages in the Sierra-Nevada, Blackwelder emphasizes the following:

Tioga stage - Cirques are still as bare and rugged as though recently abandoned by the ice; talus cones are few and small; the original polished and striated surface is still rather generally intact even on such easily weathered rocks as coarse granite; the lateral moraines generally stand out as bold enbankments marred only by a few landslides and sharp ravines; the terminal moraines are still complete except for V-shaped notches; lakes fifty to three hundred feet deep are frequent in the glacial valleys with small deltas as the upper ends and outlet streams which have incised their morainic dams only ten to seventy-five feet; rock bound tarns are in similar condition. The moraines are very bouldery Chemical weathering has made but little progress; many of the boulders still retain striated surfaces while nine tenths of them have suffered very little external change. In the canyons beyond the termini of the glaciers gravel trains were built and later entrenched; the terraces thus formed generally stand only fifteen or twenty feet above normal stream level and several times have been traced directly into the Tioga moraines. The moraines are smaller than their predecessors - <u>the average relief of the moraine fronts is about twenty-five feet while very few are more than seventy-five feet and some are hardly ten feet high. Being so little conspicuous these younger moraines have often been overlooked or regarded as mere recessionals</u>. On the east side of the Sierra Nevada the average elevation of the ends of fifteen terminal moraines of the Tioga stage is about 7500 feet.

Tahoe Stage: The moraines of this stage are the most conspicuous in the Sierra Nevada. Primary glacial features are fairly well preserved and easily recognizable, although notably marred and obscured by weathering, stream erosion and deposition. The Tahoe cirques, where not occupied by more recent glaciers, are now subdued by weathering and lack the barren, rugged aspect of the younger ones. They have been gashed by ravines, while talus and even soil have formed in others to greatly obscure the plucked rock surfaces. Old roches moutonnees are easily recognizable in the bottoms of the troughs but glacial polish and striations have almost entirely disappeared except where they occur on quartz or aplite veins or have been protected by earth or sod. The moraines are so large and massive as to over-shadow those of the Tioga stage. Old laterals 500 to 1000 feet high are not uncommon; in most cases, however, the terminal part has been largely removed by the axial stream which has generally reached grade and has developed a wide flood plain. The tributaries, however, have done little more than cut notches in the lateral moraines.

Nearly all the glacial lakes of the Tahoe epoch have disappeared. A few are still represented by marshy ponds.

Boulders are much less common on the Tahoe than on the Tioga moraines. Nearly all the granitic boulders are discolored and decayed, while some of them are decidedly rotten. Only rarely do these retain glacial striae unless they have been buried.

The Tahoe moraines are much more extensive than those of the Tioga and terminated at elevations averaging about 500 feet lower.

Tahoe terraces have been studied in the Truckee Valley extending from Truckee forty miles downstream to Reno. There are two distinct terraces which stand seventy-five and sixty feet above the river just below Truckee, the same distances at Verdi and sixty feet at Reno.

Sherwin Stage: Cirques, lakes and roches moutonnees of this age have been almost entirely destroyed. The terminal moraines are entirely gone but occasional traces of lateral moraines are suggested by sections of old bouldery terraces along the mountain sides.

McGee stage: Since there seems to be no need, for purposes of comparison with exposures discovered in the present study, to discuss in any detail the characteristics of the McGee stage, no attempt will be made to summarize those characteristics here.

EPOCHS OF GLACIATION IN THE WHITE MOUNTAINS.

An attempt has been made above to express the conviction obtained in the course of field observation that the White Mountain cirques may be classified on the basis of relative perfection of form under two heads. The differences between these two classes reflect corresponding differences in recency of occupancy by glacial ice. To the first class may be assigned the Indian Canyon cirque characterized by considerable modification through erosional processes since its formation. In the second may be included the Davis Canyon cirque and the Chiatovich Canyon cirques, characterized by their fresh and little eroded condition. Between the two should probably be placed the Middle Canyon cirque, a portion of which was relatively recently occupied by ice, although there may be some question as to whether the primary cirque may not belong to a glacial epoch even antedating that in which Indian Creek was formed.

Corresponding differences are found when other evidence of glaciation is examined. In Indian Canyon the morainal material is present only as a relatively thin veneer over bedrock except in a small portion of the cirque. It is to a large degree obscured by talus and landslide accumulations. In the three central canyons, on the other hand, the moraines remain almost intact. As before, the Middle Canyon conditions represent an intermediate stage.

On the basis of such observations, the conclusion seems justified that two glacial epochs are represented in the area under discussion, In the earlier epoch all the cirques were formed. In the later epoch glaciers returned to D^vis Cirque and to North and South Chiatovich Cirques and to the southern part of Middle Cirque but in Indian Cirque only a small glacier at most was present. During the second period the chief work of the ice was to deposit additional detrital material and to strengthen and preserve certain of the already existing evidences of glacial activity.

It must be admitted, of course, that no very definite proof has been set forth of the existance of distinct epochs of glaciation. It may be agreed that the ice may merely have remained longer in the canyons in which its records are best preserbed than in those in which its former presence is less definitely evident. It does not seem probable, however, that it could have remained sufficiently longer to have produced the profound differences observable. In other words, it seems more reasonable to suppose that the difference between conditions in Middle and Indian Canyons on one hand and those in the other canyons on the other hand, represents the modifications produced in the former during a period represented by an interglacial plus a minor glacial epoch (in addition, of course, to the changes wrought in both in post glacial time) rather than such as would be produced in only part of a single glacial epoch.

Although a second distinct epoch probably existed it was far less effective than the earlier one. If this were not so we should expect to find in Chiatovich and Davis Canyons, where the combined effects of the earlier and the later glaciation are to be observed, evidences of glacial activity on a much grander scale than in those which were but once occupied by glacial ice. Such is not the case. The differences that do exist are of a somewhat subordinate order of importance.

The conclusion having thus been reached that two distinct stages of glaciation can be demonstrated for the White Mountains, the problem of the secondary moraines observed in Davis and Chiatovich Canyons remains unsolved. To assign these two sets of glacial epochs separate from the one which produced the largest moraine and from each other is to recognize the existance of four glacial stages since the Sherwin stage. This is contrary to well-established ideas of glacial geology and to other field observations as well. So far as I have been able to see there is no significant difference in the degree of weathering sustained by the boulders of the two deposits, nor is there any other evidence that would tend to establish essential age difference. The only logical solution of the problem, then appears to be that of considering the secondary morains to be recessional in character, produced by pauses in retreat of the ice or by minor advances in a long period of general retreat.

The next problem to be solved is why glaciers were formed in some of the cirques during the second glacial period or not at all. In theory the answer is simple. The glaciers formed again in locations where conditions were most favorable for their existence. Elsewhere they did not return. If, however, the second glacial epoch had been as intense as the first, glaciers would have reoccupied all of the cirques.

There is but one essential condition for the formation of a glacier, namely, that over a long period of time snow shall fall faster than it melts. Conditions favorable for the existence of a glacier, then, have to do with snow fall and with rate of melting. The former depends partly upon altitude and partly upon climate; the latter upon altitude and upon shelter from sun and wind. Precipitation is usually greater at intermediate altitudes than at extreme ones; melting, however, decreases with increased elevations. Melting is least on northeast slopes and greatest on southwest ones.

In the formation of the White Mountain glaciers rate of melting seems to have been the decisive factor, for all occured on the northeast side of the divide, even though precipitation might reasonably be expected to be greatest on the western side. (This is not a fully established rule, however, for nofigures are available; moreover, in my own experience, many of the storms affecting the White Mountains appeared to come from the north and northeast.)

Melting is least on northeast slopes because on these slopes protection is greatest from sun and wind. The glaciers grow in the shadow of the high divides. If the divide is lowered the shadow effect is decreased and melting is accelerated.

It seems reasonable to suppose that when the cirques were formed the elevations attained athe extreme northern end of the mountain chain were greater than they now are. The northern end of the Pellisier Flats at present has an altitude of over 13,000 feet. Montgomery Peak, two miles further north, has an extreme height of 13,442 feet. Throughout the northern half of the quadrangle the Flats have a definite, though somewhat irregular, upward slope from south to north. A projection of this slope would carry the former northern extremity of the Flats somewhat higher than the present elevation of Montgomery Peak.

As has been pointed out above, there exists between the northern end of the Pellisier Erosion Surface and Montgomery Peak a sag or saddle which is very nearly 1500 feet deep. At the time the cirques were first formed this saddle probably did not exist; as has been shown, the Pellisier Flats extended continuously northward to the vicinity of Montgomery Peak or beyond at an elevation which was probably nowhere less than 13, 400 feet. As a glance at the topographic sheet will clearly show, the Erosion Surface has been attacked from two sides by headwater erosion of the westward flowing streams and by glacial action resulting in the formation of cirques on the east. The two lines of attack tend to converge and "pinch out" the

Flats to the north. Before the ice began its active attack there were also two lines of attack operating from the east and from the west and these likewise tended to converge but the point of convergence lay considerably north of Montgomery Peak.

Thus at the time the cirques were formed the conditions for accumulation of glacial ice in Middle Canyon appear to have been more favorable than they now are because of the greater "shadow effect" of the higher elevations to the west. Moreover the earlier glacial epoch was in general stronger than the later one. Under the combined influence of more favorable general and local conditions a large glacier formed in Middle Canyon.

But glaciers, by the very energy of their attack upon land forms create the conditions that lead to their own destruction. Middle glacier gnawed away what was left of Pellisier Flats at the head of Middle Canyon and broke through the divide. After the disappearance of the ice at the close of the earlier glacial stage the normal processes of erosion continued rapidly to lower the saddle which had been formed south of Montgomery Peak. This work was made somewhat easier by the presence in the saddle of a contact between two intrusive rock masses. So far had the process continued that by the time the second stage arrived a glacier was no longer able to maintain itself in the northern portion of the old cirque, at least under the generally less favorable conditions then existing.

It is less easy to explain why a large glacier did not re-establish itself in Indian cirque. Here there is no evidence of any essential change in conditions between the earlier and the later glacial stages. In contrast to the situation just considered, the Pellisier Erosion Surface is widest just south of Indian Creek.

Three possible explanations present themselves. The first is that Indian Creek is farthest south. The distance from Middle Canyon, however, is only about seven miles; from Davis Canyon, next north, it is two. It is true that in this mountain range even slight difference in position may produce disproportionate, though not, of course, striking effects. This is the cumulative result of two variations which are, first, the increase in mean temperature from north to south, and, second, the decrease in precipitation which, in the Inyo Range, diminishes rapidly from north to south for reasons set forth in the introduction. Nevertheless the distances noted above are probably too small to have much significance.

A second condition of possibly greater importance is that the highest elevations attained at the crest of the range west and southwest of Indian cirque are very much lower than those further north. Directly west the maximum altitudd is 12,746 feet, nearly 800 feet below the prevailing elevations further north. More significant are the lower elevations to the southwest which are at least 2000 feet lower than those to the southwest of, for example, North Chiatovich cirque. (It should be pointed out in this connection that the southwest elevations are more influential than the ones directly west, for the afternoon sun during a large part of the year is to the south of west.

The third reason has to do with the unsymmetrical character of the Indian Creek cirque. The north rim is from 11,700 to 12,200 feet high, the south rim is only from 10,200 to 10,700 feet. The result is that during a large part of the year when the sun is to the south somewhat more heat is reflected from the north rim into the cirque than would be the case if the south rim were higher.

Whatever the correct explanation may be it is a matter of fact that even today Indian Canyon receives less precipitation than the canyons farther north. This is indicated both by the character of the vegetation and by the comparatively small volume of Indian Creek. Moreover during the last four summers I have noted that the snow disappeared from this cirque at least six weeks earlier than it did from the cirques - especially the Chiatovich cirques - farther north.

In a strong glacial epoch Indian cirque would probably be filled with ice in spite of adverse conditions; in a weaker one, such as the later epoch has been shown to be, however, no glacier or only a small one, would be present.

There still remains to be considered in this section the question of why no glaciers were present on the west slope of the Inyos. In the Sierra Nevada a reverse condition prevails - the glaciers on the western slope were larger and descended to lower elevations than those on the east.

The answer may be that in the Sierra Nevada the important influence is the difference in precipitation between the western and the eastern slopes, while, on the contrary, in the Inyo Range the decisive factor is the difference in the rate of melting. In the former case the downfall of snow on the western slopes is very much greater than on the eastern, so that if conditions of melting were equal one might expect to find an even greater difference in sizes of the glaciers.

In the Inyo Range, however, the difference in precipitation as between eastern and western slopes is very much less marked - in fact the question may even be raised whether the eastern slope does not receive fully as much downfall of snow per unit of area as the western one.[1]

AGE OF THE WHITE MOUNTAIN GLACIERS:

The glacial stages represented here are probably the last two recognized in the Sierra Nevada; that is, the Tahoe and the Tioga. In the former all of the cirques were formed; in the latter glaciers returned to some of them, swept out the debris which had accumulated in them, deposited fresh morainal material in the canyons but accomplished comparatively little in the way of deepening or enlarging either canyons or cirques.

Reference to Blackwelder's descriptions shows that the present condition of the unrejuvinated cirques in the White Mountains accords well with that of the Tahoe cirques in the Sierra Nevada unaffected by Tioga ice. The former are a little fresher, perhaps, but that is to be expected in a more arid climate. On the contrary, the moraines which are here assigned

1. Dr. Buwalda considers this to be highly improbable. Accurate measurements of the snowfall would be both interesting and instructive.

to the Tioga stage are much higher than those he described for the Sierra. But as has already been pointed out in discussing the recessional moraines, the conditions of accumulation in deep narrow canyons might be expected to produce higher terminal moraines than would be the case in wider ones.

A second discrepancy to be noted lies in the rarity of boulders exhibiting glacial striae or polish in our Tioga moraines. This is in marked contrast to what Blackwelder describes. However, boulders exhibiting such phenomena distinctly do occur and their greater scarcity may perhaps be accounted for on the ground of greater slowness of weathering out of boulders from the White Mountain moraines.

A comparison of boulder counts made on the surface of the White Mountain moraines with those of the Tioga moraines of the Sierra would be interesting and instructive but I did not undertake such a count and have no figures available.

Perhaps the most difficult question to answer is the one naturally raised concerning the presence of moraines of the Tahoe glaciers. According to Blackwelder's observations, these moraines are many times as prominent and as extensive as those left by the Tioga glaciers, yet in the White Mountains little trace of them is to be found. Where have they gone? It is a question I cannot yet answer. It is possible that remnants of them still exist but have so far escaped attention or have been misinterpreted. It may be that they have been for the most part part buried and concealed by the debris accumulated in the canyons during and since the latest period of glacial activity, for in a climate so arid detritus is likely to gather faster than the normal agencies of transportation can remove it. Finally the possibility must be admitted that the assignment of the largest of the moraines noted here to the Tioga may be an error.

STRUCTURAL GEOLOGY.

Description of Plate XXXVII

Limestones of early Paleozoic age, dipping steeply to the right of the observer, compose the upper part of the mountain in the background. The lower part of the mountain, as well as the hills in the foreground, are of Tertiary volcanics. Extending across the face of the mountain from left to right are the exposed portions of two vertical fault planes with the slickensiding still well-preserved. The striations indicate that the movement on the fault was nearly vertical with the volcanics in the foreground dropped down against the Paleozoics. The mountain is about one mile distant from the camera.

FAULTING.

In the section of this thesis devoted to physiographic geology the various types of fault scarps which occur in the White Mountain area have been described and discussed at length; the faults themselves, however, have been given only passing mention. Physiography (or more particularly, Geomorphology) it should be remembered, is concerned with faulting only to the extent of its topographic expression. Structural geology, on the contrary, is interested in the observation and interpretation of all the features and phenomena connected with faulting in so far as they have any relationship to the general structure of the region. In the following section, therefore, an attempt will bemade to describe the faults more particularly and to make whatever deductions and conclusions they seem to justify.

In a region such as the northern half of the White Mountain Quadrangle faults are very difficult to locate accurately and to trace. To measure or compute attitudes and displacements is usually impossible. Several conditions induce this difficulty. Faults lying wholly in intrusive bodies of igneous rock are exceedingly apt to escape notice unless the fault plane itself is exposed or unless marked physiographic consequences are produced; the amount of dislocation can rarely be determined. Rocks produced by contact metamorphism are so variable in composition and attitude that the effects of faulting are often not evident. Fault scarps in loose alluvial material tend to assume a slope which does not exceed the maximum angle of repose for materials of that type; moreover, there seems to be a tendency for the fault plane to steepen its dip as it passes from b edrock into alluvial materials with the result that as the alluvium varies in thickness the scarp may exibit changes in trend which do not reflect corresponding changes in the trend of the fault trace on the sub-alluvial floor. In the parts of the area occupied by volcanic accumulations, however, the problem is an even more difficult one, for not only do extreme lateral and vertical variations in the appearance and composition of the material occur in short distances, rendering the identification or correlation of the b eds highly uncertain, but primary structures may closely simulate fault relations. An example of the last is the case of a lave flow coming to rest against a vertical granite cliff. If to these conditions are added the complications produced by the changes in composition and appearance of beds of lava or tuff resulting from hydrothermal action, an obstacle is set up which can be overcome only by detailed study.

It will be noted that in some cases fault zones rather than sharply defined faults have been mapped. This is especially true of the marginal faults of the mountain blocks. Thus we have the Montgomery fault zone as an inclusive term for the considerable number and variety of faults which delimit the White Mountain Range on the west, the Davis fault zone for the corresponding dislocations along the east front, the Queen fault zone for those which have produced the scarp extending northeast and southwest from the vicinity of the Pellisier ranch to Montgomery

Pass, and the Comanche faultzone for those which delimit Blind Spring Hill on the northeast. It seems proper, furthermore, to designate the corresponding fault scarps by the same names, as, for example, the"Davis Scarp" or the "Comanche scarp".

This scheme of representation was adopted for two reasons. On the one hand it serves to direct attention to the real complexity of the dislocations which have produced the mountain scarps. The idea that the displacements occurred along a single fracture which parallels for long distances the mountain front is untenable. On the contrary it seems certain that movements took place on a number of fracture planes in zones of varying width, mostly, it is true, rather narrow in the northern part of the Inyo-White Mountain range but tending to become broader farther south.

Considered in another way, this method of representation may be ascribed to ignorance. The location and trend of most of the faults which compose the marginal zones are not definitely known. They could be determined, in most cases, only by long and detailed field study. Although within the zones in places definitely established faults are in some places indicated, it must not be inferred that it is only along such lines that positive evidence of faulting has been observed. In a large number of cases faults were found which could not be traced over a few hundred feet. These were probably for the most part faults of small displacement. In other instances, especially in the Mont-

PLATE XXXVIII

Description of Plate XXXVIII

A. Looking north at the Queen fault scarp. The two buildings to the left of the center are at the former station of Nichols. The Nichols fault extends from behind Nichols diagonally to the right above the middle line.

B. Looking east-northeast along the Queen fault zone from a point near Nichols.

gomery fault zones, definite planes could not be recognized but the crushed and sheared condition of the rocks gave indubitable proof of the movements which had taken place.

It was originally planned to give the fault zones definite boundaries and to indicate them by separate colors or designs. This scheme was abandoned for various reasons, one being that it would too greatly complicate the map and another that it would give a false impression of definiteness concerning the limits of the zones. The true character of the latter might best be indicated by cross-lining or shading, heaviest in the middle of the zones, becoming lighter toward the edges. The position of the zones is indicated only approximately on the map by the dashed lines.

GENERAL CHARACTER OF THE FAULT ZONES:

It may be stated as a generalization which applies particularly to the great scarp-forming fault zones that the faulting is to a variable but usually considerable degree distributive in character, that the total displacement represents the sum of a large number of small displacements which may, however, often take place in a comparatively narrow zone, that shearing and crushing are frequently prominent in the zones (see plate LI,B) and that sharply defined fault planes on which much movement has taken place are only occasionally to be found.

It is very seldom that a fault corresponds in its trend with the strike of sedimentary formations which it crosses. The angle which the fault makes with the strike of the rocks may have any value from zero degrees to ninety degrees with the strike of the rocks. Another very common condition is that both walls of the fault are in rocks of the same kind. Where dissimilar rocks oppose each other across a zone of distributive faulting the transitional talus-covered slopes may obscure the true relations.

In all the fault zones with the exception of the Comanche several faults were observed which appear to have a trend oblique to the trend of the scarp. The recent fault scarps in alluvium at the mouth of Indian Creek in the Davis fault zone exhibit this tendency to a notable extent. Similarly the older faults north of Davis Creek strike obliquely into the range. Just south of the area mapped a recent fault of considerable vertical displacement trends obliquely across Inyo Valley from the Montgomery fault zone to the southern end of Blind Spring Hill. Similarly, it seems probable that the line of low hills extending from the Montgomery scarp just below the Black Warrior mine in a northwesterly direction across Pellisier Valley toward the Pellisier ranch represents a dissected and partly buried fault scarp with a northwest-southeast trend. Again, a fault in granite crosses Rock Creek near its mouth with a trend of N 45 W. In the Queen fault zone a number of faults were observed which appeared to have a trend from fifteen degrees to forty degrees more to the west than the Queen scarp.

Hulin has also mentioned the occurrence of faults which strike obliquely into the front of the White Mountain range.[1] He indicates a belief that these faults arise in joint systems in the intrusive rocks but he does not appear to have traced any of these faults to such an origin. I am unable to substantiate Hulin's view by direct evidence of this type. Moreover many of the more important faults of the range which also assume a direction oblique to its trend transgress other formations than granite rocks; conversely smaller faults are observed which are at an angle to any of the directions of jointing in the vicinity. None of these facts, of course, disproves Hulin's hypothesis but on the other hand this cannot be considered to be established until the faults have actually been traced.

Another characteristic of the marginal faults to which attention should be directed is their high degree of curvature when mapped in detail. This is true not only of the alluvial faults, where other explanations may to at least some degree apply (see page above) but it holds good to a lesser degree of some of the faults in solid rock. R. J. Russell has shown very interestingly and strikingly in a diagram the frequent discordance between the directions assumed by the recent marginal faults and the range front of the Warner Range in Northeastern California.[2] In his geological map he shows similar

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1. Hulin
2. Russell, R.J.- Basin and Range Structure and Stratigraphy of the Warner Range, Northeastern California.- Univ. Calif. Publ. Bull. Dept. Geol. Sci. Vol. 17, Fig. 26, opp. p. 468, 1928

degrees of curvature for the faults in bed rock. In one case he maps a probable curvature of one hundred and eighty degrees by connecting with a dashed curved line the ends of two parallel faults. I have not noted any faults exhibiting such a marked change in direction as this but changes of ten degrees to forty degrees are not uncommon. In such cases unless the crushed and brecciated zone is a very thick one, it does not seem to be possible that much horizontal movement can have taken place - unless, of course, folding followed the faulting, which in this region is rarely if ever true.

Many faults occur outside of the great scarp-producing zones. Most of these are of minor importance. For example, several faults with a throw of fifty feet or less can be seen in section in the basalts of Windhorse Hills from the road leading from the Chiatovich ranch up the Trail Canyon fan. The volcanic hills in the extreme northeast corner of the quadrangle are also complexly faulted, but these faults have not been studied in detail.

A number of the faults which are found outside the scarp-producing zones, however, are structurally significant. Among these are the Pinchot and Sand Spring faults along which movements which uplifted the White Mountains in part took place. The Sand Spring fault is thought to be an older structural line the formation of which antedated the uplift of the mountain block.

Several faults of importance were observed which on account of lack of time did not receive the attention they deserve. Most of these have not been indicated on the map.

AGE OF THE FAULTS:

Movements have taken place along most of the important faults in Quaternary or in Recent times. This can be demonstrated both by stratigraphic and physiographic evidence. The former includes especially the dislocation of the Quaternary basalts and of the older and younger alluvium. The physiographic evidence has already been discussed.

It is not probable that the dislocations occurred along the entire length of a given fault at the same time or that they were of the same magnitude. This is strikingly demonstrated by the eastern marginal faults of the White Mountain block. Along the Davis zone north of Trail Canyon, for example, no movements of major importance appear to have taken place after the extrusion of the Quaternary basalts, although farther south, as at the mouth of Davis Canyon, such basalts have been elevated about three thousand feet above identical lavas which lie against the base of the range. Nevertheless the basalts which cap Mustang Mountain lie at an elevation of nearly one thousand feet higher than those of Black Mountain just north of Davis Canyon. The evidence seems to indicate that the movements which differentiated the mountain and valley blocks began before the extrusion of the Quaternary basalts and took place along the entire length of the Davis zone. To the south they continued on the same line during and after the basaltic period but north of Trail Canyon they took place in the main along the Pinchot and Sand Spring fault, although some movements of subordinate importance did occur in the Davis zone.

Likewise it is clear that the movements along the McNett fault have been much greater farther south than they have been in the vicinity of Indian Canyon and different times of movement are also indicated.

There is no reason to believe that the faulting along the eastern and western margins of the White Mountain block occurred in substantially different periods of time. The movements appear to have taken place more or less concurrently, although at the northern end of the range there is evidence of somewhat more recent movement on the east side than on the west.

DETAILED DESCRIPTION OF THE FAULTS.

MONTGOMERY FAULT ZONE:

The faulting along the Montgomery zone has been rather thoroughly discussed in the above general account and in the description of the scarp presented in the section on physiographic geology. Two or three features occur, however, which have not received attention. Among these is the pronounced change in direction of the scarp which occurs between Montgomery Canyon and Morris Canyon. Between the latter and the uppermost end of Pellisier Valley the scarp trends approximately N 30 E. South of Montgomery Creek the scarp follows an almost southward direction for about two miles, then it turns to about N 45 W and continues without further change to Falls Canyon.

The question occurs whether the bend in the scarp is the result of a corresponding bend in the fault zone or whether it is produced by the intersection of two fault zones. I cannot at present give a definite answer to this question. I am convinced, however, that the explanation is not so simple as to involve merely the choice of one of these alternatives. The fault pattern in this vicinity if known in detail would probably be seen to be very complex. As has already been pointed out, it is likely that a fault which continues along the trend of the scarp between Montgomery and Falls Canyons crosses Pellisier Valley obliquely northwest toward the Pellisier Ranch. If this fault exists it is intersected by the zone extending southwest from Montgomery Pass in the vicinity of Montgomery Canyon. The angle of intersection would appear about ninety degrees but judging from the structural pattern where faults intersect elsewhere in the quadrangle I consider it probable that the angle is less definite than might be expected and that the southwest-trending fault zone may actually curve to the south before it intersects the northwest-trending zone. Thus the Montgomery zone from Montgomery Pass to the southern border of the quadrangle would be virtually a continuous zone with the fault trending toward the Pellisier ranch a branch fault formed either at the same time as, or later or earlier than the Montgomery zone.

Two noticeable offsets in the Montgomery scarp occur - one at the mouth of Queen Canyon, which has already been discussed (see page) and the second at the mouth of Montgomery Canyon. The latter may have a structural origin or it may have been formed by the cutting back of the spur north of the canyon by the stream on its northward swing. The criteria for distinguishing the two kinds of scarps are indecisive.

At its northern end the Montgomery fault zone appears to join the Queen zone almost at right angles. The appearance, however, is deceptive. As will be shown below, the Nichols fault, which is one of the principal faults of the Queen zone, trends not east-west but about N 65 E and terminates - or joins the Montgomery zone - near Bench Mark 7122 southwest of Montgomery Station. Similarly, one of the principal faults of the Montgomery zone can be observed to pass just to the east of the

PLATE XXXIX

Description of Plate XXXIX

A. Step faulting at the northeast end of Black Mountain. At least three steps are visible. Camera pointed southwest just before sunset.

B. Detail of A. The scarp in the foreground is in Quaternary alluvium overlain by basalt. In the foreground is a depression parallel to the scarp. The camera is at an elevation of about 7800 feet and pointed southwest.

PLATE XXXIX

A

B

mouth of the railway tunnel about a mile south of B.M 7122 and to continue north from that point to join the Nichols fault. The formations (chiefly Tertiary Volcanics) in an angle between these two faults have been greatly disturbed, crushed and broken up by monor faults. A branch fault in the Queen zone appears to extend from the station at Nichols due east across the upper end of Pellisier Valley to terminate in the Montgomery fault zone. The triangular area with vertices at Nichols, at B. M. 7122 and at the railway tunnel, therefore, appears to be common to both fault zones.

There is some indication that a fault which represents the combined Queen and Montgomery faults continues in a northeast direction through Montgomery Station to the border of the quadrangle. The apparent course of the fault is along a canyon-like depression 700 or 800 feet deep at the summit of the divide. The floor of the depression is marked by a series of hollows or concavities similar to those in which "sag ponds" form along the San Andreas rift. The largest of these is the one in which Montgomery Station is situated; it is approximately an eight of a mile in one direction by a quarter of a mile in the other. Certain types of depressions are not uncommon in basalt-covered regions and often have no especial structural significance, but the unusual features of the present occurrence as well as its significant location in respect to known faulting are highly suggestive. If, however, a fault does follow the trend of Montgomery Pass, it has not noticeably displaced the Quaternary basalts which extend across it.

Large blocks of ancient sedimentary rocks are found along the Montgomery scarp, especially south of Morris Canyon. Their contacts with the plutonic rocks are typically intrusive. In lithologic character they are so similar to the rocks of the McNett formation as these exposed south of Indian Canyon (east) as to be considered identical with them. It is probable that these rocks formerly extended across the intervening area where they formed the roof of the batholith. Exposures of rocks of the same kind occur in the floor of Pellisier Valley about three miles north of Hammil Station where they form a group of low hills which are now on the verge of being completely buried by the alluvium of the fans. From the position of these blocks on the fault scarp and from their relationship to the other exposures it is evident that they have been dragged up by the faulting and it is not unlikely that they owe their disposition along the fault scarp in part to differential movement between the margin and the crest of the range, although irregularities in the roof of the batholith may also be in some degree responsible for their present position.

As has been indicated, exposures of fault surfaces, especially those showing slickensiding, are not plentiful in the Montgomery fault zone. Such as could be found have dips varying from fifty degrees west to vertical with the majority not far from seventy degrees. A fault plane at the mouth of Marble Canyon, however, has a westward dip of only thirty-three degrees, which is not much greater than the angle of slope of the scarp for the first two or three hundred feet.

DISPLACEMENT ALONG THE MONTGOMERY ZONE:

There is no direct way to compute the displacement along the Montgomery fault zone by the stratigraphic method. Corresponding horizons cannot be certainly recognized in the two blocks, and differential movements within the upthrown block make it doubtful if even the displacements thus measured would represent the maximum displacement. The presence of the Pellisier erosion surface at the crest of the range, however, indicates that the summit has not been lowered to any important extent since the faulting occurred. The total displacement resulting from the faulting, therefore, may be considered to be approximately the height of the present scarp plus the depth of the alluvium in the fans at the fault plane. A fair estimate for this distance is 8000 feet.

QUEEN FAULT ZONE:

The Queen fault zone is as indifferent to variations in lithologic character and in the attitude of formations as the Montgomery zone. At its northeastern end it traverses early or pre-Paleozoic sediments overlain by Tertiary volcanics which in turn are overlain by Quaternary basalts. In the vicinity of Nichols Station granite occurs in the scarp, overlain again by the same Tertiary and Quaternary volcanics. Southwest of Nichols these Tertiary and Quaternary accumulations descend to the foot of the scarp.

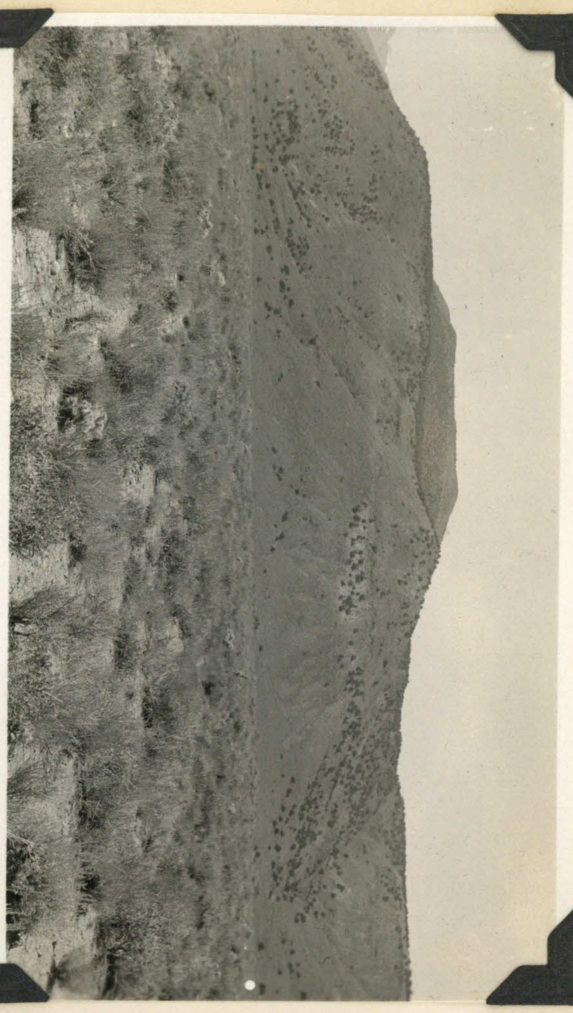
Northeast of Nichols the chief vertical displacement has taken place along the Nichols fault which has already been described as a somewhat curved fault trending about N 65 E from the station of Nichols to the vicinity of B.M 7122. The fault plane, here vertical, is best exposed in the deep southwest trending canyon in the southeast corner of Section 1, T I N R 32 E - that is, about three fourths of a mile due west of the spring a short distance below B.M. 7122. At this point Tertiary volcanic materials to the southeast are in vertical contact across the fault plane with ancient dolomitic limestones and slates unconformably overlain by the same volcanic rocks to the northwest. The trace of the fault can be clearly followed from this point to the northeast and southwest. Near Nichols Station it has brought Tertiary volcanics and basalts to the southeast into nearly vertical contact with granite. Here the fault plane dips about 85° S.E. In the first canyon to the west of Nichols the fault bends slightly to the northwest and comes to an end, terminating, apparently, against a probable older fault trending about N 20° W which has brought the Tertiary volcanics down to the southwest against the above mentioned early or pre-Paleozoic limestones. The plane of this fault is not clearly defined but appears to be approximately vertical. The Quaternary basalts are not displaced by it as they are by the Nichols fault, and it is evident, therefore, that it is of an earlier age than the latter.

To the southwest of Nichols the faulting which makes up the Queen fault zone becomes highly distributive in character. Not many of the individual faults are clearly visible on account of the soft, crumbly character of the Tertiary beds.

PLATE XL

Description of Plate XL

Black Mountain from the point at which the 6700-foot contour crosses the Davis Creek road. There is a small gap between the view to the left and that to the right. The geologic relations are as indicated in the diagram on the slip-sheet.




This has led to the accumulation of much debris which obscures the relationships. None of the faults can be traced far with certainty but some of them exhibit a tendency to assume a westerly trend, although this is by no means true of all of them. Several of the down-dropped basalt blacks have been rotated by the faulting so that some of them as indicatedby the dip of their flow surfaces are tilted to the southeast at angles varying from eight to thirty degrees. Some of the basalts along the scarp may be intrusive as sills but this could not be definitely established as in no case could it be positively established that they disappeared beneath any of the Tertiary beds.

DISPLACEMENT ALONG THE QUEEN ZONE:

As in the case of the Montgomery fault zone the maximum vertical displacement of the Queen fault zone can not be exactly computed. If the basalts which are exposed in the valley floor to the east of Nichols were formerly continuous with those basalts which overlie the Tertiary volcanics, as their lithologic character would seem to indicate, the total vertical displacement in this vicinity maybe nearly 1000 feet.This figure, however, can not be given with any assurance of accuracy. The basalts which are exposed over the greater part of the northwest corner of the quadrangle exhibit considerable variations both in thickness and in the elevation of their base. These variations are in part due to the uneven character of the surface on which they lie, in part they are due to subsequent warping (probably caused mostly by differential settling of the sub-basaltic materials). A third and very important point to be considered is that the basalts are probably not to be considered as a simgle flow or series of flows which inundated the entire surface now included in the northwest corner of the quadrangle but as the aggregate of a number of smaller flows which issued from a number of centers of volcanic activity at or near the same time. The product of the various centers are petrographically closely similar, textural variations being the most common, as is to be expected in the case of centers related to a common source. The flows are less numerous and are of greater average extent than in the north central part of the quadrangle but it is nevertheless unsafe to consider one exposure as being the equivalent of another if the two are separated by any distance.

As was true of the Montgomery fault zone, however, we will not be far wrong if we consider the vertical displacement to be measured by the height of the scarp plus the thickness of the alluvium at its base. This is about 1000 feet at the north east end, increasing to 1200 feet or more north of the Pellisier Ranch.

DAVIS FAULT ZONE-CENTRAL PART:

The Davis fault zone is a clearly marked zone from the southern edge of the map to the vicinity of Trail Canyon but from this locality north it becomes less sharply indicated by topographic features. It includes not only the recent faults which have displaced the alluvial fans but also the older ones which cross the ends of the interstream ridges and whose planes are exposed in the canyon walls. The former have been discussed at length in the section on physiographic geology. Some of these - especially those which cross the alluvial floors within the mouths of the canyons - are the result of renewal of movement along the older fault planes into which they can be directly traced on one side or the other of the canyon.

The structural relations at the eastern end of Black Mountain are especially interesting. The basalt which forms the crest of the mountain has been elevated to its present position in a series of steps from its earlier altitude at the base of the range where it apparently underlies the alluvium of the contiguous fan. At its western end the basalt lies upon granitic rocks belonging to the Pellisier group. In the canyon wall on the north side of Davis Canyon just to the west of the old Davis Ranch may be seen the plane of a nearly vertical fault which crosses Black Mountain in a direction about N 25° W. The plane may be viewed from the north on its emergence from the north side of Black Mountain opposite an elevation of about 7550 feet on the bank of Middle Creek. The rocks on the west side of the plane are Plutonics of the Pellisier group, those to the east are Tertiary flows, breccias and tuffs which may be seen in the section of the south side of the mountain to rest on a granitic floor.

Somewhat less than a quarter of a mile east of the first fault are peculiar structural conditions which are undoubtedly related to faulting but the details are masked by the basaltic talus which forms a heavy mantle on the canyon wall. In the position mentioned a prominent scarp crosses the ridge in a direction which nearly parallels the first fault but trends somewhat more to the northwest. The scarp appears to be in Tertiary volcanics, although these are concealed by the ubiquitous basaltic talus. Massive basalt in attitude of flow lies at the base of the scarp, the flow planes dipping slightly (about five degrees) to the northeast except for a distance of twenty-five or thirty feet from the scarp in which they dip steeply (thirty to sixty degrees) into the fault. These flow basalts rest, as may be clearly seen a short distance farther to the east upon coarse alluvial materials of probable Quaternary age.

In both the north and south canyon walls the basaltic talus conceals the relations directly below the scarp. A hundred feet or so farther east, however, and two or three hundred feet lower in elevation, the alluvial material can be seen below the basaltic talus on the Davis canyon side where it lies on or against the volcanics. The contact surface dips to the northeast at an apparent angle of thirty-five degrees. It may be traced, though somewhat obscured by talus, down the canyon wall to the floor of the canyon where it disappears below the valley alluvium at an elevation of about 7100 feet.

Overlying the older or pre-basaltic alluvium just described are discontinuous patches of basalt. The basalt-alluvium contact plane as seen in Davis Canyon sections dips to the northeast at an apparent angle of about ten degrees.

On the Middle Canyon side these relations are somewhat different in that the contact plane between the Tertiary volcanics and the alluvium is seventy degrees instead of thirty-five. The relations can be seen here, however, even better than on the Davis Canyon side, although they are somewhat complicated by the fact that some of the basaltic ridge-capping has slumped or faulted down along a line which approximately parallels the trend of the canyon.

Undoubtedly faulting has been responsible for the formation of the scarp described above and for the downthrow of the basalt against its base, but the fault plane is not certainly known to be the Tertiary volcanic-alluvium contact. It may be a depositional contact tilted by nearby faulting. If it is a fault contact, the plane is a warped one, for the Middle and Davis Canyon sections are nearly parallel but the dip varies from seventy degrees in the one to thirty-five in the other. Whether or not this is an actual fault plane, however, the other relations show clearly that it is approximately so.

Two or three other scarps producing faults which have displaced the Quaternary basalts cross the northeast end of Black Mountain. Two of these are indicated on the geologic map. At the eastern margin of the mountain is a third fault along which basalt to the east overlying the same pre-basaltic alluvium as has already been described lies against the pre-basaltic alluvium (nearly at its base) to the west. In a shallow

PLATE XLI

Description of Plate XLI

A. Black Mountain from the north, showing step faults. The structure is shown in the diagram on the slip-sheet.

B. Looking northwest along the fault ridge south of Dry Canyon. The ridge is composed of brecciated limestone, cemented by silica. A fault from lower left to middle right has offset the breccia.

saddle between the downfaulted basalt and the mountain base badly shattered Tertiary volcanics are exposed underlying the alluvium. An eighth of a mile farther east a small patch of the alluvium is seen to overlie the Tertiary volcanics in a nearly horizontal contact.

The complex relations which have been described can perhaps be made somewhat clearer by reference to the illustrations and the diagrams which accompany them. Plate XXXVIII-A shows the northeast end of Black Mountain with the prominent fault scarps which cross it. The light-colored alluvium can be easily seen underlying the basalt in the face of the mountain. At the right is the downfaulted patch of basalt at the mountain base. Plate XXXVIII- B is a near view of one of the scarps shown in A. Plate XXXIX is a view of the same mountain from the southeast. The prominent points can be recognized by comparison with Plate XXXVIII-A. The relations are indicated in the diagram. This view should be compared with the preceding ones.

There can be no question of the identity of the basalts at the summit of Black Mountain with those which lie against its eastern base. The total displacement accomplished by the various steps is over 2000 feet.

Fault-stepping which is quite similar to that which has been described appears to occur on the east end of Davis Mountain but the faults cannot be accurately located or traced on account of the dense basaltic talus.

To the north of Black Mountain the structural conditions become increasingly interesting and complex. The individual faults which are responsible for the structure of Black Mountain cannot be traced across the alluvial floor of Middle Canyon but similar ones can be found and traced to the north. The most prominent of these is apparently the continuation of one of the last ones to be described. This fault crosses the low ridge north of Middle Canyon near its eastern end, where its effects can be plainly seen in the crushing and recementing of the sedimentary rocks which are exposed here. Crossing the mouth of the next small canyon to the north it curves somewhat more to the west to assume a trend of N 35° W to Dry Canyon where it appears to terminate at or be offset by an important cross fault to be described below. North of Middle Creek it displaces chiefly old sediments and metamorphics overlain by rhyolite.

The course of the fault across the ridge south of Dry Canyon is marked not by a saddle but by a transverse ridge composed of a limestone breccia fifty feet or more in width which has been completely healed and the calcite of the fragments entirely replaced by silica. The intensely hard silicified product is much more resistant to weathering than the neighboring unaltered limestones and slates and remains in relief above the latter. An interesting detail is the occurrence of a cross fault trending N 30° E which has offset the breccia which forms the ridge and hence has produced an apparent offset in the topography.

On the ridge just north of lower Middle Canyon approximately one quarter of a mile farther west than the trace of

PLATE XLII

Description of Plate XLII

A. Specimen of fault breccia from ridge shown in Plate XLI, B. Two-thirds natural size.

B. Another specimen of the same breccia. Three-fourths natural size.


65a


-a

fault which has just been described is a small outcrop of basalt which rests on the north side of the ridge on metamorphic rocks derived from old sediments and on the south on alluvial gravels. To the west the basalt and the gravels and the metamorphics on which it lies are in vertical contact with the older intrusive rocks of the Pellisier group. The metamorphics belong to a group which in the next canyon north are in contact relations with the granite but in the position described the contact phenomena do not appear. The basalt appears to belong to the same flow which caps the summit of Black Mountain. The relations described are probably to be ascribed to faulting but the character and extent of the displacement are not clear.

Between Dry Creek and Trail Canyon relations similar to those which have been described are to be observed but the fault zone appears to have been shifted somewhat to the west along the Dry Canyon fault. Furthermore there is some indication that the principal faults comprising the fault zone diverge.

At the eastern end of the ridge which forms the divide between Dry and Trail Canyons the basaltic ridge-capping which rests upon alluvium which in turn overlies Tertiary volcanics has been faulted down approximately five hundred feet in one step.

A second fault trending N 30° W crosses the ridge in saddle just west of the 8464 peak. To the east of the fault are the basalts which have already been described overlying Quaternary alluvium. At the fault these lie against the same volcanics upon which they rest east of the fault in a contact which is close to vertical. The total throw cannot be precisely calculated but it is certainly not less than four hundred feet.

DRY CANYON FAULT:

It is necessary to digress here to describe the Dry Canyon fault which crosses the Davis fault zone at an oblique angle. It can be observed in the 6989 hill (triangulation station) a short distance northeast of the mouth of Middle Canyon. At the north end of this hill is a fragment of basalt overlying gravels probably formerly continuous with those which form the crest of the ridge north of Dry Canyon. The southern and higher part of the hill is made up of rhyolites exactly similar to those which cap the ridge south of Dry Canyon. The contact is vertical. There is a possibility that these relations may have been produced not by faulting but by the basalt flowing down a stream channel eroded into the dhyolite, but the occorrence and its relation to the known fault strongly suggest a fault contact. (Refer to Plate XIII-B)

Between the 6989 hill and the mouth of Dry Canyon the fault trace is covered with the alluvium of the fan. Within Dry Canyon, however, the stratigraphic evidence for faulting is plain, though the fault itself is not exposed. The ridge south of Dry Canyon is made up chiefly of dolomitic limestones of the McNett formation upon which lie thick flows of rhyolite. The ridge to the north, as has been stated, is composed at its northern end of basalts and gravels, overlying volcanics of the group to which the rhyolites belong, which across the canyon are found at an elevation seven hundred feet higher. The fault follows the bottom of the canyon for about a mile and a half above its mouth to a point south of the 8464 hill where, instead of following the bend of the canyon it continues to the northwest and crosses the prominent hill three-fourths of a mile to the west almost under its crest. On the north side of this hill the fault plane itself can be observed dipping very steeply to the east. At the bottom of the hill rhyolitic flows lie against the dolomitic limestones of the McNett formation; farther up well-stratified tuffs to the east terminate sharply against rhyolite which overlies the limestone.

The Dry Canyon fault cannot be definitely traced beyond this point, but it is possible that it continues along the same general trend to the northeastern front of the range. The topography strongly suggests a fault following approximately along the course of Queen Canyon. It is true that this canyon marks the contact between intrusive rocks to the west and argillaceous sediments of the McNett formation to the east, but the latter, although exhibiting unmistakable effects of contact metamorphism, do not appear to be as highly altered as are similar rocks on the immediate contacts with the same intrusive mass elsewhere in the area. Moreover, apophyses of the granite, pegmatite and aplite dikes and similar contact phenomena are conspicuous by their absence from the arena just to the northeast of Queen Canyon. Another significant feature is that the northwest-southeast fault across Pellisier Valley in the vicinity of Nichols appears to point directly toward the mouth of Queen Canyon, although it must be pointed out that the downthrown side of this fault is the up-

PLATE XLIII

Description of Plate XLIII

A. Looking south along scarp in alluvium south of Indian Canyon.

B. Probable fault contact between basalt and Tertiary volcanics in 6989 hill opposite the mouth of Middle Canyon.

thrown side of the Dry Canyon fault.

DAVIS FAULT ZONE-NORTHERN PART:

North of Trail Canyon the Davis fault zone becomes less well-marked topographically. The stratigraphic evidence is also less dependable than it is farther south, for, as has been pointed out, within the Tertiary volcanic series it is extremely difficult if not impossible to trace a given bed very far or to be sure of the correlation of non-continuous horizons. Nevertheless, there is no question but that the zone of faulting which we have recognized south of Trail Canyon as the Davis zone continues across the east front of Mustang Mountain toward Sugarloaf but with diminishing displacement. Ultimately it intersects the Montgomery and the Queen fault zones in a highly disturbed triangular-shaped area, previously described, southwest of Mt. Montgomery Station.

Coinciding with or closely paralleling the Davis fault zone north of Trail Canyon is a very pronounced zone of hydrothermal activity in which the volcanic rocks are strongly altered. The most apparent changes in this zone have been the silicification of the rhyolitic tuffs and the propylitization of the andesites. Within this same zone are a number of ore deposits of the epithermal type, containing chiefly gold and quicksilver. This same zone may be considered to extend as far south as the mouth of Dry Canyon to include the quicksilver deposit of the Red Rock mine. The period of hydrothermal activity here represented is possibly, though not certainly, entirely distinct from that in which important modifications in the rocks of the White Mountain batholith, described in the section on petrography, were brought about.

It is noticeable that the Quaternary basalts which lie along the Davis fault zone to the north of Trail Canyon have not been displaced to the same degree as similar though perhaps not identical basalts to the south. Some of these bodies show very little if any displacement. It is thought probable, in view of this, that the movements along the Davis fault zone either preceded or accompanied the period of basaltic extrusion but in either case ceased before the volcanic episode came to a close. To the south, however, movements continued long afterward along the same zone. They are, in fact, still continuing.

DAVIS FAULT ZONE -SOUTHERN PART:

Attention may now be turned briefly to the portion of the Davis fault zone south of Indian Creek. This is a region in which the rocks exposed along the mountain front are almost exclusively limestone, carbonaceous shales and schists of the McNett formation with thickly distributed intrusive masses of plutonic rocks which are obviously apophyses from the main batholith. The sedimentary deposits were highly deformed before the marginal faults were formed. This deformation is related in some degree to the intrusion of the granites but it in part antedates the period of igneous activity. Both folding and faulting are represented in the deformation. These older faults are mostly quite flat, with dips that do not often exceed ten or fifteen degrees to the east or northeast. They are truncated by marginal faulting. It is pos-

PLATE XLIV

Description of Plate XLIV

A. Probable fault between granite (left) and Quaternary basalt overlying franite and metamorphics (right) about two miles south of Indian Canyon.

B. Recent fault scarp in alluvium south of Indian Canyon paralleling mountain base. McNett Ranch to right of center.

sible that they may be thrust faults.

The folding in places, especially near the granite contacts, is so intense that typical fan folds are developed. Refer to Plate LXVI, A and B. The earlier fault planes have been affected in some degree by the folding.

Intersecting and displacing the older faults are the younger ones of the Davis fault zone. These may usually be distinguished from the former by their steeper dips. They are characterized by their breccias which, in contrast to the ridge-forming breccia west of the Red Rock mine just to the south of Dry Canyon and also to the breccias of the nearby older faults, are relatively little consolidated.[1]

At two or three points along the mountain front the faults of the more recent series have brought Quaternary basalts to rest against the limestones or against granite. In other cases the fault could be traced without interruption into known Recent faults farther north. Thefault planes appear to dip to the east at an angle usually of about fifty degrees.

The Davis fault zone is probably the most important zone of faulting on the east side of the White Mountain range. South of Trail Canyon it delimits the mountain block. From approximately Trail Canyon north, however, the movements which elevated the White Mountain range were distributed among the Davis, the Pinchot and the Sand Spring faults. The earliest

1. It seems to be characteristic of the marginal faults of the Davis zone that where they traverse limestones thick breccias are found, but where they cross intrusive or volcanic rocks there is little or no brecciation. There are few exceptions to this rule.

movements probably occurred along the Davis fault zone, although it is not impossible that there may have been accompanying movements along the faults farther east.

PINCHOT FAULT:

Faulting along the Pinchot line is inferred from physiographic and structural considerations rather than from definite stratigraphic evidence. Uplift to the west of the fault is considered to be responsible for raising the basalt of Wildhorse Hills above the valley alluvium, although it is not necessary to assume the presence of a fault to explain the distribution of the basalts in this vicinity. However, the canyon occupied by the unnamed stream which flows into Trail Creek at the northwest corner of Wildhorse Flat is of a character strongly suggestive of control by faulting. Southeast of Gold Hit along the same line are a series of veins and fractures filled chiefly with quartz or serpentine. The offset in the course of Pinchot Creek along the probable line of faulting is also presumptive evidence in favor of the hypothesis.

SAND SPRING FAULT:

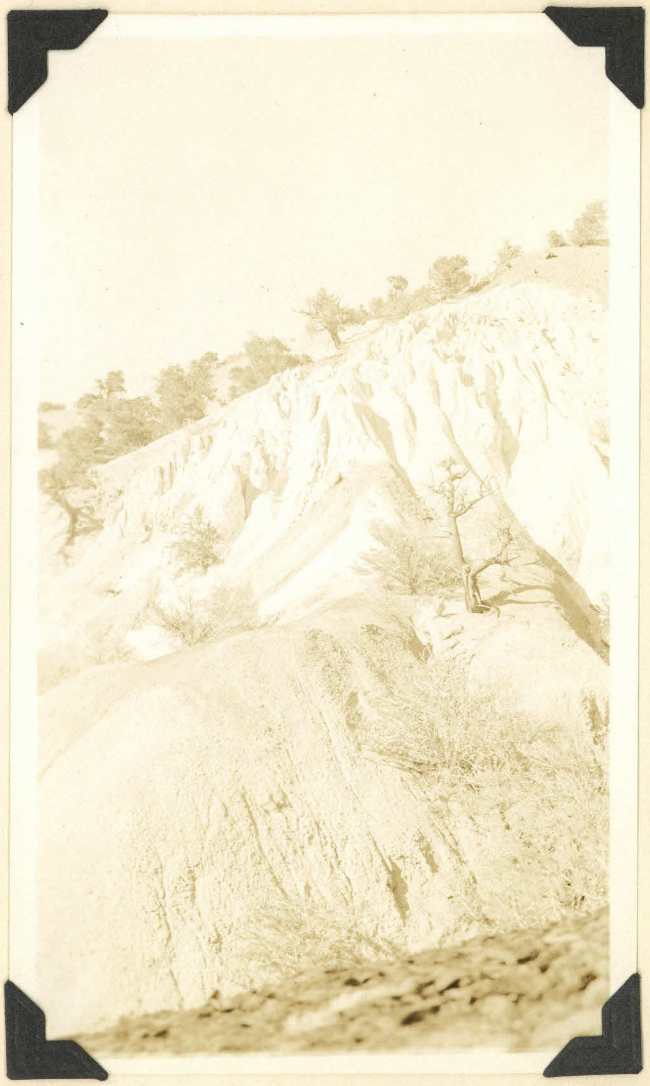
The Sand Spring fault is a well-defined line of faulting which has a trend nearly parallel with the Davis falut zone. It is best exhibited in the vicinity of Sand Spring about ten miles northwest of the Chiatovich ranch, whence its name. Just to the west and southwest of Sand Spring the Quaternary basalts at the eastern margin of Pinto Hill dip eastwardly into the fault at

PLATE XLV

Description of Plate XLV

A. Slickensided fault plane of north-south fault about two miles northeast of Sand Springs. The movement of the near block has been obliquely downward to the left. The camera points east.

B. Pulverized granite south of Indian Creek. The exposure appears from a distance to be volcanic ash, but on close examination it is seen to contain numerous small fragments of granite in a finely powdered matrix.



angles varying from thirty to fifty degrees. Two miles farther to the northeast a number of small subsidiary faults with steep westward dips are exposed in the upthrown block, Such faults in some cases show a surprising amount of brecciation along the fault plane. The apparent relations are shown in the accompanying diagram. (See page)

Physiographically the Sand Spring fault is better indicated than the northwestward continuation of the Davis fault zone. Along the fault plane are a number of drainage channels which obviously owe their direction to the faulting. To the west is a low scarp which, though less straight than the Davis scarp, resembles a fault scarp, its greater irregularity being due to the soft and easily eroded character of the volcanic materials which it crosses.

Stratigraphically the fault is also fairly well indicated. West and southwest of Sand Spring are a series of rhyolitic flows and tuffs capped by basalt (dipping steeply eastward at the fault plane but more nearly horizontal farther west) which are repeated in corresponding sequence north of the spring. Farther to the northwest the basalt is absent from the upthrown side of the fault but the underlying rhyolites and tuffs appear on the downthrown sides. With due caution in regard to placing too much confidence on apparent similarites between volcanic beds, the vertical displacement to be attributed to the faulting may be given as approximately five hundred feet northwest of Sand Spring. The displacement decreases to the northwest until eventually the fault can no longer be traced. Southeast of Pinto Hill it also dies out rapidly and disappears under the valley alluvium at the eastern edge of Wildhorse Flat.

Structurally the Sand Spring fault may be considered to mark the northeastern limit of the White Mountain block. Its relations with the Davis fault zone and the Pinchot fault zone are those of widely separated step faults but they are also similar to those of the parts of a splintered fault.

THE DYER FAULT:

The Dyer fault is a relatively unimportant fault which properly belongs to the Silver Peak block and has little directly to do with the structure of the White Mountain Range. It is a transverse rather than a marginal fault, trending about N 50 W. It is of interest chiefly because at its northwestern end peculiar conditions exist which cause the fault to assume the appearance of an overthrust with a flat northeasterly dip. Careful study shows that the fault is a normal fault dipping steeply to the north east with Tertiary volcanics to the northeast lying against a granitic intrusive to the southwest. The appearance of an overthrust is exhibited in a small cross canyon just to the west of the extreme eastern edge of the map, a short distance to the south east of the Dyer ranch. To an observer looking at the northwest wall of this little canyon the granite seems unquestionably to overlie the Tertiary tuffs. The appearance seems to be substantiated when, climbing to the top of the volcanics he finds there exposures of a thick breccia composed of fragments of both kinds of rock firmly cemented by a calcareous cement. Looked at from

PLATE XLVI

Description of Plate XLVI

A. The northern end of the White Mountain Range from a point four miles north of the Chiatovich Ranch. The view shows part of the Davis fault zone, the Pinchot fault and the extreme southeast end of the Sand Spring fault.

B. The western end of the Dyer fault. The relations are shown in the diagram on the slip-sheet.

the northwest, however, the ridge shows no relations which would even remotely suggest overthrusting nor does the fault exhibit similar characteristics anywhere else along its trend. Evidence is to be found, however, of a northeast-southeast fault crossing the ridge precisely in line with the exposure of the apparent overthrust. The conclusion reached is that the Dyer fault has been offset two or three hundred feet to the northeast forming an horizontal L of granite the angle of which was occupied by tuff. Subsequent erosion removed a large part of the tuff but left part of it lying against both arms of the L with the top of the exposure sloping somewhat to the northeast, just above which the breccia of the cross fault becomes uncovered. (Refer to Plate XLV - B for illustration)

A low fault scarp not over twenty-five feet high trending N 50° E is plainly evident at the margin of the Silver Peak salient east of the Dyer Ranch. It truncates the tips of the spurs and crosses the alluvium at the mouths of the canyons. In the former case it forms a sharp rectilinear contact between Paleozoic limestones or Tertiary volcanics and the valley alluvium. East of the Dyer ranch it changes its course sharply to about N 70° E and passes across the border of the quadrangle.

MINOR FAULTS:

A large number of faults occur in the White Mountain region which do not appear to belong to any of the zones of faulting which have been described. Most of them are relatively unimportant and none of them can be traced far. A few may have been formed before the great marginal fault zones which elevated the mountain block. This is indicated by their occurrence in the older formations and by the generally more perfectly cemented character of their fault breccias. Reference has been made to some of these truncated by the marginal faults in the area south of Indian Creek (east). Another possible line of older faulting is along the trail leading from Davis Creek south over the 8700 foot divide to Post Meadow. Along this trail are numerous exposures of a fault breccia of which the fragments are highly altered and indurated shales belonging to the McNett formation and the cementing material appears to be hematite.

It is also probable, as Kirk has indicated for the Inyo Range south of Westgaard Pass[1] that most of the transverse canyons follow lines of faulting. It has not been found possible, however, to trace and map these faults definitely.

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1. Knopf and Kirk, U.S.G.S Prof. Paper 110, 1918, p. 21.

FOLDING:

OLDER STRATA:

The rocks belonging to the older sedimentary series represented in the White Mountain Quadrangle , (the McNett formation) were subjected to severe compression before the accumulation of the Tertiary volcanic rocks which lie unconformably upon them. The developement of fan folds in the limestones south of Indian Creek has been mentioned. Another example of intense deformation is to be found in the interstratified quartzites and calcareous shales on the northeast wall of lower Queen Canyon where the bedding, brought out sharply by high contrast between the alternating light and dark beds, exhibits contortions not unlike the suture pattern of an ornate ammonite.

The degree of distortion in the strata of the McNett formation, however, is variable. It is in part to be ascribed to the effects of the batholitic intrusion. Away from the contacts the deformation becomes less intense; as it approaches them it may become so great that the original bedding may be almost completely obscured and rock cleavage become the dominant structure. Within the contact zone itself the original sedimentary structures are usually completely destroyed by the complete replacement and recrystallization of the rock mass. On the other hand beds situated at equal distance from the contact may vary decidedly in the extent to which they have been folded.

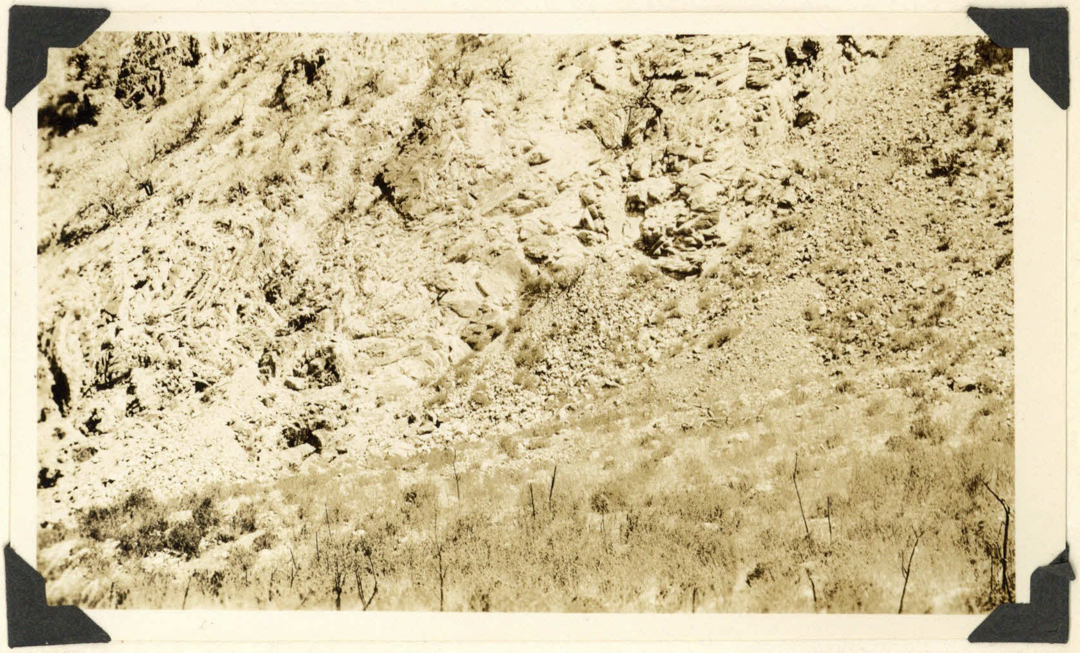
Unfortunately there are no large exposures of the McNett formation in the White Mountain Quadrangle sufficiently

PLATE XLVII

Description of Plate XLVII

A. Fan folding in limestones of the McNett formation south of Indian Canyon

B. Intense folding in limestones near granite contact.



removed from both contact zones and areas disturbed by later faulting to permit generalizations as to their structure. A large number of attitudes were taken in each exposure, care being taken in each case to select localities in which some beds seemed to be affected in the minimum degree by faulting, slumping or intrusion. In addition to this, the attitudes of the contacts between lithologically different members of the formation were ascertained by the three point method of solution whenever possible. The average results for the three chief areas in which the McNett formation is exposed east of the range seems to indicate a prevailing strike for the formation of within a few degrees of east-west and a prevailing dip to the north at an angle which ranges up to sixty degrees.

The exposures on the Montgomery scarp are too much shattered and disturbed by faulting and by the effects of igneous intrusion to yield results of value.

TERTIARY BEDS:

The Tertiary beds of the Esmeralda formation within the White Mountain Quadrangle have undergone considerable amount of folding and tilting since their deposition, although the maximum degree of deformation is far less, as a rule, than that which has been observed in the older deposits. Locally the dips may be as steep as sixty or seventy degrees but such cases are referable to disturbance by faulting. There are no indications of extreme compression. A marked difference exists in the attitudes exhibited east and west of the Sand Spring fault in that those east of the fault are more uniform than those to the west. There is moreover, a difference in direction of the prevailing dips. To the northeast of this line the average strike of the stratified volcanics is slightly to the north of east, the dips vary from 8° to 18° SE. In a few cases the strike deviates to the southeast and the dip to the southwest. Southwest of the fault the prevailing dip of the beds is to the northeast but the strike does not appear to be much changed; both strike and dip, however, as has been pointed out, are more variable and generalizations must be more cautiously applied. The dips steepen to the north but in general they are nowhere greater than 30° ;farther south they tend to become more gentle. However, along the mountain front south of Trail Canyon wherever Tertiary stratified beds are exposed along the Davis fault scarp the dip is at a fairly high angle to the north or northeast.

Northwest of the Queen fault scarp there are a number of exposures of the Tertiary volcanic materials. Exposures of stratified beds outside of the fault zone are relatively scarce, however, and the attitudes which could be taken are somewhat too variable to permit safe generalization. The impression obtained is that the regional dip is to the north.

The tilting of the Tertiary deposits was effected in a large measire before the outflow of the Quaternary basalts and much if not most of it probably occurred before the beginning of the faulting which blocked out the White Mountain range. There is evidence that an old age land surface of considerable extent was bevelled across their upturned edges before the basalts spread unconformably over them.

PLATE XLVIII

Description of Plate XLVIII

A Eastern end of Black Mountain from a point somewhat more distant than that of Plate XL. The relations of Quaternary basalt, Quaternary alluvium and Tertiary extrusive rocks are indicated in the diagram.

B. Northward-dipping Tertiary volcanics on east side of Davis Mountain, overlain by Quaternary basalt.

QUATERNARY BASALTS:

The Quaternary basalts are frequently inclined, sometimes at a high angle, and occasionally they appear to be gently folded. In every case, however, the structures exhibited may be shown to be due to primary attitude or to subsidence or settling of the underlying formations. There is no evidence that there has been folding produced by compressive forces since the last period of volcanic activity.

INTERPRETATION OF STRUCTURAL FEATURES.

In the above descriptive section the attempt has been made to present a somewhat detailed account of the faulting and folding in the White Mountain region. There now remains the more important task of interpreting these phenomena in regard to their bearing upon both local and structural development and that of the great basin and range province.

If my observations have been accurately made and my inferences correctly drawn the White Mountain Range is a horst; Blind Spring Hill and the region northwest of the Queen fault zone are uplifted fault blocks while Pellisier and Fish Lake Valleys are relatively depressed areas which either have been left behind during the elevation of the mountain blocks or participated fully or partially in the uplift and were later dropped down to their present positions. Pellisier Valley is obviously a graben; Fish Lake Valley is a structural basin of which the sub-alluvial floor, judging from the prevailing dips of the stratified volcanics at the north end, probably slopes gently downward to the south except near its western margin.

Long before the inaugeration of the era of block faulting and even before the deposition of the Tertiary beds compressive forces acted upon the area, folding and faulting the beds of the McNett formation. The origin of these forces and the direction in which they acted is not known. The folding seems to have preceded or accompanied the igneous intrusions but in no case to have followed them, for aplite dikes and sills from the latter may frequently be seen to cut across earlier folds without being folded themselves. The folding may have been extensive enough to produce a range of folded mountains at or near the site of the present range but the evidence in hand is not complete.

A later period of compression followed the Tertiary volcanic eruptions, producing relatively open gentle folding in the later stratified deposits and possibly accentuating that in the older ones. There may have been other periods of deformation than the available evidence indicates. During a long interval of quiescence which followed, erosive forces planed off the tops of the folds and formed an old age surface across the upturned edges of the strata. How extensive this comparatively level surface was we have no means of knowing but it certainly included much if not all of the area included in the White Mountain Quadrangle.

The differentiation of the present mountain and valley blocks begins three or four miles south of the northern border of the quadrangle. An east-west profile just north of Mt. Montgomery Station would have an almost even surface. A similar profile twelve miles to the south would exhibit a discordance of over 8000 feet between the mountain crest and the surface of the valley alluvium. Fourteen miles farther south the discordance is increased by 1500 feet. But the present mountain crest, the summits of the ridges north and east of Mustang Mountain and the basaltic plateau northwest of Queen even now form a virtually continuous surface only broken to some degree by step-faulting, with a rather gentle northward slope, somewhat steeper south of Mustang Mountain than it is to the north. There is every reason to believe that this accordant surface once included the sub-alluvial floors of Fish Lake and Pellisier Valleys.

Structurally Sand Spring fault forms the northeast boundary of the Inyo Range. The discordance between the prevailing direction of dip of strata of the same series east and west of the fault indicates that the blocks may have been rotated in respect to each other. It may, on the other hand, be due to shear. The beds southwest of the fault have been folded and faulted to a much greater degree than those to the northeast. Only in the case of recent faults do these disturbances affect the Quaternary basalts. This leads us to suspect that the Sand Spring fault may be a more ancient structure along which movements took place before the beginning of the major uplift to the west.[1]

If we are correct in assigning the origin of the Sand Spring fault to a period antedating the principal uplift of the White Mountain Range, we must assume that a renewal of movement took place along it during the later era of block faulting, dislocating and tilting the Quaternary basalts and forming the low Sand Spring scarp of the present time. At the same time or later companion breaks occurred along lines to the west, bringing the Quaternary Mustang Mountain basalt and its underlying alluvium to a position 4000 feet above corresponding lavas at the base of Sand Spring scarp.

1. In the general statements which have been made in respect to the structure of the deposits northeast of the Sand Spring fault, exceptions must be made to apply to the Tertiary volcanics in the rugged region in the extreme N.E. corner of the quadrangle, east of B.M. 7417. These volcanics have been intensely deformed by folding and faulting. The disturbances, however, appear related to

The uplift of the triangular shaped block between the Davis zone and the Pinchot fault was responsible for bringing the basalts at its southeast end high enough to preserve them to the present from complete burial by alluvium. These basalts probably constitute a platform which continues westward at no great distance below the surface of the fan to the marginal faults of the Davis zone. (See structure section) The occurrence farther south of low basalt covered hills which rise above the alluvium just east of the mountain blocks indicates that the platform extends for some distance in this direction.

The Dry Canyon fault appears to be a plane of adjustment along which movements have taken place to compensate for the difference in displacement along the Davis fault zone northwest and southeast of it. The best calculations that can be made indicate that the total displacement brought about by the Davis fault zone in the vicinity of Mustang Mountain is at least 700 feet less than it is at the eastern end of Black Mountain. This figure agrees well with that for the probable maximum throw of the Dry Canyon fault.

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local igneous activity of Quaternary or Recent time.

THEORIES OF BASIN AND RANGE STRUCTURE.

We now turn to discuss briefly the place of the White Mountain structures in the general structural plan of the basin and range province. This province embraces the huge area lying between the Sierra Nevada on the west and the Wasatch Mountains on the east. Originally it was called the Great Basin, but the appellation "basin and range province" has been suggested as a substitute. In this report both terms have been used to avoid repetition. I prefer the newer one because I consider it more descriptive of the true structure. "Great Basin" has the sanction of long usage and may, therefore, properly be applied.

As is well known, the province is characterized, especially in the northern part, by the occurrence of numerous subparallel mountain ranges separated by deep valleys or basins both of which owe their fundamental outlines not to erosion but to the displacement of large blocks of the earth's crust with attendant uplift, depression or tilting but not with any very great amount of deformation within the individual blocks resulting from the block faulting. The limiting ranges of the province east and west are themselves among the best of the examples of this orogenic type.

The recognition of the fault-block structure in the basin and range province is to be credited to G.K. Gilbert who published his conception in 1873.[1] The idea was adopted at once by Powell and shortly afterward by Clarence King who modified it,

1. U.S.G.S. West of the 100th Meridan (Wheeler Survey) Vol 3, pp. 21-42.

however, by insisting upon the importance in the structure of the fault block mountains of the results of an earlier period of tangential compression and folding. Later geologists, including I.C. Russell, W.M.Davis and others, taught and developed the concept until at the present time it is almost universally accepted.

The White Mountain-Inyo chain is of particular interest among examples of this type of structure for various reasons, chief among which are, first, that it stands in such close and interesting relationship to the great Sierra Nevada block and, second, that it departs from the common type of fault-block range in being a tilted horst rather than one of a series of simple tilted blocks. The presence of marginal faults on both sides of the range adds important complications to the phenomena ordinarily observed. These structural features have been mapped and described in considerable detail because of the bearing they may have upon the ultimate solution of many of the problems which confront the student of basin and range geology.

It would not be unnatural now to inquire into the nature and origin of the forces which have operated to produce a kind of structure at once so uniform and so unique over such a large area as that of the basin and range province. An inquiry of such a general nature would of course be quite beyond the bounds of this thesis which is primarily a descriptive areal study; nevertheless, the problem stares us in the face whenever we attempt to understand the origin of such forms as we have described here.

On the map of the White Mountain Quadrangle we can draw two parallel approximately northwest-southeast lines less than twenty miles apart on the eastern one of which every point will be within two or three hundred feet of the same elevation as a corresponding point directly west on the other. A third line parallel to both can be drawn between the two about one third of the distance from the western one to the eastern one every point along which from the vicinity of Montgomery Peak south will be between 8000 and 9000 feet above corresponding points on the other lines directly east and west. There is every reason to believe that all the points on all the lines were at one time within a few hundred feet of each other in altitude. Why has one of the lines now become so far displaced in respect to the others? Our observations show us that we have three blocks, the central oneof which has become elevated in respect to the other two, or, conversely, the latter have become relatively depressed. The differential movements have taken place along a number of moderately steep to vertical planes in narrow zones along the margins of the blocks. In the movements the mountain block appears to have been tilted somewhat to the east but none of the blocks appears to have suffered much internal deformation. All three stand at present thousands of feet above the level of the sea.

In travelling eastward across the northern part of the Great Basin region one sees essentially the same conditions repeated again and again, with a general parallelism of arrangement so marked as to impress even unscientific observers. Moreover the entire region stands high above the level of the sea.

For the White Mountain region, then, as well as for the entire basin and range province the same questions may be asked among which are these: why does the entire region stand so far above the level of the oceans? If the assumption is correct that the basins and ranges were once all at essentially the same or accordant levels, were those levels the levels of the present range crests or of the present basins, or were they somewhere in between? Or were they lower than either - that is, have the basins and ranges both gone up but the latter more than the former? Or, as a last and least likely possibility, were the former levels above the present range crests, from which both range and basin have since subsided? In any case, what has caused the change and how has it been produce?

Many years ago Joseph LeConte proposed an attractive explanation for the structure of the Basin region.[1] He believed that the region between the Sierra Nevada and the Wasatch Mountains, inclusive, had been bulged up by the pressure of an intumescent sub-crustal liquid into a great arch. The local intumescence of the liquid was conceived as being due to (1) the elastic force of steam incorporated into the magma by access of water from above, or, (2) to hydrostatic pressure transferred from a subsiding area in some other, perhaps distant place.

> "Such an arch, being put upon a strech, would be broken by long fissures more or less parallel to each other and the axis of uplift into oblong prismatic blocks many miles in extent. After the outpouring of liquid lava or the escape of elastic vapors had relieved the tension, these crust blocks would again be readjusted by gravity. If the blocks are rectangular prisms, some may float bodily higher and higher and some sink bodily lower, giving rise to level tables separated by fault cliffs as in the Plateau region.

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1. Le Conte, J. - Origin of Normal Faults and of the Structure the Basin Region, Amer. Jour. Sci. (3), 38: 257-263, 1889

> ...But if the fissures are more or less inclined, as is more commonly the case, then it is evident that the crust blocks will be either rhomboidal or wedge-shaped . . . . Now by the laws of flotation how would such blocks adjust themselves? It is quite evident that every rhomboidal block would tip overon the over-hanging side and tip up on the obtuse angle side, producing in every case normal faults, and every wedge-shaped block would sink bodily lower or float bodily higher according as the base of the wedge were upward or downward, producing again in every case normal faults. . . . Of course erosion would modify the results thus formed. . . . It must not be supposed, however, that this took place at once, but gradually; the lifting, the breaking down and the readjustment going on together pari passu; each readjustment probably giving rise to an earthquake. There are many evidences that the process of readjustment of these crust blocks is still going on."

Le Conte considered that the process has in the main taken place at or since the end of the Tertiary.

I have to confess that I find in this theory much to commend it. It is true that it has been criticized on the grounds, first, that such an arch would be incompetent and could not exist; second, that the butresses at either end could not withstand the tremendous pressures directed against them; third, thatt the extension of the earth's crust indicated by computations based on the actual displacements along normal faults in the area is greater than would result from the lengthening produced by such arching. The first objection may be answered by the statement that the incompetency of the arch to sustain itself without upward pressure from below is the very foundation of the theory. The reply to the second is that an arch such as Le Conte postulated does in fact exist at the present time (though it may not terminate at the Wasatch on the east), for his assumption was that <u>the arch broke as it rose</u> and perhaps never as a whole was much higher than it now is.

If we are to accept the idea at present most favored by petrologists that beneath the solid "crust" there exists a fluid or potentially fluid sub-stratum we are certainly not far from the conditions Le Conte suggested for the Great Basin region. An up-warp of some kind does certainly exist, whether it be called an arch or something else.

The validity of the third objection to Le Conte's idea is to at least to some degree impaired by the fact that so little is known of the actual attitude of the faults below the surface and of their former attitude above the present exposures. There is still some dispute, for example, as to whether the present scarps approximately represent the position of the fault planes or have been much worn back from those planes. The tendency is to accept the view that the faults themselves were much steeper than the scarps. More definite information is needed before this objection can be urged too strongly.

Lending some support to Le Conte's theory, on the other hand, are the evidences of tremendous volcanic activity in the Basin region accompanying or closely preceding the principal period of faulting. When we view the tremendous quantities of material which have been transferred from below to above the earth's surface in the form of molten lavas and of pyroclastics we cannot escape the conclusion that the emission of so much matter must have had something to do with the break-up of the older "crust" in the Basin region. It is true that a very large part of the volcanic activity appears to have taken place considerably before the period now generally accepted for the faulting, but it cannot yet be considered as definitely established that earlier movements did not occur whose effects are perhaps not evident in the present scarps, although it must be admitted that an earlier period of normal faulting does not seem consistent with the undoubted evidence of compression of those beds supplied by the folding so commonly found in them. However, the distribution and thickness of terrestrial Miocene or Pliocene deposits in the intermountain region indicate that basins existed there before Quaternary time. Le Conte's explanation for the upward pressure and outpouring of the lavas may be untenable, but the fact cannot be ignored that they wer extruded. Whether the pressures were the cause or the result or had nothing to do with the faulting, they nevertheless did exist.

Lindgren,[1] it is interesting to note, appears to adopt at least in part the views of Le Conte. The uplift of the Sierra Nevada, he states, involved also the Great Basin, and was accompanied or followed by the subsidence of the block immediately to the east of the Sierra Nevada scarp. After summing up the evidence, he concludes:

> "All this shows clearly that the dislocation along this consists in a sinking of the eastern blocks. Nowhere can any evidence be found substantiating the theory that the fault scarp has been formed by an uplift of the western block."[2]

Elsewhere[3] he continues:

> "It follows from the irregularity of the subsidence which has taken place at different times that these movements can in no way have been responsible for the uniform tilting of the western slope."

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1. Lindgren, W. - Tertiary Gravels of the Sierra Nevada, U.S. G.S. Prof. Paper 73, 1911, p. 48
2. Ibid, p. 41
3. Ibid, p. 43

Louderback, on the other hand, sees no reason for believing that recurrent faulting occurred along the front of the Sierra Nevada. He does not deny that elevations of the Sierra Nevada and of the country directly to the east

> "may have begun and been in operation some time before the faulting commenced,"

but he thinks that it would seem most natural to correlate the uplift of the range with the faulting along the eastern front and knows of no facts inconsistent with this relation.[1]

Knopf,[2] on the basis of his own and Lawson's studies in the southern Sierra Nevada, has adopted the view that the elevation of the range took place in two stages. The first, consisting of an uplift of about twenty-five hundred feet, involved at least a part of the Great Basin. The second and major uplift involved a displacement of about six thousand feet west of Owens Lake and resulted in the formation of the eastern fault scarp and the intrenchment of the streamson both sides of the range. He bases his belief that the earlier uplift involved the country east of the Sierra Nevada on the ground that a mature topography such as he and Lawson have described east of the Sierra crest could not have been evolved

> "if the initial uplift of twenty-five hundred feet had been accompanied by a relative subsidence of the floor of Owens Valley."

I find myself unable to escape wholly from an impression - which may be based more upon general appearance

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1. Louderback, G.D. - Period of Scarp Production in the Great Basin, U.C. Publ. Bull. Dept. Geol. Sci. Vol. 15, 1924, p. 32 and p. 31

2. Knopf, A. - U.S.G.S. Prof. Paper 110, 1918, p. 88

than upon scientific reasoning - that the uplift of the Inyo-White Mountain range and of the Sierra Nevada took place at essentially the same time and that the intervening country as well as at least part of the region to the east was also uplifted either partly or wholly with the ranges. This impression is based chiefly upon the sub-equality in elevation between the Inyo-White Mountain range (especially at its northern end) and that of the Sierra Nevada, upon the marked similarity in summit topography between the two ranges, and upon the apparently well-founded theory that subsidences in the floors of Saline and Owens Valleys have taken place in recent times. It seems easier to believe that elevation of the whole region took place at the same time and under the influence of the same forces with some parts either lagging behind or later dropping back than it is to believe that the elevations of the two ranges to virtually the same height took place independently of each other and at different times.

Before leaving the subject of basin range strucure as applied to this region it seems desirable to direct attention to one other feature. In the classic descriptions of block fault mountains the tendency has always been to emphasize the rectilinear outlines of their bases, and the discussion has always proceeded on the assumption that the limiting faults are of simple character - single faults which parallel the mountain base.

In this thesis the complex nature of the marginal faults has been recognized and emphasized. "Fault zones" have been discussed rather than single faults, each zone being made up of several or of many faults which tend to parallel each other but which may diverge at considerable angles. This is especially true of the eastern marginal faults (Davis zone). Louderback also has discussed such complexity of marginal faults and has pointed out their common occurrence.[1] Knopf met with similar complications in the southern part of the Inyo Range.[2] He says:

> "The features of the range front from the mouth of Waucoba Canyon to the Montezuma mine and southward, display in an unusually clear way the complications that rendered difficult the decipherment of the orogenic history from physiographic criteria alone. The dislocations that determined the relief of the range took place along a series of faults many of which have a tendency to coincide with the base line of the range for some distance and then to run at a narrow angle into the mass of the range."

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1. Louderback, G.D. - Morphologic Features of Basin Range Displacement, U.C. Publ. Bull. Dept. Geol. Sci. Vol. 16, 1926, pp. 15-18

2. Knopf, A. - U.S.G.S. Prof. Paper 110, p. 89

INTRUSIVE CONTACTS

Contact metamorphism is important in the geology of the White Mountain quadrangle. Almost nowhere in the area can the contact between the intrusive rocks of the central batholith and the members of the older sedimentary series be correctly indicated on the map by a sharp line. The condition is represented cartographically by a "zone of intense contact metamorphism" entirely surrounding the principal intrusive mass. For simplicity this zone has been given sharp smooth boundaries, but if drawn in detail the latter would be highly intricate and not sharp but of a transitional character. It should be emphasized also that this zone is intended to include only the more intense contact phenomena. Few if any of the older sedimentary rocks of the area are free from all contact effects.

The contact zones as mapped are characterized by a bewildering complexity of rocks highly diverse in composition and texture. Very few of them could be assigned to any precisely defined petrographic group, for they have a complex origin. They represent all stages and conditions of contact metamorphism but chiefly those in which addition of material from the magma has played a prominent part. Products of exomorphism and endomorphism can both be recognized. Usually, however, the original nature of the rock has been entirely obscured; it is, in fact, a new rock, containing many or most of its former constituents but enriched, in the case of derivation from an intrusive, by material assimilated from the sediments, or, in the alternative case, by material added by gaseous or watery emanations from the magma or by the actual injection of magmatic material. Intense silicification of the limestones is one of the most striking exomorphic effects.

The contact zones are further complicated by a veritable network of aplite and pegmatite dikes - usually the former - sent out by the intrusive mass.

Frequently two generations of aplites and pegmatites may be observed. The earlier I have tentatively designated as "the sill type." These have penetrated along the bedding planes of the sediments (especially shales) forming migmatites of "injection gneisses". They vary in thickness from a few millimeters to several feet. The thicker ones commonly exhibit chilled border zones, aphanitic or almost glassy, with gradually increasing granularity to the middle of the vein. These were injected while the country rock was still cold, the magma still at relatively high temperature. The second type commonly cuts at oblique angles across the former, heedless of bedding planes, following, possibly, tension cracks ceveloped by the pressure of the magma against its walls as it pushed its way upward. Dikes of this type are granular to their very boundaries which are always sharp and distinct. Their appearance is that of an aplite at the edge, but toward the middle they often tend to become increasingly like pegmatites. Rarely do they show any tendency to send off-shoots along the former bedding planes of the sediments; such channelways appear to have been sealed by the aplites of the earlier type. They have an average thickness greater than the latter, varying from an inch or two to several feet.

The dikes of the second type appear to have been injected at a time when there was less thermal difference between the magma and the country rock.

Contact rocks of the type just described are best exhibited at the south end of Davis Mountain north of Indian Creek (east).

The width of the contact zone varies from a few hundred to two or three thousand yards. In some places it may narrow down to a few feet. Nowhere, however, is it a matter of inches.

In some localities typical contact minerals are prominently developed. These include epidote, garnet, vesuvianite, wollastonite, diopside and others less common. These are collected best near California-Nevada boundary marker No. 63 and at an elevation of about 9,000 feet in Dry Canyon.

In general it may be said that the shales of the sedimentary series show effects of contact metamorphism at greater distances from the intrusive mass than do the limestones. In the zones of most intense alteration the shales have been completely injected, recrystallized or even absorbed. Farther away from the actual contact they form "knotenschiefer" or "fleckschiefer", rocks typical of the less advanced stages of contact metamorphism. Shales interbedded with limestones may exhibit this type of alteration when the accompanying limestones show no change. This is often to be observed wouth of Indian Creek (east). On the other hand very large bodies of of "knotenschiefer" may be exposed. Such a body covers an area of three or four square miles north of Queen Canyon.

An adequate discussion of the subject of contact metamorphism in the White Mountain quadrangle, then, would involve the careful differentiation and mapping of not one but several zones. Within the limits of time permitted for field work detailed study of this kind has not been possible. In the chapter on petrography, however, will be found a description of some of the more important contact metamorphic zones.

The contact zones are widest and most complex to the west and north of Montgomery and Boundary Peaks, north and west of Post Meadow and in the limestones and argillaceous rocks south of Indian Canyon.

AREAL DISTRIBUTION OF THE ROCKS

SUBJACENT SERIES

McNETT FORMATION:

The oldest rocks exposed in the White Mountain quadrangle are those comprising what has been provisionally termed the "McNett Formation." This formation is non-fossiliferous and since it cannot be traced directly into any other group of rocks of known age, its place in the geologic time scale is not definitely known. On the basis of such evidence as can be adduced, it is thought to be of early or pre-Paleozoic age. The nature of this evidence, together with detailed descriptions of its character and of its probable affiliations will be found in the chapter on Stratigraphic Geology. It is sufficient to say here that the formation consists chiefly of rather thin-bedded impure dolomitic limestones, calcareous, ferruginous and carbonaceous shales and minor amounts of quartzite, together with various types of metamorphic derivatives.

The largest exposures of the McNett formation are distributed along the northeast side of the White Mountain range in a zone which trends from south of Indian Creek northwest to the region beyond the station of Nichols on the Southern Pacific narrow gauge line.

Other localities in which the McNett formation appears are to be found along the Montgomery fault scarp south of Morris Creek. These areas are for the most part smaller than the ones on the east side of the range; the rocks are much shattered and altered by metamorphic processes.

PLATE XLIX

Description of Plate XLIX

A. Argillites with some interbedded quartzites, McNett formation, lower Queen Canyon.

B. Limestones of the McNett formation south of Indian Canyon.

The Indian Creek exposure is the most instructive in that it is the only one in which the principal members of the formation are exposed in their maximum thickness for the area. It lies chiefly south of the creek but the shale member is found also at the south end of Davis Mountain and along the south side of Indian Mountain, where it has undergone most intense contact metamorphism.

Between Davis Mountain and Middle Creek the continuity of the formation is interrupted by the granitic intrusive mass. Covered in part by basalts and Tertiary volcanics, it extends as far northwest as Trail Canyon. Between Trail Canyon and the mouth of Queen Canyon the limestone member is absent, but the shale member, here altered by contact metamorphism to "knotenschiefer" or "fleckschiefer", extends through without interruption, except as obscured by overlying Tertiary volcanics, along the north side of the trail southwest of Mustang Mountain and as far southwest as the mouth of Queen Canyon. North and northeast of this point the formation is intermittently exposed along the Montgomery and Queen fault scarps. No exposures are to be found, however, southwest of Nichols, where it seems to be dropped out of sight by faulting.

A small area of the McNett formation is exposed just to the west of the mouth of Queen Canyon. From this locality south as far as Morris Creek the intrusive has broken through to the mountain front.

In the extreme northeast corner of the quadrangle is a small area of thin-bedded dense black limestone interbedded with quartzites and some shales. These rocks are lithologically

PLATE L

Description of Plate L.

A. Marble from the contact zone between the McNett formation and the Pellisier granite.

B. Sample of knotenschiefer ("green knotted schist") from the contact zone, Queen Canyon.


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quite different from the McNett formation. They are considered to be equivalent to the Cambrian or Ordivician beds exposed in the Silver Peak range north of Emigrant Pass.

Sedimentary rocks which can be traced directly into exposures mapped as Paleozoic in the Silver Peak quadrangle[1] are conspicuous in the salient in the salient of the Silver Peak range just to the east of the Dyer ranch. These rocks consist chiefly of dolomitic limestones and red, green and black fissile shales.

Nowhere in the area are the basement rocks on which the McNett formation rests exposed to view.

PELLISIER GRANITE:

The Pellisier granite with its differentiates makes up the great central batholith of the northern White Mountain range. It is a medium- to coarse-grained rock, chiefly of a peculiar bluish-gray color, with abundant quartz, feldspar and dark minerals. Its contacts with the rocks of the McNett formation are always intrusive. Petrographically it is probably a true granite, but certain peculiarities in its composition and texture make it difficult to classify.

The Pellisier granite is exposed along both mountain fronts from the Queen-Trail Canyon line southward, as well as in the central part of the range. The intrusive rocks that make up the greater part of Blind Spring Hill appear to belong to the same group. It also sends out numerous dikes and apophyses into the older sedimentary series. Such dikes are commonly aplites, more rarely pegmatites. Frequently the tops of cupolas projecting into the sediments are to be seen un-

1. Spurr, J.E. - Geology and Ore Deposits of the Silver Peak Quadrangle, U.S.G.S. Prof. Paper 53, Geologic Map.

covered by erosion. These are especially common in the McNett formation south of Indian Creek. The small intrusive masses along the fault scarp north of Queen Canyon and north of Nichols also probably belong to the main intrusive mass.

Aplite border phases are also common, as, for example, along the south end of Davis Mountain as well as at various places on the Pellisier erosion surface which is probably not far from the former roof of the batholith.

Across Fish Lake Valley, southeast of the Dyer Ranch, is a small body of quartz monzonite, intrusive into early Paleozoic sediments. This mass is probably to be considered as belonging to the intrusive complex of the Silver Peak range, and may or may not be directly related to the White Mountains batholith.

The age of the Pellisier granite is not precisely indicated. It is younger than the McNett formation, which it intrudes, and older than the Tertiary volcanics which lie upon it. By analogy with the great Sierra batholith it is assumed to be Jurassic or early Cretaceous in age.

BOUNDARY PEAK GRANITE:

The intrusive mass which is indicated on the geologic map as the Boundary Peak granite is a differentiated phase of the Pellisier and is closely related to the latter in age and, to a less degree, in composition. It has been mapped as a separate unit because it possesses certain important differences. Some of these are apparent only in microscopic study and are described in detail in the section on petrography. Others, however, are apparent to the naked eye.

The Boundary Peak granite is very light, almost white in color, by which it is distinguished at once from the bluish-gray Pellisier granite. This color difference is due in part to the smaller content of mafic minerals, but it also results in part from differences in the color of the feldspars.

A second and more important difference is in structure. The Pellisier granite has a rather widely spaced system of joints about equally well developed in three directions which are fairly constant over the entire area. The Boundary Peak granite, on the contrary, has one direction of jointing much more prominent than the others and so closely spaced as to almost justify calling it sheet jointing. (See Plate L, A)

The Boundary Peak granite is exposed over a wide area at the northern end of the batholith. It is the material of which Montgomery and Boundary Peaks have been formed. These shining white pinnacles, visible for many miles in all directions, suggested the name which the range bears.

The contact between the Boundary Peak and the Pellisier granite is sharply exposed southwest of Montgomery Peak at an elevation of about 11,000 feet. This locality may be observed from the automobile road three or four miles north of Benton Station. The line of contact may also be observed from the east side of the range just below the saddle between Montgomery Peak and the northern end of Pellisier Flats. Here, however, the actual contact is somewhat obscured by talus.

Wherever the evidence is visible it indicates that the Pellisier granite is the older rock. In few places, however, is the contact visible. For the most part it is either concealed or there is a gradational change from the one rock to the other.

PLATE LI

Description of Plate LI

A. Looking west in Middle Canyon. The contact between the Pellisier granite (left) and the Boundary Peak granite (right) is in the saddle in the distance. Note morainal material in center of view and alluvial terraces to left of center.

B. Pinnacles in Boundary Peak granite, north side of Boundary Peak, showing influence of jointing. The camera is at 11 000 feet.

PLATE LI

A

B

A striking difference in characteristics between the two rocks is that the Pellisier granite almost everywhere contains both abundant inclusions of the rocks into which it has been intruded (xenolith) and autoliths, while the Boundary Peak granite is singularly free from both. This gives rise to interesting speculations as to what extent the differences observed between them may be due to assimilation of foreign material by the Pellisier granite.

BASIC PLUTONIC ROCKS:

The areas in which basic intrusive masses appear at the surface are comparatively small and are chiefly to be considered as differentiates of the batholith along its contacts. Small bodies of pyroxenite occur on the south side of Queen Canyon near the point where it is crossed by the Mineral-Esmeralda county line. These are associated with a highly varied and complex group of intrusives which obviously have been derived from the parent mass by endomorphic processes.

South and west of the divide between Queen and Trail Canyons is a somewhat larger body of hornblende diorite which forms an intrusive breccia with the granite to the west which it appears to have preceded.

A third and still larger dioritic intrusive is to be found along the Montgomery fault scarp east of Sugarloaf Mountain. Here it is in contact with a porphyritic granite which s is quite similar to certain phases of the Boundary Peak granite occurring about one and a half miles southwest of Mustang Mountain. The diorite, however, is quite different from the diorite described from the latter locality. It is definitely older than the granite with which it is in contact.

DIKES AND SILLS:

In the portion of the McNett formation exposed south of Indian Creek evidence may be found of a period of igneous activity antedating that in which the intrusion of the White Mountain batholith took place. Occurrences of sheet-like extrusive rocks which are probably sills (although it is possible that they may be ancient surface flows) are interbedded with the rocks of the McNett formation. They vary in thickness from an inch or two to four or five feet. All are of intermediate to basic composition. Their relatively great age is suggested by the fact that they have been folded with the sedimentary rocks in which they occur. In appearance, however, they are rather fresh. They are found almost exclusively in the limestones - seldom in the more argillaceous members of the formation.

Aplite dikes are exceedingly abundant in the area. In all cases they have risen directly from the batholithic invasion. They occur in great numbers in the contact zones along the western front of the mountains, north and south of Indian Creek (east) and in the area between Morris Creek and the next large canyon on the northeast. On the other hand they are entirely absent from the contact-metamorphosed sediments just to the northeast of Queen Canyon and from the exposures of limestone Between Middle Creek and Trail Canyon. In general they appear to be more common in the exomorphic portions of the contact zone but they are present in both.

PLATE LII

Description of Plate LII

A. Topography in Boundary Peak granite, southwest side of Queen canyon.

B. Jointing in granite near mouth of Marble canyon, Montgomery fault zone.

Another locality in which aplites occur with great frequency is in the granitic rocks along the crest of the range. This lends support to the belief that the present summit region is not far from the former roof of the batholith in that portion of the area.

In contrast to aplites, pegmatites are almost entirely absent from all parts of the area except in a small region between Queen Canyon and the next large canyon to the southwest, including the upper portion of the latter canyon itself. Here they are present in fair abundance. In the contact zone at the southern end of Davis Mountain the central parts of the aplite dikes frequently approach pegmatites in appearance and composition.

SUPERJACENT SERIES.

TERTIARY ROCKS:

If we omit from consideration Quaternary alluvium we may say that more than half of the total area of the northern half of the White Mountain Quadrangle is underlain by rocks of Tertiary age. They form a very thick series chiefly volcanic in character which appears to be very closely related to the Esmeralda formation of Turner and the Cedar Mountain beds of Buwalda, with which they are almost continuous.

In the White Mountain range itself these accumulations occupy most of the territory lying to the northeast of a line drawn from the mouth of Queen Canyon to that of Trail Canyon. Smaller exposures occur along the eastern mountain front, especially between Dry Canyon and the next canyon to the south. A small area is to be found at an elevation of nearly 11,000 feet two or three miles north of Boundary Peak.

In the northwest corner of the Quadrangle they form the basement upon which the Quaternary basalts rest. They are the surface rocks over many square miles northeast of the Chiatovich ranch and the Sand Spring fault. Various kinds of rocks make up the series, including flows, breccias, tuffs and playa deposits. The last are to be found in the low group of hills north of the Chiatovich ranch in Fish Lake Valley where they occur as soft muds and clays interbedded with tuffs and conglomerates but no flows.

PLATE LIII

Description of Plate LIII

A. Tertiary volcanics overlying knotenschiefer of the McNett formation, upper Queen Canyon.

B. Pinto Hill, a Quaternary lava cone.

The Tertiary volcanics are almost entirely intermediate to acidic in composition, the latter being much more abundant. No basic rocks are found. Both extrusives and intrusives occur but the former greatly predominate. Wherever their base is exposed they are seen to rest unconformably upon pre-Tertiary intrusive, sedimentary and metamorphic rocks. For the most part they are gently folded or tilted. Locally they may be faulted to an extreme degree.

In the playa deposits north of the Chiatovich ranch vertebrate remains have been found which are the basis for the assignment of these beds to the lower Pliocene. It seems possible, however, that the accumulation of the deposits may have occupied much of the middle and upper Tertiary, although this is contrary to what is indicated for many other localities.

QUATERNARY BASALTS:

Basaltic rocks of Quaternary age are most prominently exposed in a broad belt across the northernmost part of the quadrangle. They also occur in an important zone extending southeast from Mustang Mountain along the mountain front, where they form the flat tops of several high ridges, including Black Mountain and Davis Mountain.

The Quaternary basalts exhibit marked variations in texture. In composition they range fron andesites to true basalts. Their age determination is based in part upon the fact that they overlie the highest Tertiary deposits and upon their conformity to the present topography. They occur chiefly as flows, probably from a number of separate vents but connected at no great

PLATE LIV

Description of Plate LIV

A. South side of Davis Mountain, showing Quaternary basalt overlying granite at left, contact metamorphic rocks in middle, granite and Tertiary volcanics at right.

B. Near view of Tertiary volcanics in Queen Canyon.

depth with a common magma chamber. In thickness they do not average more than fifty feet but in some places they may attain two hundred feet or more.

A few basaltic lava cones are to be found along the eastern margin of the mountain block. Pinto Hill is one of these. (Plate LI - B)

STRATIGRAPHIC GEOLOGY.

EARLY OR PRE-PALEOZOIC ROCKS.

THE MCNETT FORMATION:

The oldest stratified rocks exposed in the northern half of the White Mountain Quadrangle are a group of dolomitic limestones, schists, slates and quartzites, locally highly altered by contact metamorphism, for which I have proposed the name McNett formation, since they are typically exposed on Indian Creek near the McNett ranch in Fish Lake Valley. The beds are apparently entirely non-fossiliferous. For reasons which will be discussed below they are considered to be of early Cambrian or pre-Cambrian age.

Neither the top nor the bottom of the series is exposed in the area mapped and their total thickness is therefore unknown. The total exposed thickness, obtained by adding the maximum estimated thickness of the schists which occur north of Queen Canyon to the estimated thickness of the limestones exposed on Indian Creek, is certainly not less than 2500 feet and is probably more.

The dolomitic limestones are the lowest beds of the formation exposed. In the occurrence between Trail and Dry Canyons they are medium gray, thin-bedded, impure and usually fine grained to almost aphanitic; frequently they are marked with fine dark lines parallel to the bedding. Alternating beds are often of different shades of gray, varying from light to dark. In the Indian Creek exposure the limestones are predominantly light gray or white. If white they weather to buff. Here also they are rather thin-bedded but they are somewhat coarser grained than farther north. At the lower part of the section they are often interbedded with thin layers of calcareous shale or schist; higher in the section these layers are absent. Near the contact with the intrusive rocks the limestones have undergone contact metamorphism. In places, especially where the original limestones are pure, they have been converted by the contact processes into beautiful white marble which is, however, too closely jointed to be of commercial use. Elsewhere they have been silicified to a high degree by emanations from the magma; the replacement is usually selective so that seams or layers of silicified material commonly alternate with unaffected beds. In the replaced material the original structure of the limestone is often preserved in minutest detail; often, however, instead of replacing the limestone metasomatically the intrusive has sent thin stringers of aplite to penetrate along the bedding planes. Frequently the materials thus injected have been compressed into a sort of calcareous gneiss or sometimes into "granite-augen-schist" to use Turner's terms.[1]

It was the extremely high degree of contortion of such interlaminated deposits in the Silver Peak Quadrangle that caused Turner to regard them as pre-Cambrian gneisses and schists.

Farther up in the section(approximately 1200 feet above its lowest exposure) the limestones rather abruptly give way to schists. These are for the most part true "Knotenschiefer" - the

1. Turner, Bull. Geol. Soc. Amer. Vol. 20, 1909, p. 231.

"green knotted schists " of Turner and Spurr.[1] In the White Mountain region these schists may be green blue or black when freshly exposed; when deeply weathered they are often reddish brown. The color appears to depend upon the amount of carbonaceous material present or upon the state of oxidation of the iron. The differ in the degree of schistosity which they exibit - some are highly foliated, others are hardly more than indurated shales. They are usually highly micaceous but the mica present varies from a brotite-like variety in some cases to sericite in others. The "knots" or nodules may occasionally be chiastolite or, more frequently, aggregates of tiny particles of feldspar. Reticulated threads of hermatite are often noticeable.

Nearer the igneous contacts the originally shaly material has been greatly indurated, often thoroughly permeated by emanations from the magma and always partially or completely recrystallized. Frequently it has been complexly injected to form injection gneiss or migmatite.

Quartzites occur in the series but they are rare. They are limited almost exclusively to a few beds, ten to twenty-five feet wide, which occur interbedded with indurated shales near the intrusive contact west of Post Meadow. They are light colored, almost white, fine grained in the middle to aphanitic toward the upper and lower contacts with the shale. These contacts are gradational; it is not ordinarily possible to tell where the shale ends and the quartzite begins.

1. Spurr,-Ore Deposits of the Silver Peak Quadrangle, U.S.G.S Prof. Paper 55, 1906, p. 18.

PLATE LV

Description of Plate LV

A. Contact breccia between hornblende diorite (dark) and Boundary Peak granite (light); on ridge about $1\frac{1}{2}$ miles southwest of Mustang Mountain. The granite intrudes the diorite.

B. Contact between limestone of the McNett formation, (left) and the Boundary Peak granite (right), Trail Canyon.

I have adopted the view that these bodies are true quartzites with considerable reluctance. They appear to consist of little else than quartz in small interlocking grains, but their occurrence and their increasing fineness of grain toward their margins strongly suggests that they may be highly siliceous sills which originated in the intruding magma. They cannot be traced far enough laterally to establish either view. If they were connected with the granitic rocks erosion has removed the evidence.

AGE OF THE MCNETT FORMATION:

In the few references which are to be found in the literature to the geology of the White Mountain region the assumption is made that the old sedimentary rocks which are exposed there are Cambrian in age. Similarly, on all published generalized maps of California geology the White Mountain range is shown with a core of intrusive rocks surrounded by a rim of Cambrian strata. As far as I have been able to determine, this age assignment is based on no definite evidence of any kind. No systematic stratigraphic work leading to published results have ever been carried on within the area. The rocks have been considered Cambrian because Cambrian rocks have been found to the east and south.

This assumption has no satisfactory basis. The age of the beds is uncertain. They appear to be non-fossiliferous. They may be Cambrian but it is by no means impossible that they may be pre-Cambrian. They may even be post-Cambrian. I am inclined to the belief that they are pre-Cambrian but in the absence of more conclusive evidence than is at present available I have preferred to map them simply as early or pre-Paleozoic in age. The known evidence will be discussed in the following pages.

In the Silver Peak Quadrangle which lies just to the east of the White Mountain region a sedimentary series occurs which is very similar in lithology to the McNett formation. These strata may be observed to advantage in the upper part of Paymaster Canyon southeast of Weepah. Spurr, referring to them says, " In the hills north of Clayton Valley in the northeast part of the quadrangle, the Cambrian shows a thickness of several thousand feet of dolomitic limestones and marble, quartzites and green knotted schists beneath the lowest fossiliferous horizon, which is limestone carrying Archaeocyathus."[1] W. H. Turner, who mapped and studied the deposits in detail, however, suggests that they may be Algonkian in age.[2] After quoting Walcott's definition of the base of Cambrian he continues:

> "On this basis the dolomite, quartzite and green knotted schist underlying the Olenellus Zone north of the Clayton Valley may be called Algonkian. This might apply as well to some of the quartzite and quartz-schist immediately west of the village of Silver Peak, and to the basal dolomite generally of Mineral Ridge, as well as to some similar rocks south of Cow Camp. No fossils have been found in these basal dolomites and quartzites. On the geological map these basal beds are placed with the lower Cambrian. They are referred to here more especially to call attention to the fact that the series underlies the fossiliferous Cambrian rather than to insist on the Algonkian age of these rocks, as it is quite possible that they represent the base of the Cambrian."

1.Spurr,J.E.-Ore Deposits of the Silver Peak Quadrangle" U.S.G.S. Prof.Paper 55, 1906,p. 18. 2) Turner, H.W. - Contribution to

PLATE LVI

Description of Plate LVI

A. Hornblende-biotite granite from Blind Spring Hill, showing clustering of phenocrysts.

B. Injection gneiss from south end of Davis Mountain.

Lithologic similarity is indeed an unsubstantial basis to adopt for the correlation of strats but when better evidence is lacking use must be made of what exists. I have visited and observed the Silver Peak occurrence discussed above and was deeply impressed by the extreme similarity which exists between them and the rocks of the McNett formation in the vicinity of Indian Creek. This similarity is not limited to the nature and sequence of the beds but extends also to their non-fossiliferous character and to their apparent position in relation to the known Cambrian.

In the southern part of the White Mountain range Kirk has recognized a thick sedimentary series which he assigns to the pre-Cambrian.[1] This assignment is made on the basis of an important unconformity which occurs at the base of the Campito sandstone, of a lithologic break between the known Cambrian and the underlying formations and of the non-fossiliferous character of the older rocks. " The position of this great series of sandstones and dolomites, here classed as pre-Cambrian, beneath the oldest known fossiliferous Lower Cambrian (the oldest Lower Cambrian known in America) is in itself strongly suggestive of its pre-Cambrian Age."[2]

Kirk has sub-divided his pre-Cambrian rocks into three groups; a series of sandstones and thin-bedded impure dolomites of unknown thickness and slight areal extent, the Reed dolomite of heavy-bedded, massive character and the Deep Spring formation, consisting of sandstones and dolomitic limestones. The Reed dolo-

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the Geology of the SilverPeak Quadrangle. Nevada Bull.Geol. Soc. Amer. Vol. 20, 1909,p 238.
1. Kirk,E. Stratigraphy of the Inyo Range -Section in U.S.G.S. Prof. Paper 110,1918,pp. 23-25. 2).Kirk. Op.cit. ,p. 25.

mite is at least 2000 feet thick and the Deep Spring formation is not less than 1600.

Kirk correlates his Reed dolomite with the above-mentioned dolomites of the Silver Peak Quadrangle, but he is in doubt concerning the schists and quartzites which accompany the latter. Overlying the Reed dolomite in one place, however, is a series of beds 1600 feet thick which a few miles away is practically absent. Kirk suggests that the schists of Spurr and Turner may represent either this 1600 foot series in whole or part, or the underlying Campito sandstone or both.

The relationship of the McNett formation to the Reed formation is not known but it is probable that careful stratigraphic work in the southern part of the quadrangle would disclose it. Overlying the dolomitic limestones of the McNett are black and green knotted schists which grade upward into blue slates. In the area between Indian Creek and White Mountain Peak (south of the area studied) these blue slates appear to be overlain by a highly metamorphosed conglomerate (almost a para gneiss) of great thickness which, in turn, is overlain by a coarse sandstone. I was unable to spare time to continue my reconnaissance to the south of White Mountain Peak, but it seems likely that fairly continuous exposures may be found to the vicinity of the Reed dolomite. In general in the area mapped by Kirk and Knopf successively younger formations are exposed from north to south. If this rule holds true for the northern part of the range, the McNett formation may be found to underlie the Reed dolomite by several thousand feet. Intervening structural conditions may, of course, invalidate

PLATE LVII

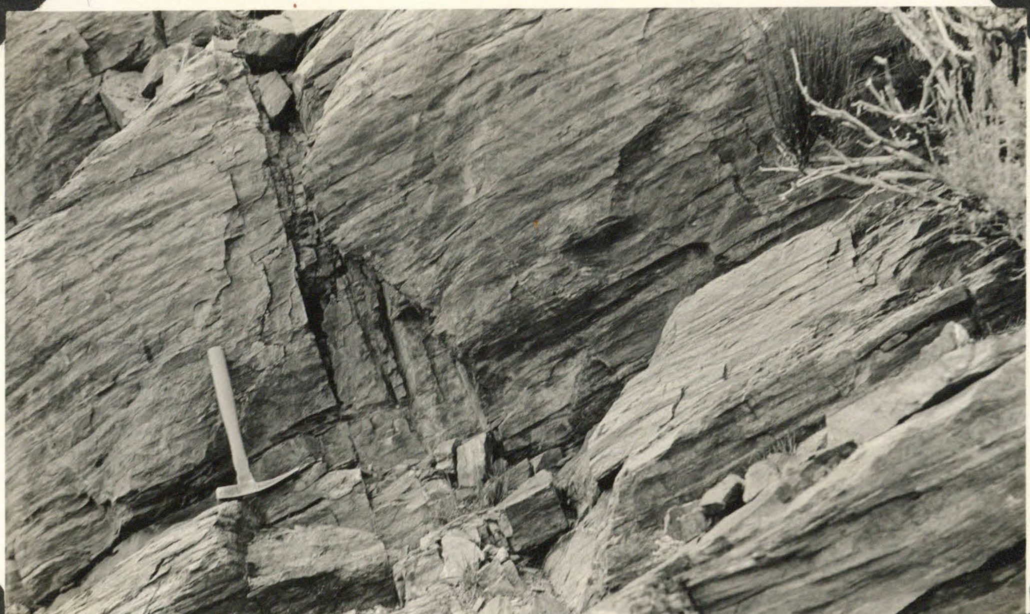
Description of Plate LVII

A. Argillaceous member of McNett formation, north side of lower Queen Canyon.

B. Argillites of the McNett formation injected with thin stringers of material of magmatic origin. South end of Davis Mountain.

PLATE LVII

A



B

this suggestion.

Besides the dolomites, quartzites and green knotted schists of whose age he expresses some doubt, Turner describes in the Silver Peak area a complex consisting of "granite-gneiss, quartz-monzonite-gneiss, granite-augen-schists, calcareous augen-schists and small lenses of hydrous mica-schists," which he definately assigns to the pre-Cambrian. This complex, he states, distinctly underlies the lower cambrian beds and was "probably made gneissic and schistose before the Cambrian was laid down."[1] The members of the complex were, before they were crushed and folded, intruded by thin stringers of white granite which appears not to be intrusive into the overlying Cambrian and is therefore included with the pre-Cambrian complex. The complex is considered by Turner to be equivalent to the Grenville series of the Pre-Cambrian of Canada.

The McNett formation in the White Mountain Quadrangle contains a "complex" exactly similar to the complex which Turner describes and illustrates. The similarity extends not only to megascopic characteristics and field associations but to microscopic determinations and appearances as well. But the "complex" included in the McNett is clearly due to intense contact metamorphic effects produced by the invasion of the Pellisier granite. Interested by the similarity between the occurrences described by Turner and those in the McNett I visited the former and made a field study of them. I was not surprised that the conditions there were no different from those already studied in the White Mountain Quadrangle - that is, the "complex" was really an in-

1. Turner, H.W. -Contribution to the Geology of the Silver Peak Quadrangle, Bull. Geol.Soc. Amer. Vol.20, 1909, pp.226 and 230-238

this suggestion.

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1. Turner, H.W. -Contribution to the Geology of the Silver Peak Quadrangle, Bull. Geol.Soc. Amer. Vol.20, 1909, pp.226 and 230-238

tensely contact metamorphosed portion of the dolomite-quartzite-schist series described above. H. G. Ferguson of the United States Geologic Survey, who was at that time preparing to undertake a remapping of the Silver Peak Quadrangle, concurred in this view. To an inquiry concerning his opinion of Turner's pre-Cambrian complex he replied as follows: "Turner's area of pre-Cambrian west of Silver Peak does not exist. He was confused by the intense metamorphism in that area.[1]

If, on the other hand, Turner's assumption of a pre-Cambrian complex of gneisses and schists in the Silver Peak Quadrangle is invalid, the probability that the McNett formation is equivalent to Turner's dolomites, quartzites and green knotted schists, doubtfully pre-Cambrian, is strengthened rather than lessened, because of the additional evidence of lithologic similarity. That similarity is so close as to leave little question in my mind as to the virtual identity of the two groups. If such an interpretation is correct the position they occupy in the time scale will depend at least in part upon where we draw the base of the Cambrian.

At the time Turner's article on the geology of the Silver Peak Quadrangle was written the lower limit of the Cambrian was considered to be at the bottom of the Olenellus Zone. C.D.Walcott stated: " At present I draw the basal line in the Cambrian in Utah and Nevada at the bottom of the arenaceous shale carrying the Olenellus fauna."[2] Since then, however, the lower limit of the Cambrian has been greatly depressed. The earliest known Cambrian horizon now recognized is that at Barrel Spring,

1. Ferguson,H.G. - Personal Communication, February 26, 1932.
2. Walcott,C.D. - Amer. Journ. of Sci. Vol. 37, 3rd series, 1889, p. 374.

Nevada, which contains the two trilobites Nevadia weeksi and Holmia rowei. This zone appears to lie four thousand to six thousand feet below the Olenellus zone (which is, however, not the lowest horizon at which Olenellus appears).[1]

On the basis of these figures there appears to be room in the Cambrian for the dolomites, quartzites and green knotted schists, estimated by Turner to have a total thickness of about 6500 feet, inasmuch as the "lowest fossiliferous Cambrian" which they underlie is composed of slates, quartzites and limestones containing Olenellus, Archeocyathus and probably Salterella,[2] which would indicate a zone about four thousand feet above the present recognized base of the Cambrian.[3] It is by no means certain, however, that these underlying beds represent this interval. Kirk seems to be in agreement with this view, as is indicated by the fact that he states that[4]

> "the basal dolomite of Spurr and Turner is doubtless to be correlated with the Reed dolomite of the present report."

On the other hand, Turner states that the non-fossiliferous beds underlie those containing Olenellus and Archeocyathus with apparent conformity. It is quite evident, therefore, that the age of Turner's dolomites, quartzites and green knotted schists is still in doubt.

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1. Walcott, C.D. - The Cambrian and Its Problems - in Problems of American Geology, Yale Univ. Press, 1913, pp. 205-206
2. Turner, Op. cit., p. 239.
3. Walcott, C.D. - Op. cit., p. 205.
4. Kirk, U.S.G.S. Prof. Paper, 110, p. 23.

PLATE LVIII

Description of Plate LVIII

A. Calcareous member of the McNett formation, south fork of Indian Canyon.

B. Closer view of the sediments shown in A.

In the Inyo range the case is quite different. The section which Kirk has mapped there as Cambrian is the type section of the lower Cambrian and carries the oldest known Cambrian fauna.[1] It rests on the underlying beds which Kirk has assigned to the pre-Cambrian with marked unconformity. The pre-Cambrian age of the Reed dolomite and of the Deep Spring formation, therefore, seems to be well-established.

I have visited the Cambrian areas described by Walcott and by Kirk in the Inyo range and have not observed there any series of deposits at all similar lithologically to those of the McNett formation.

In summarizing the age of the McNett formation, then, it may be said that lithologically it is strikingly similar to rocks which are either pre-Cambrian or lowermost Cambrian in the Silver Peak quadrangle and totally dissimilar to any series in the Inyo range assigned to the Cambrian by Kirk, that it is non-fossiliferous and that it possibly underlies or is equivalent to Kirk's Reed dolomite. It is regarded, therefore, as being either lowermost Cambrian or pre-Cambrian in age.

1. Kirk, U.S.G.S. Prof. Paper 110, p. 26

TERTIARY ROCKS

Rocks of Tertiary age are prominently represented on the map which accompanies this thesis. Excluding that part which is covered by Quaternary alluvium, they form the surface rock in nearly half the area. They are exposed chiefly in a strip seven or eight miles wide across the northernmost part of the quadrangle.

These Tertiary accumulations are very largely of volcanic origin. They include flows, breccias, tuffs and various other forms of extrusive material. Besides these are to be found several kinds of water-laid deposits, ranging from ancient river gravels to playa accumulations. The last-named are most important because they contain vertebrate remains which furnish the chief evidence for the age of the entire series.

The volcanic materials range in composition from rhyolites to andesites but the more acidic rocks greatly predominate. Basic rocks are rare or absent. The intermediate lavas are well up in the series but wherever definite information can be obtained the more acidic types appear to close the sequence.

The Tertiary rocks lie unconformably upon the older sediments and intrusive rocks. In a number of places ancient stream channels and small valleys are exposed in section filled to the top with volcanic material.

After their deposition the Tertiary beds were folded and tilted and an erosion surface of low relief was worn

PLATE LIX

Description of Plate LIX

A. Playa or lacustrine deposits of the Esmeralda formation, Fish Lake Valley, seven miles north of the Chiatovich Ranch. Vertebrate remains were found in the beds shown in the lower left. The camera points northeast.

B. Close view of the sediments shown in A. Vertebrate remains occur in the lowermost beds.


75b

across the upturned edges of the strata. In a number of places gravels and basalts of Quaternary age may be seen to lie upon this old surface.

Accurate figures for the total thickness of the Tertiary accumulations are not obtainable. The entire series is not exposed at any one place, while lateral variations and irregularities are so great as to make impracticable any attempt to use marker beds for locating oneself in the section. There is little question, however, that the maximum thickness amounts to thousands of feet.

The playa deposits are best exposed in the group of hills just to the north and northeast of the Chiatovich ranch in Fish Lake Valley. In this locality they have a total thickness of about 800 feet. They dip to the southeast at an angle which is somewhat variable but which always lies between eight and eighteen degrees. It is usually nearer the former than the latter figure. There has been a small amount of cross-folding - or, more probably, differential settling - which has produced wide southeastward-pitching synclines and anticlines. Locally the beds have been faulted but the displacements are small. Several vertical fault planes on which have occurred dislocations of ten or fifteen feet downward to the west may be seen in section from the north along the face of the 6061 hill eight and a half miles north of the Chiatovich ranch.

In composition the beds are for the most part soft and easily eroded mudstones, marls, sands and, toward the top, tuffs and conglomerates.

The uppermost bed in the series is a peculiar conglomerate with pebbles about the size of marbles cemented by siliceous material which appears to be volcanic ash. About one third of the pebbles are obsidian, well-rounded but pitted. Of the remainder most are of rhyolite; a few are of pumice. This conglomerate bed is the only one sufficiently characteristic to be recognized over any considerable area.

Beds of yellow and brown tuff are conspicuous toward the top of the series. Some of these weather dark, nearly black, so that at a distance they may easily be mistaken for basalt. Most of playa beds, however, are light colored - white, gray, buff, pint, green or yellow.

The position of the playa deposits in the Tertiary section is not accurately known on account of the difficulties involved in correlating beds of this kind. Their base is nowhere exposed; the relation of the uppermost beds to the Quaternary basalts is likewise uncertain. It seems probable, however, that these deposits are equivalent to most of the much thicker part of the section exposed to the west and northwest.

North and northwest of Sand Spring the materials become coarser and frequently exhibit current bedding. They have the appearance of having been accumulated on detrital slopes where they were partially sorted and distributed by stream action, the finer materials being washed out into the playa, the coarser remaining behind. To the west of Sand Spring fault flows and small intrusive bodies (chiefly sills) increase greatly in number and importance. The flows are often parallel to the bedding of the underlying tuffs but in many cases there is an angular unconformity between the lavas and the underlying bedded materials. This may indicate that folding and tilting were going on during the period of volcanic activity. Frequently, however, it seems logical to suppose that the lava ran down the slope of a hill across the edges of the tuffs and that the lava was brought into more nearly horizontal position by tilting at a later time.

Mention has been made above of river gravels which are of frequent occurrence in the Tertiary section. For the most part these are found well up in the series. One of the most readily accessible exposures lies to the east and north of Queen Canyon where the gravels may be traced from the vicinity of the Queen mine first north and then west for a total distance of about two miles descending in that distance from 9000 feet to about 8800 feet. Along most of the distance they are overlain by volcanic materials, chiefly in the form of flows; where exposed, however, they consist of loose well-rounded pebbles of which few are over six or eight inches in diameter, derived almost exclusively from the batholithic mass to the south but stained deep red by seepage from the overlying volcanics. In thickness they are not over five to ten feet.

A similar occurrence can be followed for a short distance about a mile southwest of Sugarloaf Mountain where the gravels lie in a channel of diorite at an elevation of nearly 8500 feet.

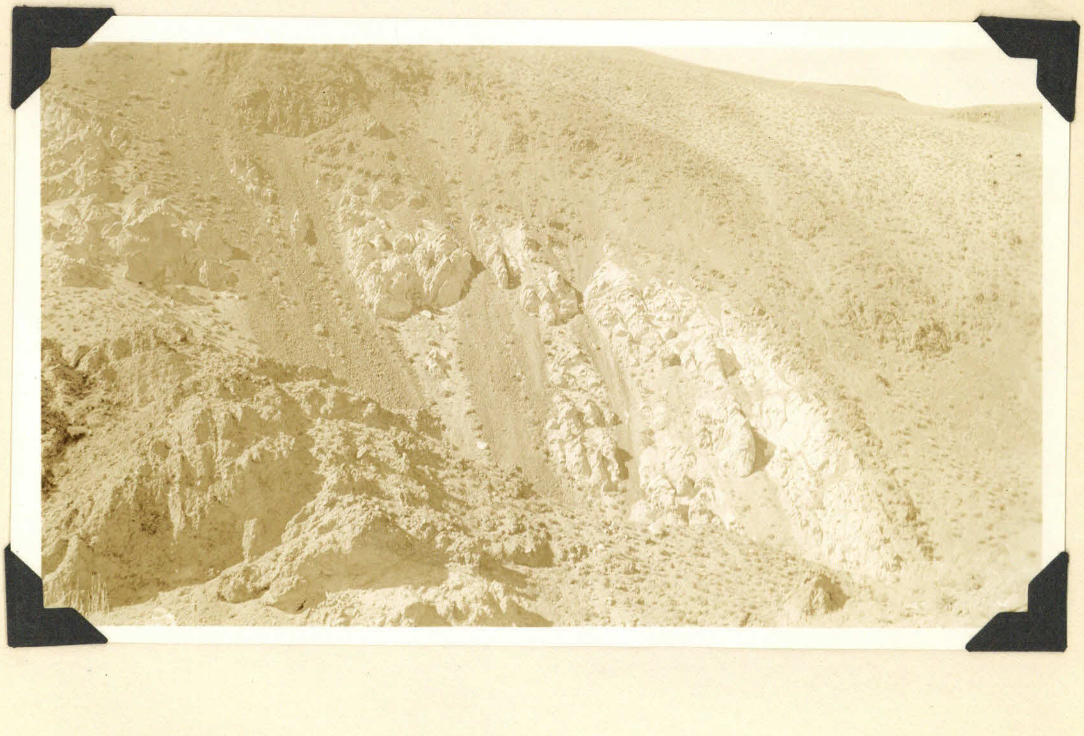
About a mile directly west of Sugarloaf Mountain at

PLATE LX

Description of Plate LX

A. Stratified tuff, Esmeralda formation south of Gold Hit.

B. Tertiary volcanics near Sand Spring.



an elevation of about 7800 feet is a third exposure of conglomerate. This exposure differs from the others in being not less than fifty feet thick and in being well-cemented in a siliceous matrix. The pebbles are of the same material as those found in the other occurrences, they are well-rounded and of rather uniform size. The exposure covers an area about two acres in extent. The base of the conglomerate is not clearly exposed but the overlying beds are pink and white tuffs of the Tertiary volcanic series. The assignment of this conglomerate to a fluviatile origin is not certain. The character and condition of the pebbles are strongly suggestive of lacustrine deposition.

Exposures of finer-grained, cross-bedded materials undoubtedly deposited by Tertiary streams are common in various places in the volcanics north and south of lower Trail Canyon.

Tertiary detritus probably accumulated in an alluvial fan is interestingly exposed in the extreme southeast part of the area about one and a half miles east of the Dyer ranch. It consists almost exclusively of angular fragments of limestone, mostly in elongated slabs with long axes in parallel orientation. The fragments are well cemented by a calcareous cement colored red by seepage from the overlying lavas. The detritus lies at the base of a thick Tertiary section, consisting largely of andesitic flows and tuffs in the Silver Peak Range.

AGE OF THE TERTIARY DEPOSITS.

The Tertiary rocks which have been described above are directly equivalent, at least in part, to the Esmeralda formation of the Silver Peak Quadrangle, described and named by H.W. Turner,[1] with which they are virtually continuous. They are likewise in part equivalent to the Cedar Mountain formation which J.P. Buwalda has traced directly into the Esmeralda.[2]

In the original definition of the Esmeralda formation Turner applied the term only to fresh-water deposits "composed of sandstones, shales and lacustral marls, with local developments of breccia and conglomerate on a large scale."[3] Later, however, Spurr extended it to cover not only the water-laid deposits but the interbedded layers of andesitic and rhyolitic lavas as well, probably, according to his view, ranging in age through the entire Tertiary. In describing the series he says, "They consist of soft shales, sandstones, marls, tuffs,

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1. Turner, H.W. - The Esmeralda Formation, a Fresh Water Lake Deposit, U.S.G.S. 21st Annual Report, Part 2, (1899-1900) pp. 197-208, with accompanying papers on the Fossil Plants of the Esmeralda Formation by F.H.Knowlton, pp. 209-220, and on a New Series of Fossil Fish from the Esmeralda by F.A. Lucas, pp. 223-226. See also Turner, Amer. Geologist, Vol.25,1900,p. 168. Turner Amer. Geologist, Vol. 29, 1902, pp. 268-269; Spurr, J.E. - Ore Deposits of the Silver Peak Quadrangle, U.S.G.S. Prof. Paper 55, 1906, pp. 19-21.
2. Buwalda, J.P. - Tertiary Mammal Beds of Stewart and Ione Valleys in West Central Nevada, U.C. Publ. Bull. Dept. Geol. Sci. Vol. 8,pp. 335-363, 1914; Merriam, J.C. - Tertiary Vertebrate Fauna from the Cedar Mountain Region of Western Nevada, Univ. Calif. Publ. Bull. Dept. Geol. Sci. Vol. 9, 1916, pp. 161-198.
3. Turner, H.W. - The Esmeralda Formation, U.S.G.S. 21st An. Rept. 1899-1900, Part 2, p. 198.

PLATE LXI

Description of Plate LXI

A. Aplite dikes in recrystallized argillaceous member of the McNett formation, south side of Davis Mountain.

B. Tertiary alluvium, consisting mostly of angular fragments of limestone, salient of Silver Peak range east of Dyer ranch, Fish Lake Valley.

volcanic breccas etc., with interbedded layers of andesitic and rhyolitic lava. The thickness of the whole accumulation is very likely several thousand feet. This mass has not yet been satisfactorily differentiated into separate menbers, but it undoubtedly contains materials deposited under widely varying conditions. Some of the beds are lake sediments; some appear to have been deposited in running water and were probably distributed by stream action. Others bear the marks of dry, subaerial origin. Also there is probably a great range in the period of deposition, as will be presently shown from a consideration of the fossil evidence. It is probable that practically the whole Tertiary, from the Eocene through the Pliocene is represented. In short, it is probable that the beds are the record of the whole period of Tertiary sedimentation, beginning with the period when the Nevada land mass ceased to have free drainage to the ocean, at the close of the Cretaceous, through the whole of the climatically changing but in general arid Tertiary period, when the material eroded from the mountains was accumulated in the valleys, in lakes, or in subaerial sheets, down through the Pliocene. Both the early and the more recent Pleistocene accumulations of the region are of very much the same nature as many of these Tertiary beds, and probably form a direct continuation of them; but in the Pleistocene material the proportion of lake beds does not appear to be nearly so large as in the Tertiary formations." [1]

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1. Spurr, J. E. Op. cit. p. 19.

In view of Spurr's use of the term, I feel justified in applying the name "Esmeralda Formation" to the entire volcanic series in the White Mountain Quadrangle below the Quaternary basalts. The total thickness of the Esmeralda in the Silver Peak Quadrangle is given by Turner to be 14,800 feet.

How great a time range was covered by the accumulations of the Tertiary volcanic materials is not definitely determinable. Spurr has indicated for the Silver Peak Quadrangle that the volcanic activity here represented may have occupied a large part of Tertiary time. In certain portions of the area, as in the 7417 foot mountain on the borderline between T1N and T2N in the northeastern corner of the quadrangle, the uppermost pyroclastics are nearly conformable to the overlying Quaternary basalts and are probably of upper Pliocene or early Quaternary age. Elsewhere, however, the angular discordance between the underlying Tertiary strata and the Quaternary basalts is very marked.

One or more of the stages occupied in the accumulation of the Fish Lake Valley deposits is dated with comparative accuracy by vertebrate fossil evidence. Collections made by paleontologists from the University of California have been studied and described in part by R.A. Stirton, who assigns the beds from which the fauna was obtained to be Lower Pliocene.[1] He lists the following mammalian fauna from the Fish Lake Valley deposits:

1. Stirton, R. A. Correlation of the Fish Lake Valley and Cedar Mountain beds in the Esmeralda Formation of Nevada, Science, New Series, Vol. 76, No. 1959, 1932, pp. 60-61

PLATE LXII

Description of Plate LXII

A. Quaternary basalt overlying Tertiary volcanics, Davis Mountain north of lower Indian Canyon. The relations are complicated by faulting. Camera points northwest.

B. Looking northeast from mouth of Davis Canyon, showing Tertiary volcanics overlain by Quaternary basalts. In the middle distance is the flat-topped 7414-foot lava covered mountain which lies in the northeast corner of the Quadrangle. It is about fourteen miles from the camera.

Meterix latidens Hall

Metechinus nevadensis Matthew

Mystipterus vespertilio Hall

Aelurodon haydeni (Leidy)

Hypolagus cf vetus L. Kellogg

Sylvilagus ?

Eucastor tortis Leidy

Mylagaulus sp.

Entoptychus ?

Diprionomys magnus L. Kellogg

Diprionomys parvus L. Kellogg

Diprionomys quartus Hall

Diprionomys tertius Hall

Macrognathomys nanus Hall

Peromyscus dentalis Hall

Hypohippus near nevadensis Merriam

Pliohippud cf. leidtanus Osburn

Hipparion cf. occidentalis Leidy

Prosthennops cf. crassigenis Gidley

Procamelus gracilis Leidy

Procamelus cf. robustus Leidy

Alticamelus cf. priscus Matthew

Stirton considers that the Fish Lake Valley fauna is equivalent to the Upper Snake Creek and Valentine of Nebraska and the Little White River of South Dakota. There are possibly also some relations with the Ricardo but these are not clear. He believes that the Fish Lake Valley and the Cedar Mountain faunas are the same or closely related.

The exact stratigraphic location from which this fauna was obtained was not indicated. In the summer of 1931, however, I collected horse teeth from a position about four hundred feet below the top of the series as exposed one half mile south of the 6061 hill eight and a half miles north of the Chiatovich Ranch. I turned the specimens, which consisted of two lower molars and several fragments, over to F.D. Bode of the California Institute of Technology for determination. Mr. Bode referred them to the genus Merychippus, sp, indet., of Miocene age, The teeth were accompanied by a large amount of skeletal material which, though fragamental, did not appear to be waterworn or reworked. These specimens were obtained from the uppermost part of the fossiliferous zone in that part of the section.

The paleontological evidence for the age of the Esmeralda formation in the type area is not reliable. The fossil leaves, as determined by Knowlton,[1] were mostly of new species and hence not reliable indicators of geologic age. According to Stirton[2], however, Berry in 1927 identified the plants as "most certainly Upper Miocene (reference not cited.) The fish all belonged to one species, Leuciscus turneri and are very similar to living forms."[3] This was thought to indicate that the deposits are Pliocene. The fresh water invertebrates were reported by Merriam to whom they were referred, to contain three Eocene forms and one supposedly Miocene form found in the Truckee beds farther north.[4]

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1. Knowlton, F.H. U.S.G.S.,21st An Report, Part 2, 1889-90,pp.197-208.
Stirton,R.A. Op. cit.
3. Lucas, F. A. U.S.G.S., 21st An. Rept. Part 2, 1899-90,pp. 223-226.
4. Turner, H.W. U.S.G.S., 21st An. Rept. Part 2, 1899-90, pp. 203-204

Merriam, who made a special study of the vertebrate fauna derived from the Cedar Mountain beds, concluded that this fauna is Upper Miocene and close to the Barstow. Stirton, how, ever, has decided from the study of additional material, that the Cedar Mountain deposits contain two faunas, Miocene and Pliocene. The Miocene deposit is said to be a lens of re-washed materials.[1]

Buwalda collected and determined the following fresh-water mollusks of which the first two are abundant both in the Cedar Mountain deposits and in the Esmeralda type locality:

Helisoma cordillerana Hannibal
Vivaparus turneri Hannibal
Form near Melania sculptilis
Form near Corneocyclas meeki Hannibal

The first two species listed above are also very abundant in Tertiary deposits south of Walker Lake near Hawthorne. These beds have similar stratigraphic relations. Louderback believes that these are sufficient grounds for considering that the Hawthorne beds, the Cedar Mountain deposits and the Esmeralda accumulations are of the same or not very different stage.[2]

Ferguson,[3] who has studied the occurrences in both areas, states that the volcanic sequence of the Hawthorne region holds good for the Silver Peak area also, "namely; domin-

1. Stirton, R.A. Op. cit. p. 60.
2. Louderback, G. D. - Period of Scarp Production in the Great Basin- U.C. Publ. Bull. Dept. Geol. Sci. Vol. 15, 1924, p. 10.
3. Ferguson, H.C. Personal communication, Feb. 26, 1932.

Plate LXIII

Description of Plate LXIII

A. Looking from Indian Canyon southeast across Fish Lake Valley toward the Silver Peak Range, twelve miles distant. Quaternary basalts are shown overlying Tertiary volcanics which, in turn, rest upon early Paleozoic sediments. The clump of trees in the left middle distance is at the Dyer Ranch.

B. Tertiary volcanics southwest of Sugarloaf Mountain. The McElroy Mine is above the lava outcrop to the right. The camera points south.

PLATE LXIII

A

B

antly rhyolite conformable with the Esmeralda andesite and andesite breccia, possibly a little rhyolite, distinctly later, possibly Pliocene; and basalt, Pliocene to Recent."

In the vicinity of Tonapah, which lies forty miles to the east of the White Mountain region, is a thick series of volcanics chiefly acidic in character, in the upper part of which occur the Siebert tuffs from a quarry in which a collecting party from the California Institute of Technology has extracted a large and varied fauna. This collection has not as yet been thoroughly studied but from what has been done Stock considers it to be Upper Miocene in age and probably closely related to the Barstow fauna.[1] Nolan of the United States Geological Survey, who has recently completed a re-study of the Tonapah ore deposits, considers that most of the Tertiary series there is equivalent to the Esmeralda of the Silver Peak region but he also finds evidence of the existance of a pre-Esmeralda series of considerable thickness.[2]

Farther to the north are the Truckee beds which are exposed in type section in the Kawsoh Mountains near Hazen, Nevada. These beds are considered, on the basis of the frest water molluscan forms found in them[3] and of a later study by F.K. Knowlton[4] of their fossil plants, to be approximately contemporaneous.[5]

Farther south are other Tertiary deposits which have become well known through the study of the Barstow (Upper Miocene) and Ricardo (Lower Pliocene) faunas.

1. Stock, Chester, - Personal communication, Feb. 1, 1933
2. Nolan, Thos. B. - Personal communication.
3. U.S.Geol. Explor. 40th Parallel, Vol. 1, 1878,p. 442 and Vol. 4, 1877, p. 182.
4. See Merriam, J.C. Univ. Calif. Publ. Bull. Dept. Geol. Sci. Vol.9,p. 167. 1916. (5) Louderbach, G.D. - Period of Scarp Pro-

It is seen, therefore, that the Tertiary accumulations of the White Mountain region are closely related in character and in time of deposition to a number of other deposits extending for many miles in a direction not far from parallel with the eastern front of the Sierra Nevada. Although these deposits were contemporaneous they were probably collected in independent drainage basins and the times of their accumulation tended to overlap. It is probable that some of them, including the Esmeralda formation, required more than one geologic period for their building. Spurr many years ago summarized the matter in the following words:[1]

> "From these observations it appears that a broad belt of Tertiary sediments, generally folded and faulted, runs northwest and southeast in the region lying immediately east of the Sierra Nevada, and reaches at least as far north as northern Nevada and as far south as the Majave Desert. These beds consist of a variety of sediments, but wherever encountered contain much volcanic material in the form of pumice, tuffs and intercalcated lava sheets, showing vigorous rhyolite and andesite eruptions during the period of accumulation. Much of the material was laid down in inclosed lake basins, and some of it at least during periods of aridity like that existing at present, as is indicated by chemically precipitated calcareous limestone, gypseous beds, colemanite (borate of lime) beds, etc."

1. Spurr, Op. cit. p. 21.

HISTORICAL GEOLOGY.

GENERAL DISCUSSION.

It is now possible to set down in orderly form the facts concerning the geological development of the White Mountain region which have been brought out in the foregoing discussion.

In early or pre-Paleozoic times a sea occupied all or nearly all of the area we are studying. Conditions were at first favorable for the deposition of limestones intermixed with considerable amount of muddy material. Frequently the muds predominated, producing beds consisting of shales or calcareous shales.

Conditions gradually changed in such a way as to permit deposition of somewhat purer limestones. After twelve hundred feet or more of calcareous materials had been accumulated there came a rather abrupt change in the sedimentation. Shales took the place of limestones and these continued to be the dominant type of sediment for a period which was probably as long as that consumed in the making of the more calcareous members of the series.

Whether the forming of these earlier strata progressed in relatively deep water or in shallow water surrounded by low lying land areas is not known. The scarcity of arenaceous matter in the deposits is noticeable but this is compatible with either kind of origin. No criteria suggestive of shallow water accumulation such as ripple marks or mud cracks have been observed but their absence does not necessarily imply waters of great depth. Proof of deposition in deep water might be considered as indication of a Cambrian rather than a pre-Cambrian age for the beds inasmuch as Walcott has maintained that all the known pre-Cambrian sediments in North America are non-marine.[1]

The events that transpired in the area during all or the greater part of the Paleozoic and at least half of the Mesozoic have left no recognizable trace in present conditions in the area. Between the doubtful Cambrian and the known Tertiary no strata remain to tell us the story of what may have occurred. That these beds were deposited and later removed by erosion seems probable in view of their occurrence in nearby areas.

Probably during the middle or late Mesozoic a period of intrusive activity began, bringing the White Mountain batholith into position. The invasion was accomplished in part by stoping and assimilation, in part by the crowding aside of the sediments. The effects of the latter process are to be seen in the intensely compressed condition of the strata around the batholitic margins. It seems probable that part of the folding, to which the beds were subjected occurred before the intrusion took place but how long before or to what extent cannot yet be stated.

The invasion of the magma was accompanied and followed by an intensive attack upon the surrounding rocks by magmatic emanations assisted by heat and pressure. This produced a high degree of alteration in the sediments, most complete in general near the contacts, less so farther away.

Either while the magma cooled and consolidated or at a much later time profound changes took place in the batholith

1. Walcott, C.D. - The Cambrian and its Problems - In Problems of American Geology, Yale Press, 1915, pp. 202-204.

itself. Almost without exception wherever these intrusive rocks are now exposed they give evidence of alterations which have not been produced by the action of weathering. The original minerals have been in most cases partially, in a few cases completely attacked and destroyed and new minerals have been formed in their place of materials transported at least some distance by solutions which have thoroughly permeated the rock mass. New textures have been produced, superficially resembling cataclastic textures but distinguished from the latter by careful study.

Whether the alteration just described took place in the course of the cooling and consolidation of the magma (deuteric or paulopost changes) or whether they were brought about at a much later date by a reheating of the already solid rock aided and assisted by a resurgence of vapors and liquids from a deep seated source by a process approaching anatexis is as yet a matter of opinion. I am inclined to favor the latter view.

We have no direct means of accurately dating the batholithic period in the White Mountain region. The best opinion favors the view that the emplacement of the Sierra batholiths occurred in the late Jurassic. The similarity of the White Mountain occurrences to those of the Sierra Nevada suggests that they are products of the same period of igneous activity.

The history of the White Mountain region during the Cretaceous and early Tertiary is also obscure. It is not known how far back in the period the earliest volcanics of the Esmeralda series were extruded. Certainly, however, the later Tertiary was a time of intense volcanic activity, producing the great accumulation of volcanic materials which have been described. Folding and tilting of the Tertiary strata accomanied or closely followed their formation. Some faulting may also have occurred.

A long age of quiet followed the close of the reign of vulcanism during which the hills were smoothed away and the canyons developed into wide gentle valleys with gentle graded slopes. An old age surface of erosion was formed. River and alluvial gravels were accumulated in the valleys and depressions of this oldland.

If the views expressed by Le Conte, Lindgren, Knopf and others are correct, the region at that time may have stood at only moderate elevations above the sea. Local basins existed, however, in which thick accumulations of detrital material were built up to form the playa deposits and lacustrine beds of the present day. The abundance of borax, colemanite, gypsum and similar minerals in these deposits is considered by many to indicate an arid or semi-arid climate for the entire area.

In Quaternary times there was a renewal of vulcanism. From a number of vents basaltic lavas flowed out and spread over much of the oldland surface. The close similarity of the various flows suggests that they were derived from accordant heights in a common reservoir. The volcanic era was closed with indications of a return to more acid lavas. The most recent extrusions in the area are obsidians and rhyolitic tuffs.

Shortly after the basaltic lavas cooled - or possibly in part even before they were extruded - the block-faulting began which gave form to the present major topographic features of the region. The nature of these movements has already been discussed in detail.

As a direct consequence of the latest period of volcanic activity hydrothermal solutions rose to the surface along channelways prepared by the crushing and fragmentation of the rock in the fault zones. These solutions not only produced extensive alteration of the Tertiary and Quaternary volcanic rocks for considerable distances on either side of the marginal faults but they were probably also instrumental in the deposition of ores of commercial importance, especially those of quicksilver along the eastern mountain slope. The Red Rose Mine,(quicksilver) on Sugarloaf Mountain, the Tip-Top Mine (gold, silver and base metals) in the canyon just below, the B and B (quicksilver) the Red Rock (quicksilver) are all situated along this zone of hydrothermal activity.

The geologic history of the White Mountain region can be summarized in the following outline form:

Pleistocene to Recent	Modification of structural forms by erosional processes. Accumulations of detrital material in fans and basins. Hydrothermal activity and ore deposition. Block-faulting, elevating the mountains and depressing the lowland areas. The movements continue into the present. Extrusion of the Quaternary basalts.
Pliocene.	Formation of an erosion surface of low relief across the upturned edges of Quaternary basalts. Folding and possibly some faulting of the volcanic series.
Eocene to Pliocene	Extrusion of Tertiary lavas and accumulation of detritus in intermont basins.
Jurassic	Intrusion of the White Mountain batholith with folding and metamorphism of the intruded rocks.

Paleozoic or post-Paleozoic	Tilting and flexing of the ancient sediments.
Early or pre-Cambrian	Deposition of the limestones and shales of the McNett formation.

This historical outline agrees closely with the sequence of events recorded by Buwalda for the Cedar Mountain region.[1] This is as follows:

1. Pre-Tertiary sediments including marine Jurassic as latest recognized member.
2. Intense folding and intrusion of granodiorite.
3. Profound erosion.
4. Extrusion of older (Tertiary) lavas.
5. Deformation of lavas by flexure.
6. Upper Miocene non-marine sediments.
7. Further deformation, gentle folding.
8. Erosional period, smoothly truncated folds of lacustral series (probably Pliocene)
9. Basic lavas poured out on erosional surface.
10. Late deformation by differential uplift of Cedar mountain and neighboring ranges and of parts of valleys with respect to other parts
11. Partial dissection of the relatively smooth (Pliocene) erosional surface.

This, in turn, is in agreement with the general hist-

1. Buwalda, J.P. - Tertiary Mammal Beds of Stewart and Ione Valleys in West Central Nevada, U.C. Publ. Bull. Dept. Geol. Sci., Vol. 8, 1914, pp. 335-363.

ory of the western part of the Great Basin, the general features of which Louderback has set down as follows:[1]

1. Volcanic products, chiefly andesitic or rhyolitic flows, or both, with more or less clastic material, resting on the pre-Cretaceous bedrock that had been folded, intruded and deeply eroded to a surface which had, in general, reached a moderate or low relief before the Tertiary deposits were laid down.

2. Sediments, made up of terrigenous or pyroclastic material, or both, representing lake, river, ash, alluvial and other non-marine clastic deposits, lying on the lavas, usually unconformably but generally with only slight angular discordance. They also are found on the deeply eroded surface of the pre-Cretaceous bedrock, naturally with profound unconformity. Lavas are sometimes found intercalated in the sedimentary series.

3. Deformation of these sediments, usually into gentle flexures of moderate dip.

4. An erosion surface cut across these sediments, often of very gentle, sometimes of practically no relief.This frequently has the appearance of a surface of river planation.

5. Basic lavas,(where determined, usually basalts) poured out on this erosion surface.

6. Deformation of the erosion and late lava-surfaces (4 and 5), sometimes by gentle warping or flexure, but most strikingly by block faulting. A comparatively small amount of

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1. Louderback, G.D. - Period of Scarp Production in the Great Basin, U.C. Publ. Bull. Dept. Geol. Sci., Vol. 15, 1924, pp. 4-5.

volcanic activity has occurred since the beginning of these deforming movements.

7. Modification of the deformed surface, by dissection in the elevated portions, by deposition of lake, river or alluvial material on most of the depressed portions. Some of the depressed portions are, however, subject to a certain amount of erosion, and some appear to have suffered but little modification since the last deformation.

ECONOMIC GEOLOGY.

GENERAL CHARACTER OF THE ORE DEPOSITS.

The ore deposits of the north half of the White Mountain quadrangle may be grouped into two main divisions. The first of these consists of deposits of an older epoch of mineralization. which may be considered to be genetically related to the batholithic intrusions. The ores belonging to this group are chiefly those of silver, copper, lead and zinc. Some occurrences of tungsten minerals are also reported. In the southern half of the quadrangle there is an important production of non-metallic minerals of economic importance, especially sillimanite and andalusite, which were formed in the same general period, but such deposits have not been found in sufficient size to be commercially important within the area described in this thesis.

It is possibleto subdivide the deposits of this first group into those which are mostly contact-metamorphic in character, those which occur in veins in the intruded rocks (limestones and schists) and those which occur in veins in the intrusive mass. With the exception of only a few unimportant prospects these are all found in the western part of the area.

At the time the field work in preparation for this thesis was in progress, access could not be had to any of the mines in deposits of this class. None were in operation. In all but one or two cases the workings were caved, the buildings removed and any collections of minerals and rocks which may once have existed were scattered or destroyed. A caretaker

Plate LXIV

Description of Plate LXIV

Buildings at the Comanche Mine, Blind Spring Hill.

was stationed at one of the mines (the Comanche) but even here the tunnel leading into the deeper workings was impassible and access could be had only to the uppermost part of the oxidized zone. We are dependent, therefore, for our information upon such meagre and usually inaccurate accounts as are to be found in incidental references in the earlier geological reports or upon local tradition which is always unscientific and often untrustworthy.

The deposits of the second group are associated with the later period of volcanic effusion or, more accurately, with hydrothermal activity which formed the concluding stage of that period. Quicksilver is the chief product of these deposits, but they have also yielded some gold. The minerals occur for the most part in veins and pockets in the upper part of the Tertiary volcanic series, but one of the more important quicksilver mines is in altered limestone and schist. None of the mines of this class is in operation at the present time.

DESCRIPTIONS OF MINES AND DISTRICTS

BLIND SPRINGS DISTRICT:

Several old and formerly important mines are to be found on Blind Spring Hill south and southwest of Benton Station in the extreme western part of the quadrangle. These constitute the old Blind Springs mining district which was organized about 1862 and which has since yielded mineral products valued at several million dollars. The most important mines in the group are the Comanche, the Diana and the Karrick which are at present in the possession of the Comanche Mining and Reduction Company of Los Angeles. Some of the workings are in the Mount Morrison Quadrangle.

The deposits in the Blind Springs district are in veins in the intrusive rock which forms Blind Springs hill. This is a hornblende granite. The ores are said to be sulfides or antimonial sulfides of silver, copper, lead and zinc. The following minerals have been reported: pyrite, chalcopyrite, bornite, tetrahedrite, sphalerite, galena, argentite, pyrargyrite, stephanite, cerargyrite, native silver and cerussite. Native copper has been found as well as small quantities of gold. In the oxidized zone the writer has observed also malachite and azurite. The principal veins are the Anderson, Borasca, Comanche, Cornucopia and Lyford. These form a series of parallel fault fractures which strike N 10°W and dip from 30° to 45° E with the exception of the Comanche, the largest of the series, which dips 82° E.[1]

1. Calif. State Min. Bur., 23rd Rept. of the State Mineralogist, 1927, pp. 391-395.

The following description of the structure is taken from an account by H.A. Whiting, E.M., in the 8th Annual Report of the California State Mineralogist:[1]

"The rock in which the lodes of Blind Springs District occur is a very coarsely crystalline hornblende granitite, in which the orthoclas crystals are often very large, measuring in some sinstances observed, three inches in length in length by one in breadth. This granitic mass has been subjected to at least two series of dynamic movements, with both of which certain intrusions of eruptive rock are associated. . . . By the earlier of these dynamic movements, the fault-fissures were produced which no constitute the principal veins of Blind Spring Hill, both as respects extent and productiveness, and which, in the case of the Kearsarge, and perhaps of the Comanche also, are directly related with intrusive rock masses. To the later movement must be referred a series of eruptive dikes which cut through the Blind Spring granite in a nearly east and west direction, and with a very high dip angle, inclining, however, a little to the north. Wherever such dikes or their coordinated and approximately parallel fractures have been met with in the several mine workings, they fault the older fissures. . . . The ore bodies of these lodes occur in irregular masses, which, however, in their mutual relations of direction, have a dip toward the south in the plane of the vein, and are found now on one wall, again passing to the other. The walls are generally smooth, especially the foot-wall, and often show slickenside surfaces, which latter occurrence, it is reported of the Comanche, was always associated with and so came to be looked upon as an indication of rich ore. To the west of the Comanche are found a series of narrow veins, which in several instances have been moderate producers. These smaller form an acute angle of a few degrees with the strike of the Comanche series. They dip westward at such low angles that they are called locally "blanket veins", and, from the conditions of the case, have only been worked to a depth of eighty to one nundred and twenty-five feet."

The same writer reports the existance of a number of faults trending nearly east and west which displace the mineralized fractures but are themselves not ore-bearing to

1. Eighth An. Rept. State Mineralogist, Calif. State Min. Bur, 1888, pp. 380-381.

any important extent. Some of these dip northward at a low angle.[1]

> "From what was seen of the Humboldt croppings and of their relations with respect to those of the Comanche, it appeared as though the former vein together with cöordinated members of the same series, were in some way dynamically related with the east-west faulting dikes above referred to."

The ore bodies in the Diana-Karrick vein system occur as irregular lenses of antimonial copper-lead-silver ore carrying from 20 to 150 ounces in silver per ton with from twenty cents to two dollars per ton in gold.[2]

According to figures supplies by F.F. Milner, for a number of years Wells-Fargo agent at Benton, and published in the 8th Annual Report of the State Mineralogist, the total value of the bullion shipped from the Blind Springs district from 1862 to 1888, was $3, 945, 000. Of this amount the Comanche Mine contributed one million, the Diana-Karrick $900,000 and the Cornucopia $300,000. The caretaker at the Comanche Mine informed me that the total production from the Comanche-Diana-Karrick group to the time operations were suspended was about $20,000,000!

WHITE PEAK DISTRICT:

The White Peak or Montgomery District, comprising a number of mines in and about Montgomery Canyon on the west slope of the White Mountain Range, is of historical interest only, all of the mines having been closed down or abandoned for many years. The following description is by H.A. Whiting:[3]

1. 8th An. Rept. Calif. State Mineralogist, 1888, pp. 381-382.
2. 23rd An. Rept. Calif. State Mineralogist, 1927, p. 394.
3. 8th An. Rept. Calif. State Mineralogist, 1888, p. 378.

"The mines in the Montgomery district occur for the most part in limestone, though a few are said to lie in granite. Of the latter, the Silver Glance was instanced and described as a very small vein, rich in the mineral which gives name to the mine. The two lodes upon which most work is reported to have been done and which yielded the greater portion of the output from this district are the Phoenix and the Mountain Queen (now Creekside). These veins are described as occurring with limestone for a hanging wall, and for a footwall, another calcareous member of the metamorphosed sedimentary strata lying against the White Mountain granite. The veins strike northwesterly at comparatively low angles, conforming in both respects, it is said, with the stratification of the enclosing rocks. Their width varies considerably, but it is stated to be about three feet as an average. The ore bodies occur in bunches which make into the limestone hanging, never into the footwall; and the ores are argentiferous mixtures of lead, copper, iron and zinc sulphurets, with rarely more than traces of gold. The lowest working upon any of these veins is reported to be about one hundred and thirty feet below croppings."

According to the estimates of J.E. Milner, referred to above, the White Peak district shipped $60 000 worth of bullion between 1862 and 1888.

INDIAN QUEEN MINE:

The Indian Queen Mine figures prominently in the tradition and romance of the White Mountain region. According to the story of old time residents, well-substantiated (if not enlarged upon) by frequent repetition, the mine was a rich producer of silver, having yielded a total of not less than ten million dollars worth of the precious metal. More reliable information is hard to obtain.

The mine was located in Queen Canyon in the Oneota Mining district of Nevada. It has been abandoned for many years. The tunnels and shafts have caved in and the workings are completely inaccessible. No samples of the ore could be obtained.

According to Lincoln[1] the mine was located in 1870. A four-stamp mill was erected in 1873 and a notable production of high grade ore was made for a number of years. There was a revival of mining interest in 1905 and the Indian Queen resumed production in 1907. This latter production, however, was small. In 1908 all of the mines in the district shipped one hundred and nine tons of ore which yielded $973.00 in gold, $3, 319.00 in silver and 27,000 pounds of lead - a total value of $5,523.00. Small yields were reported in 1907, 1911, 1913 and 1914. In 1917 the total production of the district was $4,137.00 in gold, silver, lead and copper.[2]

In 1888 the Indian Queen mill was reported to have "8 stamps, 4 pans, 2 settlers and one White and Howell revolving furnace."[3] The ore shipped by Wella-Fargo express from Benton from 1862 to 1888 was said to have a value of $500,000.00[4] This, however, may have been only a part of the ore produced. According to Lincoln[5] the Indian Queen vein lay between granite and slate and its ore was very base. From surface indications, the mine appears to have been in the contact metamorphic zone. Rhyolite overlies the older rocks near some of the workings but the Tertiary rocks appear to be younger than the ore.

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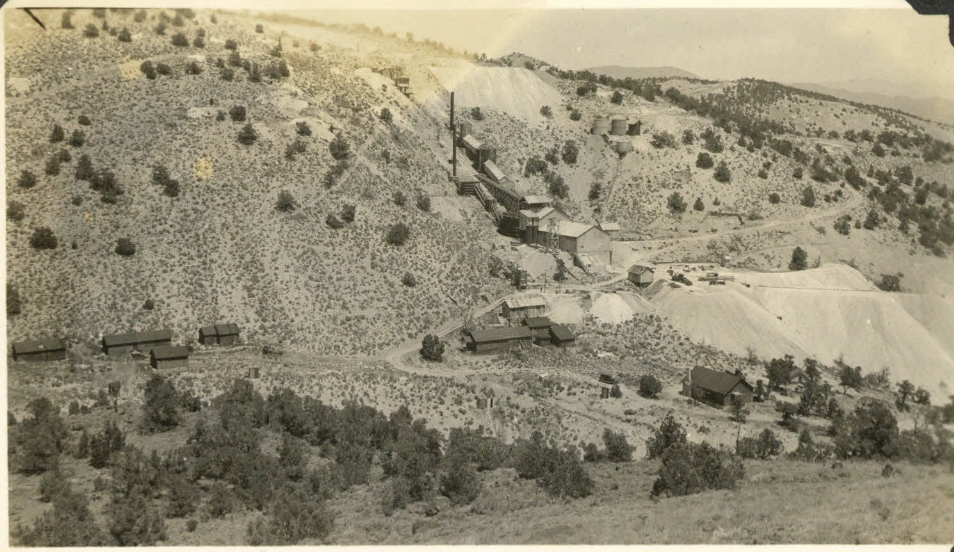
1. Lincoln,F.C. - Mining Districts and Mineral Resources of Nevada, Reno, 1923, p. 140.
2. U.S.G.S. Min. Res. of the U.S., 1905,p. 268; 1906,p. 295; 1907, I. p. 349, 1908,I. p. 479; 1909, I. p. 402; 1911, I. p. 686; 1912,I. p. 792; 1913, I.p. 832; 1914,I. p. 695; 1915, I. p. 631; 1916, I. p. 476; 1917, I. p. 284; 1918,I,p. 248; 1919, I. p. 400; 1920, I. p. 328.
3. Calif. State Bur. Mines, Rept. State Mineralogist, Vol. 8, 1888, p. 377.
4. Ibid, p. 377.
5. Op. cit. p. 140.

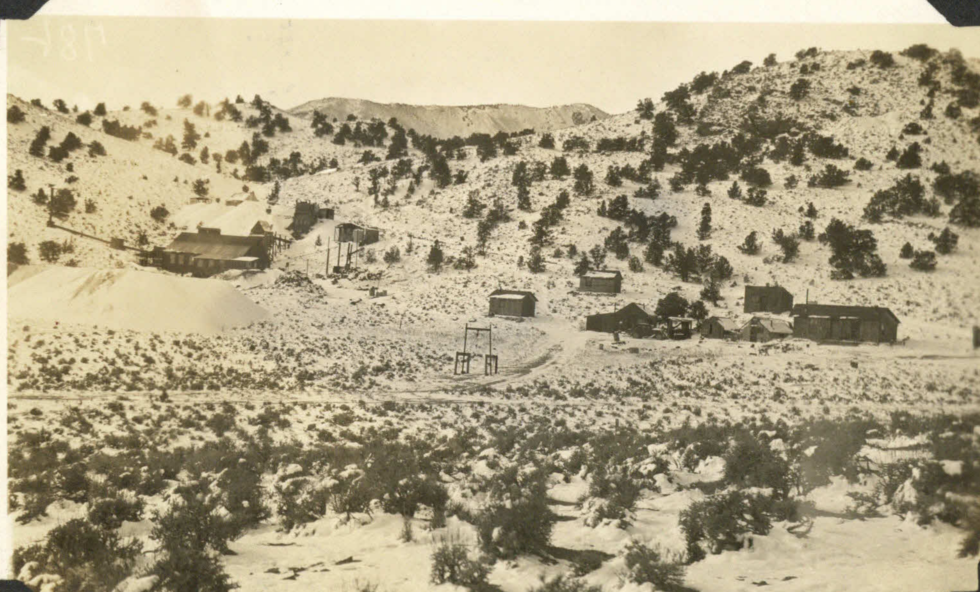
PLATE LXV

Description of Plate LXV

A. General view of the B and B Quicksilver Mine.

B. Buildings of the Red Rock Quicksilver Mine. The tunnel is above the furnace house in the upper left.





SCHEELITE DEPOSIT:

Hess and Larsen report a contact metamorphic deposit of scheelite about three miles northeast of Queen.[1] The principal rocks are said to be thin beds of quartzite, slaty rocks and hornfels with some interbedded marble, intruded by a considerable body of dark biotite-pyroxene-quartz-dionite and small dikes of granite porphyry. the whole series being covered here and there by remnants of later volcanic rocks that fill in great irregularities in the older series. The scheelite is in the sediments near the contact with the diorite. The natural exposures are poor but there are layers of tactite[2] in places several feet across, made up mostly of garnet with epidote, calcite, vesuvianite, quartz, fluorite, chlorite, molybenite, pyrite and scheelite.

I was unable to locate the deposit by the description given. Plutonic rocks intrusive into ancient sediments occur near Nichols, three miles northeast of Queen, but the sediments are chiefly limestones and the intrusive much more nearly corresponds to quartz monzonite in composition and in megascopic appearance than to diorite; the volcanic rocks, moreover, are certainly not remnants. Across the valley, however, somewhat north of east of Queen and west and northwest of Sugarloaf Mountain there is a body of quartz diorite intrusive into ancient sediments which may be the locality described. Metamorphic zones of the kind mentioned are common throughout the area and do not serve to identify any particular locality.

1. Hess and Larson, U.S.G.S. Bull. 725 D. p. 277.
2. For tactite see Hess, Amer. Journ. Sci. 4th Ser. Vol. 48 pp. 377-378. 1919.

GOLDEN GATE PROSPECT:

The Golden Gate is a gold prospect located about a half mile northeast of Nichols. The workings are in a contact metamorphic zone between quartz monzonite and ancient sediments overlain by Tertiary volcanics. The ore is said to lie in quartz veins. A number of shafts and tunnels have been dug but the claim was not being worked when last visited in 1931.

McELROY PROSPECT:

D.F. McElroy is working a prospect about one mile south-southwest of Sugarloaf Mountain. An east-west tunnel several hundred feet long has been excavated with the expectation that it will cut a large ore body. The prospect appears to lie on an important fault line. The tunnel crosses a thick clay gouge a hundred feet or more from its portal which forms "swelling ground" in the miners' terminology, making the mining operations both difficult and dangerous. The ore, which consists chiefly of galena carrying silver, is in veins in the Tertiary rhyolites and andesites. Fluorite accompanies the ore. Some gold is found at higher levels. A two stamp mill has been erected.

RED ROSE QUICKSILVER MINE:

The Red Rose Mine is located at an elevation of 9100 feet on Sugarloaf Mountain, five miles south-southeast of Mt. Montgomery Station. The only mineral of value is cinnabar. This occurs in veins and fractures in a rhyolite flow two hundred and fifty feet thick, overlying andesite. The rhyolite has been much altered by hydrothermal solutions which have bleached the rhyolite to a white material highly silicified and porcelain-like for the most part but in places soft and pulverulent. The best ore appears to have occurred in this soft material which Ransome, who visited the mine in 1917, suggests is alunite. A considerable amount of hemitite, (turgite?) is present, which, on account of its red color, is frequently mistaken for cinnabar. Ransome thinks that certain phases of the occurrence strongly suggest downward enrichment or superficial redeposition.[1]

Eight tons of selected ore retorted seventeen flasks in 1917, according to Ransome. Two retorts were installed a the mouth of the tunnel in 1917.

The mine was formerly owned by the Mount Montgomery Mercury Company, F.C. Beedle of Belleville, Nevada, President. Later it came into possession of Captain Whitney of Mina, Nevada, who, however, died of a heart attack at the mine late in 1931. Since then the mine has not been in operation.

TIP-TOP MINE:

The Tip-Top Mine was a gold and silver producer, located about three eighths of a mile a little east of south of the Red Rose. The workings were in a canyon about four hundred feet below the Red Rose tunnel. A hundred ton cyanide plant was installed in 1915. Although little yield was reported in Mineral Resources of the United States between 1908 and 1920,

1. Ransome, Mss. notes.

Lincoln[1] states that it produced $130, 000.00 up to 1918. The ore is said to have been in veins in andesite and rhyolite. When I first visited the mine in 1929 the tunnels had completely caved, the buildings were destroyed and even the dumps had been washed away by a "cloudburst".

B AND B QUICKSILVER MINE:

The B and B Quicksilver Mine is located almost exactly on the Mt. Diablo Base Line about three and a half miles due east of Mustang Mountain. It lies in a zone of hydrothermal alteration in Tertiary rhyolitic tuffs. These have been greatly silicified by the solutions which deposited cinnabar. The latter occurs in fractures in the silicified tuff, accompanied by considerable amounts of hematite or turgite.

The mine is equipped with two rotary oil furnaces which replaced the more primitive D-retorts, permitting the handling of large quantities of ore. The open cut method of mining was employed exclusively, gasoline driven scoop shovels being employed to excavate the ore, which is of low grade.

I am indebted to Mr. C. H. Vaughan, caretaker at the mine, for the following historical sketch:

The mine was located in 1926 by George Crysler of Tonopah. It was leased to the Tonopah Mining and Development Company, in 1927 under $70,000.00 bond but they failed to meet the requirements of the contract and gave up the mine. In 1928 Buell and Birney of Tonopah took a lease and option on the property. They were joined by B. F. Good, of Long Beach. Later in the same year Buell organized the B and B Quicksilver Company

1. Op. cit. p. 140.

of Bakersfield, which took over active operation at the mine. A road was constructed from Mount Montgomery Station at a huge expense. An oil furnace was installed in 1928 and a second in 1929. Thirteen hundred flasks of quicksilver were produced in the first six months of 1929 at a clear profit of $31,000.00. Between June 1 and June 22, 1931, the production was fifty-four flasks. The company had become involved in financial difficulties, however, owing partly to the decline in the price of quicksilver, and closed down the mine June 22, 1931. It is now in receivership.

RED ROCK MINE:

The Red Rock is the only one of the quicksilver mines which obtains its ore from the older rocks. It is located in the principal marginal fault zone of the eastern mountain front (Davis Fault Zone) just south of the mouth of Dry Canyon at an elevation of about 7500 feet.

Just to the west of the mine is a prominent northwest-southeast ridge of limestone fault breccia which has been cemented and even the limestone fragments completely replaced by silicia so that at first glance the rock might be mistaken for a brecciated quartzite. The local miners, however, have noticed points of similarity to the unaltered limestones a short distance west and have applied the term "blue lime" to the formation.

In general the faulting has brought the shales and schists members of the McNett formation down against the underlying limestones but the relationships have been greatly complicated by cross faults with a northeast trend, some of which have noticeably offset the limestone breccia.

Near the limestone breccia the calcareous shales have been largely converted to talc.

The ore is found principally along the contact between the talcose rocks and the breccia in veins, seams and packets for several feet on either side of the contact surface. Cinnabar is the only mineral of economic importance. Some stibnite is found with the ore.

Mining is principally by tunnels, drifts and stopes. There is a D-retort, a rotary oil furnace and several buildings for the workmen at the mine.

Discovery of the ore was made by George Dunnigan, a prospector about 1914. The best information available indicates that the mine has yielded $200,000.00 or more worth of quicksilver since its discovery.

PETROGRAPHY OF THE NORTH HALF OF THE WHITE MOUNTAIN QUADRANGLE CALIFORNIA-NEVADA

by

George H. Anderson

A thesis presented to the Division of Geology and Paleontology of the California Institute of Technology in partial fulfillment of the requirements for the degree Doctor of Philosophy.

Pasadena, California

1933

TABLE OF CONTENTS.

ABSTRACT.

The igneous rocks of the north half of the White Mountain Quadrangle consist of a group of closely related intrusives, probably of Jurassic Age, and a Tertiary-Quaternary series of extrusives. The former, chiefly granitic in composition, compose the White Mountain batholith which intrudes calcareous and argillaceous rocks of early Cambrian or pre-Cambrian Age. The batholith is surrounded by a wide zone of intense contact metamorphism.

The volcanic series may be subdivided into two groups. The earlier, whose accumulation probably occupied much of the middle and late Tertiary, is predominately siliceous in composition. The later, for the most part Quaternary in age, consists of basic andesites and basalts.

In the following thesis all of these groups of rocks, including the contact metamorphics, are described in detail. Especial attention is paid to certain compositional and textural peculiarities exhibited by the intrusives. These peculiarities are highly significant, not only in the history of these particular rocks, but also in respect to the general problem of the genesis of sodic and alkaline types. They are the result of replacement processes which appear to have been active on an enormous scale throughout the batholithic mass at a time considerably later than at least the outer parts of the magma. They involved the introduction of large quantities of material, especially sodium and silica and possibly also iron and magnesium from some source outside the field of reaction. The results are evident in the wholesale albitization of the potash feldspars, formation of secondary minerals including quartz, sericite, chlorite, epidote, biotite and hornblende and in the development of a texture here designated pseudo-cataclastic texture, which closely resembles true cataclastic texture but is distinguishable from the latter by criteria set forth below.

The results of a careful search of the literature for material bearing upon replacement processes in igneous rocks are set forth in the thesis. Various theories which may account for the phenomena are critically discussed.

THE PLUTONIC ROCKS.

INTRODUCTION:

The study of the plutonic rocks of the area described in this thesis has proved to be one of the most interesting phases of the investigation. Microscopic examination of thin sections prepared from these rocks has revealed peculiarites in texture, in alteration and in petrologic history which would be quite unsuspected from an inspection of the hand specimen or the occurrence in the field. Some of these peculiar features have not, within the author's knowledge, been described elsewhere.

The investigation of these phenomena is still far from complete. In an areal study of this kind so much time must be devoted to the general problem in all of its multitudinous details, in the field and in the laboratory and in the library that little is available for the pursuit of any one phase beyond the frontiers of existing knowledge. The writer frankly admits, therefore, that in the following pages problems are presented for which no solutions are offered. He hopes to undertake eventually to secure the quantitative data necessary for the correct understanding of some of them.

NATURE AND DISTRIBUTION OF THE PLUTONIC ROCKS:

The plutonic rocks of the area, with possibly one exception, are all conceived as being part of or intimately connected with one large intrusive body which may properly be named the White Mountain batholith. Within the northern half of the quadrangle this mass forms the core of the principal mountain range. Together with several outlying bodies which are undoubtedly connected with the main intrusive at depth, the batholith is exposed over approximately one hundred square miles of the area covered by the geologic map.

There is some evidence that the batholith was not intruded as one body but as a sequence of several intrusions, as Cloos has postulated for the Sierra batholith.

GENERAL COMPOSITION:

Estimation of the average original composition of the White Mountain batholith is not an easy matter. Changes which have been brought about during its later history have obscured the determination of its original character by microscopic methods. These changes have in part been in the direction of enrichment in the sodic or soda-calcic feldspars so that an accurate knowledge of the modifications thus brought about may be of considerable importance in the classification of the primary rock. One basis for such knowledge would be a series of chemical analyses which, unfortunately, are not yet available.

Among the difficulties which have been encountered in accurately classifying the specimens examined under the microscope are the following:

1. In a great many instances alteration has taken place in such a way that determination of minerals by ordinary methods have been made doubtful or impossible. Plagioclase feldspars, for example, have frequently been so completely sericitized that twinning lamellae may be only vaguely discerned and extinction angles as vaguely measured. The same condition obscures index comparisons by the Becke method, while interference figures are rendered so hazy as to be valueless. Microcline and orthoclase again, are almost always perthitic; the amount of the interlaminated albite is difficult to measure and its origin hard to determine. Very often the microcline has an appearance described by Professor L. C. Graton as a 'sick look', which leaves its exact character in doubt.

2. Determination of the relative proportions of minerals either accurately by the Rosiwal method or approximately by inspection in almost every case encounters formidable obstacles. These are due either to the very fine grain size of the minerals in the interstitial recrystallization zones (to be described below), to the highly irregular sutured grain boundaries or to the presence of symplectic intergrowths, such as myrmekite, which are found in great numbers throughout these rocks.

3. Albite, especially that which appears to have been formed deuterically by replacement of orthoclase or microcline, is often untwinned and hence difficult to re-

cognize; its chemical composition, of course, is determinable only by analysis.

4. In a number of slides a mineral has been observed which closely resembles orthoclase in all its optical properties but sign, which is positive. The composition of this mineral is as yet unknown, so that it must be omitted from all calculations of rock composition.

The decision as to the original character of the rock will depend in all cases upon what views are adopted as to the changes which have taken place. If we refer these changes to processes which occurred during or immediately following the final consolidation of the magma, (" deuteric phenomena" in the sense of Sederholm) we may arrive at conclusions quite different from those we will reach if we consider the changes to be due to external causes operating long afterward.

The writer believes that the original composition of the White Mountain batholith was that of granite bordering on quartz monzonite. This judgment is based upon an examination of about seventy-five slides prepared from samples obtained from various parts of the batholith. Differentiated phases occur which range in composition from granite to hornblende diorite or even to pyroxenite. Since its consolidation the mass has been greatly enriched in soda, especially by the albitization of the potash feldspars. It is possible to consider these rocks as being members of the " spilitic suite " for Dewey and Flett and other British authorities have extended the meaning of the term to include certain soda-granites (see page of this thesis). It must be remembered, however, that spilites are derived from magmas of high sodic content. In the case here considered the soda may have come from a foreign source.

Following are typical mineral analyses of specimens selected at random from various parts of the main batholith. Only essential and auxiliary minerals are included. Figures refer to percentages of primary minerals.

SLIDE No. 173:

Minerals present:

Quartz (partly of secondary origin) 8 to 10%
Potash feldspar - 12 to 15% (considerably albitized)
Plagioclase feldspar (probably albite of about Ab_{90} An_{10} but accurate determination impossible) 65 to 70%
Biotite 7%
Hornblende 3%

SLIDE No. 166:

Quartz (partly secondary) 10%
Potash feldspar (albitized) 50%
Plagioclase (not certainly determinable but albite from index and sign) 30%
Biotite 10%
Hornblende 1%

SLIDE No. 179:

Quartz 8 to 10%
Potash feldspar (partly albitized) 50%
Oligoclase ($Ab_{87}An_{13}$) 40%
Biotite 3 to 5%

SLIDE No.229:

Quartz 12%
Potash feldspar 50%
Oligoclase ($Ab_{85}An_{15}$) 35%
Biotite 5%

The following is a mineral analysis from a more basic phase (quartz diorite):

SLIDE No. 384:

Quartz 5%
Orthoclase 5%
Andesine ($Ab_{55}An_{45}$) 60%
Biotite 10%
Hornblende 15%

The following represents a more acid (aplitic) phase:

SLIDE NO. 364:

Quartz 25%
Potash feldspar 60%
Albite 15%
Muscovite 1%

THE PELLISIER GRANITE:

The Pellisier granite, which is the principal intrusive rock in the southern half of the area covered by the geologic map, is for the most part rather coarse grained and medium to dark grey (See Plate LXIV, Fig.1.) Gradational phases, however, may be finer grained or distinctly lighter in color. In some places, especially in the region south of lower Indian Creek (east) are several isolated bodies of granite, probably to be regarded as cupolas of the main batholith, which closely resemble the almost white Boundary Peak granite. On account of their proximity to exposures of typical Pellisier granite, these have been included with the latter in mapping but they may actually be more closely related to the Boundary Peak mass.

The relatively dark color which is for the most part characteristic of the Boundary Peak granite is due not only to its ferro-magnesian mineral content but also to a peculiar tint possessed by its feldspars and, to a less degree, by its quartz. The cause of this peculiarity is not fully known. In some cases it appears to be due to the presence of numerous microlites or of gaseous or liquid inclusions (See page)[1]

1. Gilluly has noted a similar bluish tint in the quartz of an albite granite of probable replacement origin near Sparta, Oregon. He considers this tint to be due to the presence of needle-like inclusions resembling rutile. See Gilluly, James-Replacement Origin of the Albite Granite Near Sparta, Oregon. U.S.G.S. Prof. Paper 175 C, 1933, p. 69.

It is exhibited not only in the main intrusive mass but also in some of the aplites associated with it, especially those in the summit areas of the range. It is, indeed, regarded as possible that all of the aplites genetically connected with the Pellisier granite may be of this type and that the extremely light colored ones, whether they occur in the Pellisier granite itself, or in the metamorphosed sediments, may have been derived from the Boundary Peak intrusive. There seems at present to be no way to decide this question.

The texture of the Pellisier granite is almost exclusively of the kind described below as "pseudo-cataclastic texture". This is considered to be a replacement texture, produced by hot aqueous solutions or vapors which circulated through the rocks after their consolidation. This process has resulted in partial or complete albitization of the potash feldspars, in sericitization to various degrees of the plagioclases and in the production of a fine grained secondary matrix which is interstitial to the primary mineral grains of the original rock. All stages in the development of this matrix can be observed, from that of the earliest introduction of the solutions in the veinlets which insinuated themselves along the grain boundaries, to those of the almost complete replacement of the original rock. (See accompanying illustrations, especially Plate LXVII, all figures, Plate LXX, Fig. IV. and Plates LXXI and LXXII.)

Even in the comparatively few slides in which the secondary matrix is not prominent a considerable degree of

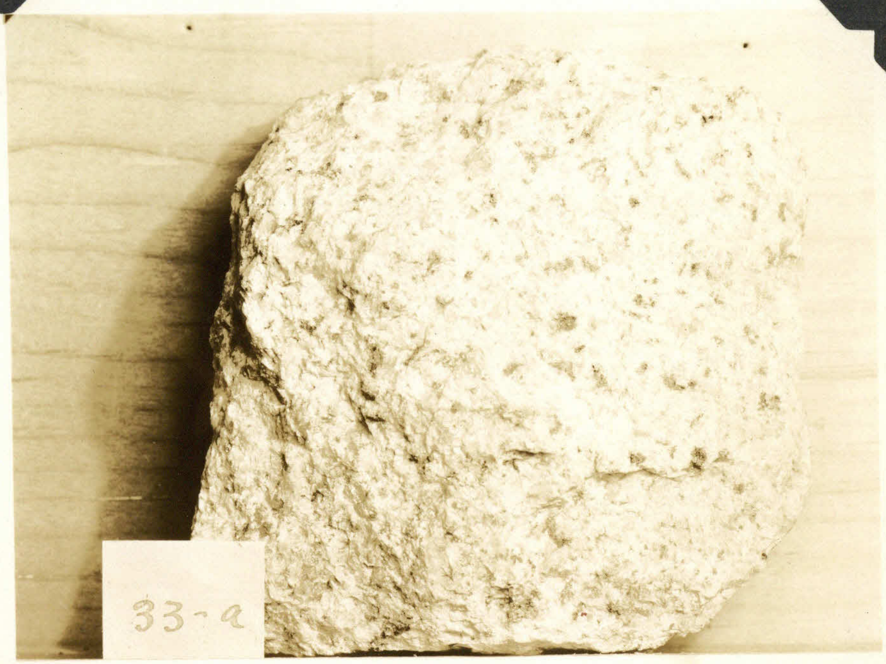

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PLATE LXIV.

FIGURE 1
Typical specimen of Pellisier Granite. Natural size.

FIGURE II
Typical specimen of Boundary Peak Granite. Natural size.

alteration has usually taken place, obscuring the original character of the rock.

No modifications in these alterations and textures have been observed to take place with approach either to contact zones or to known faults. Although in some cases more intense effects were noted in samples taken near contacts or faults, in other specimens from similar locations the changes exhibited are comparatively slight. Conversely, the most advanced stages are observed in some localities on or near the crest of the White Mountain range.

The principal primary minerals of the Pellisier granite include quartz, orthoclase or microcline or both, plagioclase feldspar (always albite or oligoclase), biotite and often hornblende. Primary muscovite is rare. Apatite, zircon and titanite are frequently present in small quantities. Opaque minerals, usually pyrite, magnetite or hematite, are to observed in virtually every section. Occasionally one sees rutile. Pyroxene is seldom seen but swarms of biotite or chlorite are often seen pseudomorphic after pyroxene.

The potash feldspars, as has been emphasized, have all been converted partly or completely to albite by various types of replacement. The microcline usually shows its characteristic twinning, although if the degree of replacement is an advanced one the twinning may be vague or confined to a small part of the grain. In some cases the birefringence is so unusally low that a grain appears almost isotropic between crossed nicols. Under high magnifications this peculiarity is usually seen to be due to the presence in the microcline of numerous microlites or of very small inclusions of gas or liquid which, being truly isotropic, confer a similar appearance upon the host. Ex-solution albite lamellae of various types are nearly always to be observed in the potash feldspar grains, in every case apparently antedating the replacement albite.

The primary plagioclase is usually albite although quite frequently it is oligoclase. The extinction angle where determinable in the zone perpendicular to 010 varies from -16 degrees to 0 degrees and the optic sign correspondingly from plus to minus. The primary plagioclase is usually sericitized or epidotized to an advanced degree, but occasionally it is quite fresh looking. Frequently in the latter case the unaltered grains poikilitically enclose feldspar grains of a somewhat higher index and occasionally of a different sign. In such cases the enclosing grains may be secondary. Primary plagioclase is often poikilitically enclosed in potash feldspar.

Albite exhibiting typical chess-board structure frequently is to be observed in the sections. Occasionally this may form the only feldspar in the rock. Such albite is considered to have been derived by replacement of the potash feldspars.

The earlier biotite is a green variety and strongly pleochroic with X= pale yellow and Y= Z= brown, almost opaque. In this it differs decidedly from the secondary biotite of the replacement veins, in which X= pale greenish yellow and Y= Z= deep green. Both varities are often partly altered to chlorite, which is present in large amounts in the veins.

Small prisms or needles of apatite are frequently present in great numbers in the biotite. A similar association of biotite with rutile is not rare. Titanite and zircon sometimes occur in or near the biotite.

The hornblende is deep green, Y= Z= dark green. It is often twinned. The optic angle is very large and the sign usually minus but sometimes plus. Extinction angle Z on C averages about eighteen degrees. IT is sometimes intergrown with biotite in such a way as to suggest alteration to the latter; a similar association with chlorite is common.

Among the primary minerals the normal Rosenbusch order of crystallization usually holds good. Cases in which albite is later than potash feldspars or quartz are interpreted as being due to deuteric or post-consolidation processes. In such occurrences, which are not rare, the albite is commonly untwinned and is distinguishable from the orthoclase only by its optic sign and index. Primary quartz is frequently poikilitically inclosed in microcline or deuteric albite and sometimes in the primary plagioclases.

The relative proportions of the minerals are variable. Quartz usually forms 15 to 25% of the rock but locally it may decrease to almost zero and in a few slides it is not present. Potash feldspar appears to have made up 35 to 60% or more of the original rock, while the primary plagioclases vary from 25 to 50% of the total mineral content. If the plagioclase is albite, as is usually the case, it sometimes equals or exceeds the potash feldspar in amount; but if it is oligoclase, as is much less common, it is rarely more than half as abundant as microcline or orthoclase.

The primary biotite content averages about 5 to 7% but it may sometimes be present in twice that amount. The total biotite content, primary and secondary, may in some instances be as high as 25% or even more.

Hornblende is rarely found in quantities greater than 3 or 4%. It is entirely absent from many sections.

From these figures it seems probable that the original rock was for the most part a hornblende-biotite-granite. Absence of hornblende gives local phases the composition of a biotite granite. With decrease of quartz it assumes in small areas the character of a quartz syenite or even a true syenite.

Mention has been made of the presence in many thin sections of the Pellisier granite of an unknown mineral having the general appearance of orthoclase to which it is closely similar in birefringence and in index but from which it differs in optic sign. In many occurrences this mineral is in contact with quartz, microcline or albite. It is seen in each case to be lower in index than either quartz or albite, and about equal to microcline. Well centered optic axis figures were obtained in several cases in which the sign was definitely determinable as positive. Although definite measurements have not yet been made, the optic angle is estimated from the curvature of the isogyre to be about

60 to 70°. This value is sufficiently far from 90° to preclude the possibility of any mistake in determining the sign, on the one hand, or the probability of abnormality induced by strains, on the other. It seems possible that the mineral may be similar to the "isorthoclase" of Duparc.[1] More careful measurements to determine its exact nature are in progress.

Textural as well as compositional variations occur. The intrusive body which makes up Blind Spring Hill is considered to be a phase of the Pellisier granite with which it is probably connected at depth. This is a porphyritic type with large phenocrysts of gray orthoclase set in a medium gray groundmass consisting of the customary quartz, potash feldspar, plagioclase, biotite and hornblende. The phenocrysts are usually an inch across and sometimes as much as two inches. A peculiar feature is that the phenocrysts frequently form clusters or swarms, each consisting of from twenty to a hundred or more rather closely packed crystals. Often the areas between these swarms, hundreds of square feet in size, are almost devoid of the phenocrysts.

Other porphyritic varieties occur south of Post Meadow, just east of the 12,870 peak on Pellisier Flats, and at various other places in the area. In some cases the phenocrysts are pink, while the feldspars of the groundmass are almost transparent and hardly to be distinguished from quartz.

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1. Duparc, L. - Comptes Rendus, Vol. 138, 1904, p. 714, cited by Winchell, Optical mineralogy, 1927 Ed. p. 322.

Inclusions are very common in the Pellisier granite, being found in all parts of the mass and in various stages of assimilation or of recrystallization. These inclusions are almost exclusively of shales or schists. Although the sediments into which the mass was intruded are in large part dolomitic limestones and calcareous shales, inclusions of these rocks are almost entirely missing. There seems no reason for doubting that such inclusions must have been virtually as numerous as those of the more argillaceous rocks but if they were they must have been assimilated into the magma, or the magma must have reacted with them to produce hybrid rocks whose derivation is no longer evident. It is possible, of course, that the blocks sank to considerable depths without reaction.

With pre-existing igneous rocks, most if not all of which are probably early phases of the same intrusive mass, the Pellisier granite has formed contact breccias, as it has also done in many cases with the members of the sedimentary series.


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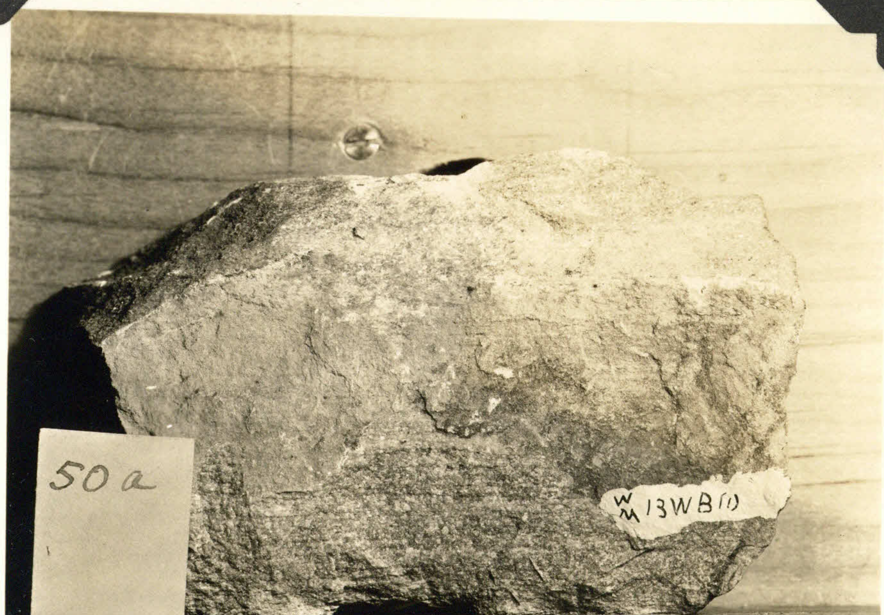
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PLATE LXV.

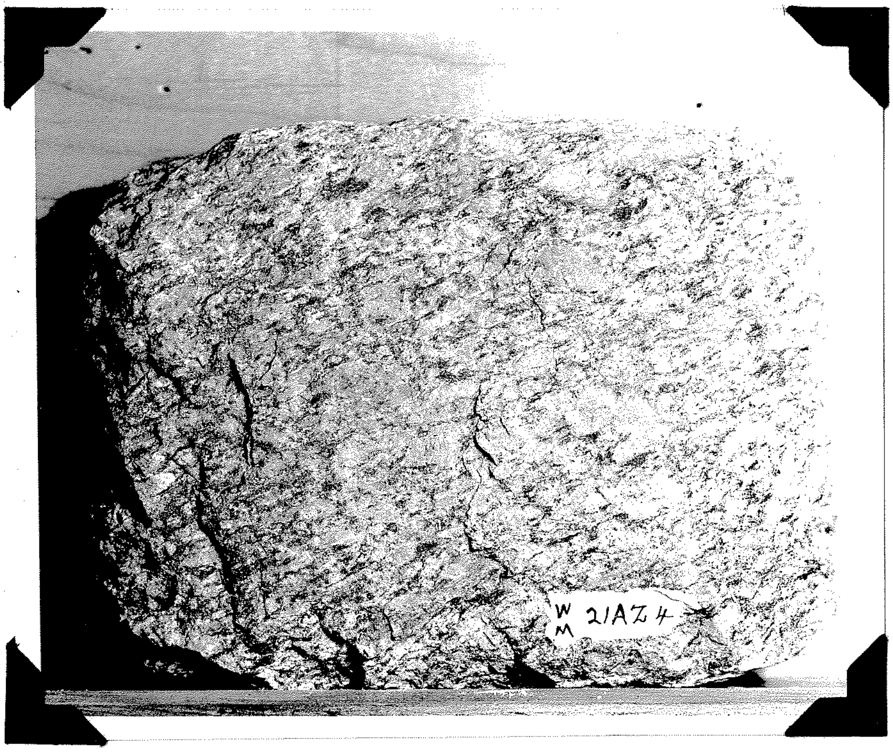


FIGURE I
Porphyritic gneissic variety of Pellisier granite from Montgomery scarp above Queen Dicks. Natural size.

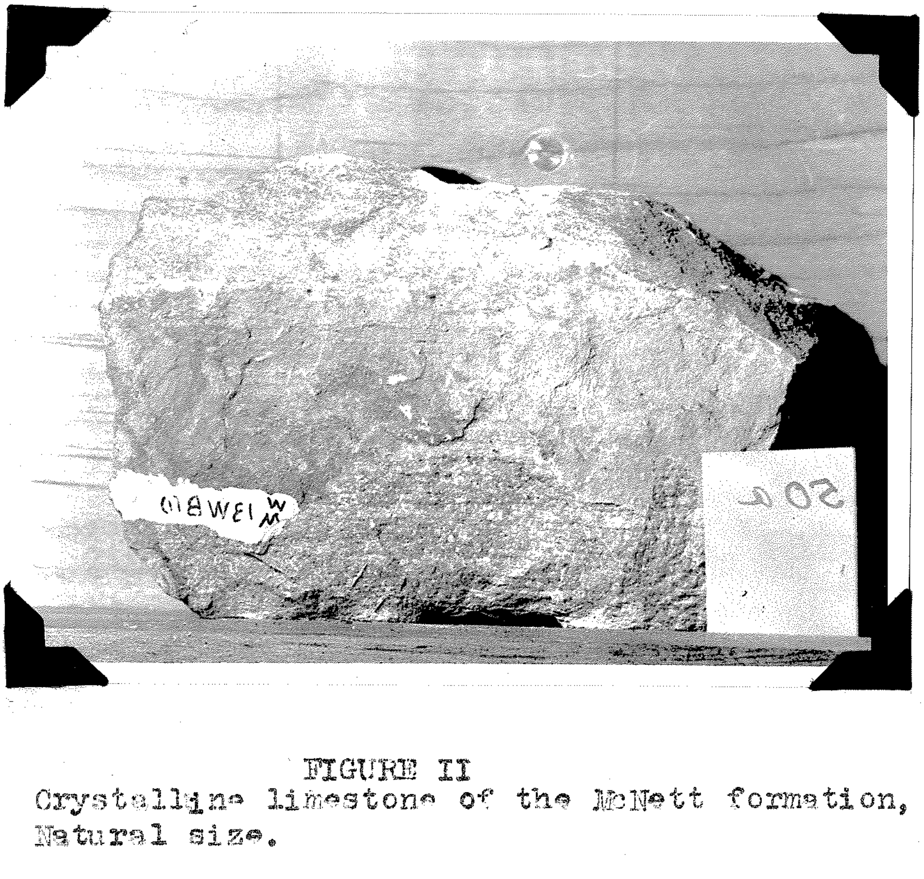


FIGURE II
Crystalline limestone of the McNett formation, Natural size.

THE BOUNDARY PEAK GRANITE:

The relations of the Boundary Peak granite, from which the prominent peaks at the northern end of the White Mountain range have been carved, with the Pellisier granite are not entirely clear. In certain localities as, for example, just southwest of Montgomery Peak, intrusive contacts have been found where it is clearly evident that the mass to the south is the older. Rarely, however, could such a definite contact be discovered. The change from the one rock to the other appears to be graditional in some cases; in others the actual contact may be concealed by talus. It is probable that the one body is to be considered a phase of the other and that when the later one was brought into position the Pellisier granite had become only partly solidified. Where consolidation had taken place definite contact relations were formed but where the older mass was still molten the two phases mingled and the change from one to the other is a gradual transition.

The difference in composition between the two rocks is not great. Both are granite but the Boundary Peak phase has less biotite and very little or no hornblende. The Boundary Peak granite exhibits pseudo-cataclastic texture as prominently as the Pellisier. Both have been affected by the same types of replacements. There is, however, a pronounced difference in color between the two granites. The Boundary Peak granite is very light in color, almost white. This difference is due in part to its lower content of ferromagnesian minerals and in part to the lighter color of the quartz and the feldspars. The peculiar greyish tint which has been indicated as being characteristic of these minerals in the Pellisier phase is not present in the other. The Boundary Peak is in general somewhat finer grained and, at least in the vicinity of Montgomery Peak, it contains many less inclusions and basic segregations. A final and very noticeable point of dissimilarity is in the character of the jointing which, in the Boundary Peak, is very much more prominent in one direction than in the others and so closely spaced as to almost form a sheeted structure. The Pellisier granite, on the other hand, has three directions of jointing almost equally well developed.

The texural and compositional variations of the Boundary Peak granite parallel those of the Pellisier. It is often impossible to determine whether a given specimen is to be considered as a variation of the one or of the other. In some cases such a rock may be graditional between the two.

In the contact zones with the sediments the Boundary Peak granite forms an even more varied assortment of hybrid rocks than does the Pellisier. These are strikingly exhibited west and northwest of the Queen Mine. With its differentiated marginal facies the Boundary Peak granite forms contact breccias. A prominent one of these involves the granite and the hornblende diorite on the ridge north of Upper Trail Canyon.

DIKE ROCKS:

Aplite dikes are exceedingly abundant in and along the margins of the White Mountain batholith. Pegmatites are rather rare. The middle parts of the aplites, however, are often pegmatitic. As has been indicated above it is usually difficult to distinguish between the aplites derived from the one or the other of the two granites. Sometimes, however, the distinction can be made on the basis of the peculiar grayish tint of the quartz and feldspar.

Both the aplites and the pegmatites show the effects of replacement in the same manner as the parent rocks. The original minerals of the aplites are almost entirely quartz and feldspar. The latter are microcline or orthoclase, more or less completely albitized, and plagioclase which may be albite or, in some cases, oligoclase. In the secondary interstitial matrix sericite and chlorite frequently occur. Even biotite may make its appearance in the matrix. In consequence the rock ceases to be a true aplite and becomes a fine-grained granite or granite porphyry.[1] Undoubtedly in such cases it was originally an aplite.

Almost all the aplites contain myrmekites. Some of them show a very marked development of granophyric texture, for which Gillson,[2] Fenner,[3] and others have argued, at least in part, a replacement origin.

1. Biotite may, however, be present in small quantity in aplite. See De Lapparent, Jacques-Lecons de Petrographie, Paris, 1923, p. 156. Aplite, according to this author, consists of orthoclase, albite, quartz and small quantities of ferro-magnesian minerals characteristic of granite.
2. Gillson, J.L. Journ. Geol. Vol. 35, 1927, p.
3. Fenner, C.N. Journ. Geol. Vol. 34, 1926, pp. 750-754

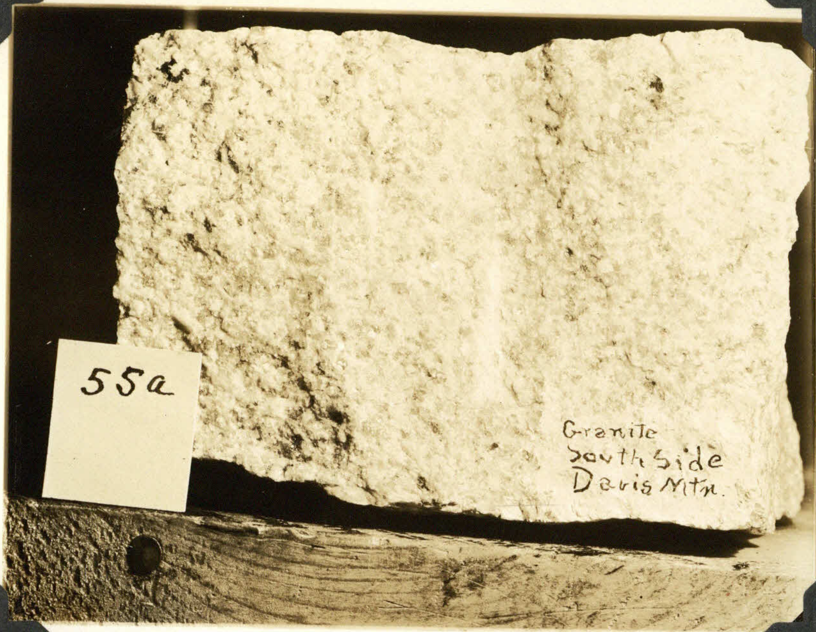
All stages in the development of the pseudo-cataclastic texture are exhibited by the aplite dikes.

Pegmatites are especially abundant just west and south of lower Queen Canyon, but they occur elsewhere in the area as well. They commonly show the characteristic graphic intergrowths between quartz and feldspar. Their minerals are almost exclusively quartz and microcline or orthoclase with some muscovite. The potash feldspar is usually in an advanced stage of albitization. Tourmaline and other pneumatolytic minerals are rare, in spite of the fact that mineralized veins containing fluorite are rather common in the general region in which most of the pegmatites occur. Incipient to advanced stages in the development of the pseudo-cataclastic texture are characteristic of these dikes. This would seem to indicate for the development of this texture a time considerably after the consolidation of the batholith.

Relatively unchanged relicts of the original intrusive rock are preserved in scattered locations throughout the batholith. These relicts indicate for the primary rock the hypidiomorphic texture commonly found in granite.

HORNBLENDE-BIOTITE-QUARTZ-DIORITE.

The principal areas of diorite occur along the outer margins of the White Mountain batholith. One of these forms the nose of the prominent ridge west and southwest of the trail between Queen and Trail Canyons. The second and larger one is to be found about two miles west of Sugarloaf Mountain.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Granite
South Side
Davis Mtn.

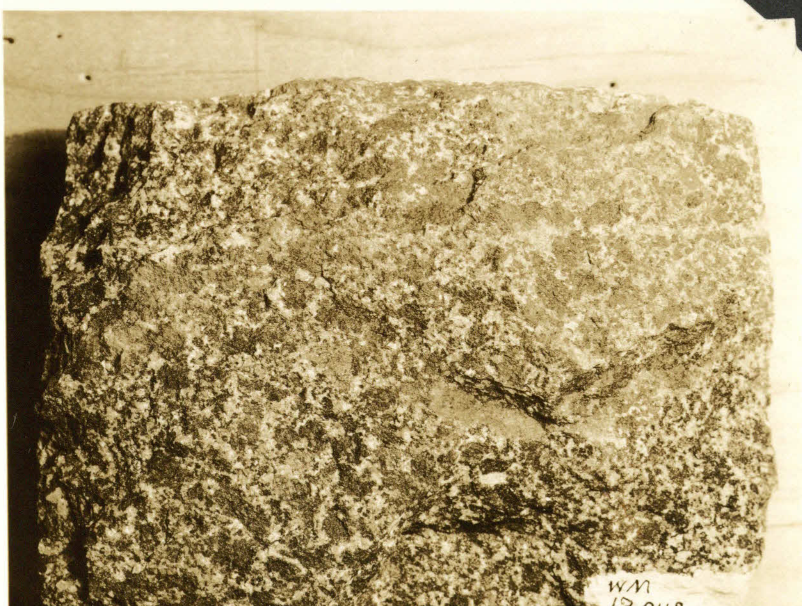
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PLATE LXVI.

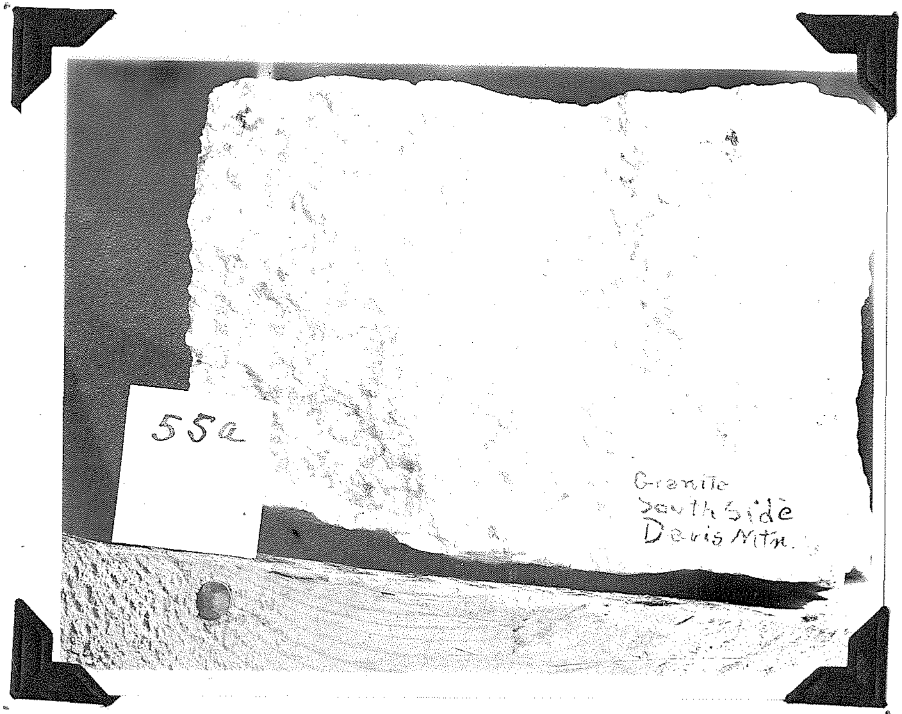

FIGURE I
Granite, south side Davis Mountain. Natural size.

FIGURE II
Hornblende-diorite from point about two miles southeast of Mustang Mountain. Natural size.

Many smaller occurrences of rocks corresponding in composition to diorites or quartz diorites are to be found in the contact zone.

The diorite of the locality first mentioned is a medium-grained, rather dark greenish-grey rock with a mottled appearance. Upon close examination the mottled effect is seen to be caused by the fact that the dark minerals fill the interspaces between the plagioclase grains and are rarely found inclosed in them.

The primary minerals of the rock are andesine, hornblende, biotite and quartz. Much of the biotite is secondary, as are also epidote, chlorite and calcite. The maximum extinction angle of the andesine in the zone perpendicular to 010 is 22°. It is optically positive and its index is approximately equal to that of quartz. Zoning is conspicuous in some of the grains. The hornblende is a green pleochroic variety with an extinction angle of Z on C of about 20°. The optic angle is very large and the sign varies from plus to minus.

The primary biotite is a brown pleochroic variety with X= deep brown, Z= pale brown, Y= nearly colorless.

The feldspar appears to have been the earliest mineral to crystallize in most cases, followed by hornblende, biotite and quartz in the order named.

Andesine composes about 25% of the present rock, hornblende 35%, quartz 7%, biotite 15%, epidote 15% and chlorite 5%.

The diorite of the second locality is finer grained and darker in color than that first described. Along its southern boundary it is in contact relation with a porphyritic granite which is doubtless connected at depth with the Boundary Peak or the Pellisier. The diorite is the earlier rock.

The rock exhibits several peculiar features. One of these is that it contains two varieties of plagioclase feldspar in about equal amounts. The older of these is oligoclase with a maximum extinction angle in the zone perpendicular to 010 of 6° and index slightly lower than that of quartz. Its composition, therefore, is about $Ab_{75}An_{25}$. Several of these grains are zoned. Many of them are badly sericitized, several contain considerable secondary calcite. The other plagioclase is an almost pure albite with a maximum extinction angle in the zone perpendicular to 010 of 18° to 20° and index considerably below that of quartz. The albite shows very distinct twinning lamellae and does not resemble most of the replacement albite of the granites to the south which is mostly either untwinned or has the characteristic chess-board structure. It may be deuteric, although the grains do not have the typical shape of those of deuteric origin.[1]

A second peculiarity is the presence of the

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1. See Gillson, J.L. - Journal Geology, Vol.35,1927,pp 26-30

initial stages of the pseudo-cataclastic texture common in the granites described above. Under moderate magnifications tiny veins are seen winding in and out between the primary grains. In most of these sericite is the only mineral which can be certainly identified but where plagioclase borders orthoclase small clusters of myrmekite are developed. Otherwise these rocks possess texture usually found in diorites.

An especially interesting and unusual feature is the presence in very small grains in or bordering these veins of a bright red semi-transparent weakly pleochoric mineral which may be proustite or pyrargyrite.

The rock contains small amounts of orthoclase and quartz but no twinned microcline. Green hornblende and biotite occur. Two or three aggregates of chlorite plainly psedumorphic after pyroxene are to be observed.

The hornblende and biotite are present in about equal amounts and together make up about 30% of the rock. Oligoclase forms about 30% and albite about 20%. Ten to fifteen % of orthoclase and 5% of quartz complete its composition, except for apatite which occurs in very numerous small needles, usually associated with the biotite.

PLATE LXVII

Description of figures.

Fig. I - Albite replacing orthoclase. The orthoclase occupies most of the central part of the photomicrograph. In the lower right is a grain of quartz. Note that solutions appear to have penetrated along all the boundaries of the orthoclase, corroding it and forming a "vein" containing fine-grained quartz, albite, chlorite, and microcline. Along the boundary with the quartz, the solutions have penetrated within the orthoclase grain, forming a typical replacement structure. The orthoclase is streaked and sp spotted throughout. Crossed nicols, X 60.

Fig. II - This field includes a part of that shown in Fig. I, but the section has been moved to include the region to the left of the first. The orientation is also somewhat different. In the albite replacing the orthoclase to the right the "chess-board" structure can be dimly discerned. The microcline grain to the left (note the faint microsline twinning) and its included albite are in process of being corroded and replaced by a fine-grained vein-like,aggregate of quartz, feldspar and chlorite. Crossed nicols, X 40.

Fig. III - Microcline grain undergoing attack and replacement from all sides by myrmekite and albite. Note especially the frayed borders, the minute myrmekitic intergrowths entirely surrounding the grain, and the chess-board albite at the bottom. The "sick look" of the microcline is apparent. Crossed nicols,X 60.

Fig. IV - This is the same field shown in Fig. I but in different orientation. Note chess-boamd structure of the replacing albite, and the spotted and streaked condition of the orthoclase. Crossed nicols, x60.

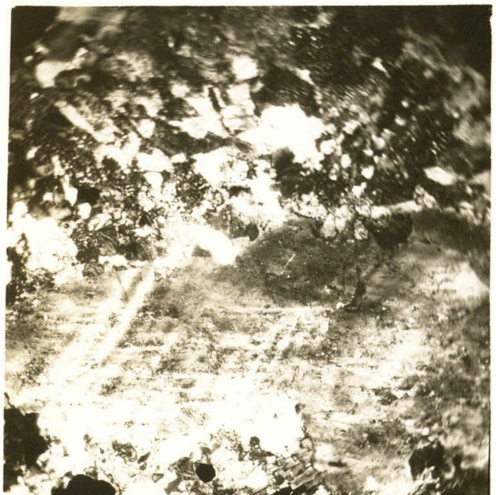

PLATE LXVII.

Figure I.

Figure II.

Figure III.

Figure IV.

POST CONSOLIDATION MODIFICATIONS.

In the foregoing paragraphs I have attempted to give an idea of the general character of the intrusive rocks. I shall now describe in more detail certain characteristics which are not usually found in rocks of this type and which therefore demand special explanation. These peculiarities appear to be due to changes, not the result of weathering, which have taken place during the later history of the mass rather than to primary processes. They involve the entire exposed part of the batholith. They affect both composition and texture. In the discussions that follow it will not be possible to separate the compositional and textural alterations except for convenience in making an introductory summary, because the latter are intimately related to and dependent upon the former.

The changes in composition are of two kinds:- changes in chemical composition and changes in mineral composition. The latter may or may not involve the former. Even in a "closed system" it is well known from the work of Becke, Grubenmann, Niggli, Goldschmidt, Eskola and others, that a mineral assemblage will exist which represents equilibrium under the prevailing conditions of temperature and pressure. If the physical conditions change, even though no new material be introduced from without the rock mass, old minerals will decompose and new ones, more stable under the changed conditions, will form in their place. The transformation may be very sluggish, but in the course of geologic time equilibrium will be re-attained. The net result may be a change in mineral composition with no accompanying chemical change in the composition of the mass. This is the process known as "doliomorphism" and the resulting rocks are said to be "doliomorphic."[1]

To what degree the changes in the White Mountain rocks represent mineral transformations with accompanying chemical changes is not yet clear. The answer requires the interpretation of chemical analyses yet to be made. It does, however, appear certain that some of the mineralogical changes which have been noted could have been brought about only through the introduction of considerable amounts of foreign material.

The mineralogical changes which have taken place comprise, first, the substitution of albite for the potash feldspars and possibly also to some extent for the calcic plagioclases. These changes unquestionably have resulted from the addition of large amounts of soda from some source outside the immediate field of observation. A second series of changes have resulted in the production on a very large scale of an interstitial matrix containing sericite, epidote, chlorite, quartz and often biotite. These

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1. Tyrrell, G. W. - Principles of Petrology, New York, 1926, p. 78; La Croix, A. - La Notion de type doliomorphe en lithologie. C.R., tom, 177, 1923, pp. 661-665.

PLATE LXVIII

Description of Figures.

Fig. I - Pseudo-cataclastic texture in granite, advanced stage. The primary grains of the figure were originally potash feldspars which have been converted by partial albitization to "patch", and "vein" perthites of replacement origin. The large grain to the left still possesses a faint trace of microcline "grating structure". The fine-grained interstitial matrix or "veins" consists almost exclusively of quartz with a little chlorite. Crossed nicols, X10.

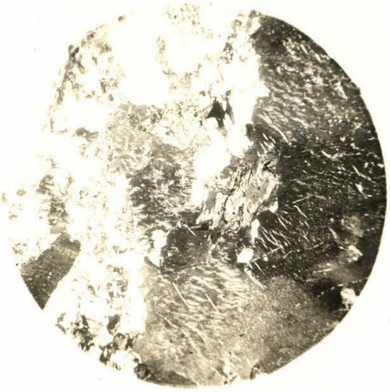
Fig. II- "Patch and vein" perthite, showing replacement of potash feldspar by albite. Crossed nicols. X10.

Fig. III - Perthite of "rod" and "film" types, possibly of replacement origin. The "vein" in the upper right contains quartz, epidote, and chlorite and under higher magnifications, it is also seen to be fringed along its entire length with myrmekite. Crossed nicols, x 10.

Fig. IV - "Chessboard" albite, derived by the complete albitization of microcline. To the right is a grain of quartz. Virtually the entire section is made up of quartz, primary albite of normal variety, biotite, and chessboard albite. Crossed nicols. X 10.

Fig. V - "Rod" and "film" perthite with an interstitial vein containing quartz, epidote, chlorite, and myrmekite, attacking and corroding the perthite.

Fig. VI- "Rod" and "film" perthite (left) in a secondary matrix (right) containing quartz, epidote, biotite, and an abundance of myrmekite. The constituents of the "veins" are not clearly distinguishable at this magnification. Just to the left of the center of the field is a rather large grain of chlorite. Crossed nicols. X 10.



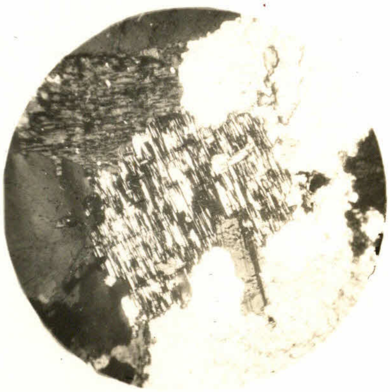
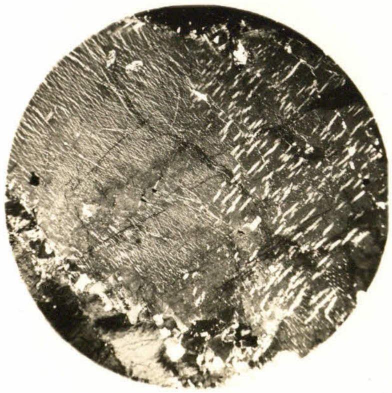
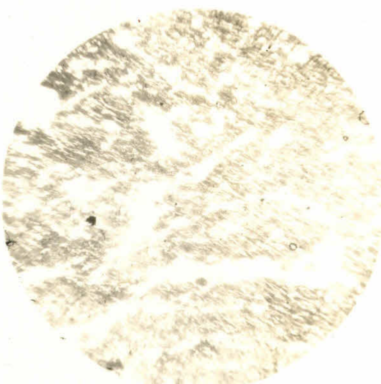
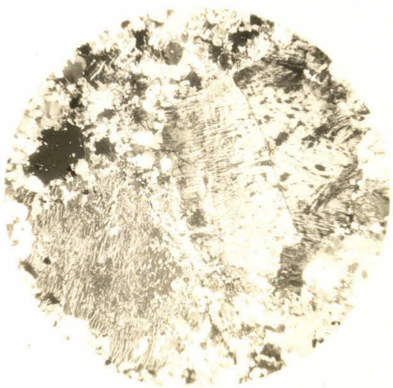





PLATE LXVIII.

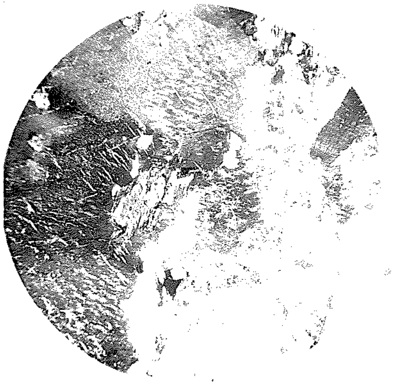


Fig. I.

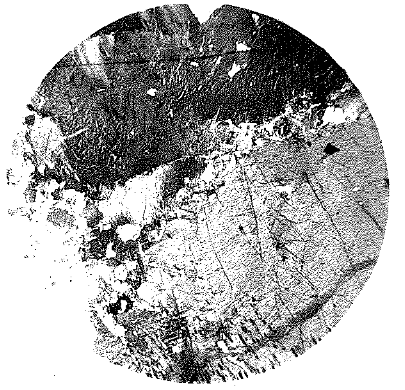


Fig. II.

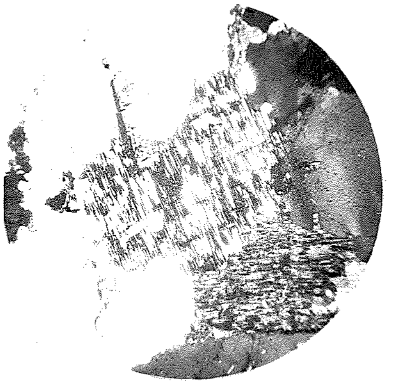


Fig. III.

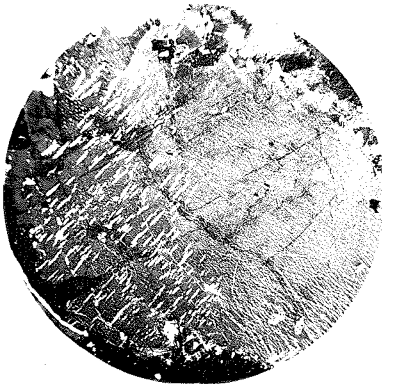


Fig. IV.

Fig. V.

Fig. VI.

have been formed as the result of a neo-mineralization[1] most, if not all, of which has taken place after the final consolidation of the rock. To what extent they represent the addition of material from some distant source is not certain. It is entirely conceivable that much or even most of the sericite may have been formed from the potash set free by the albitization of the orthoclase and the microcline; the second stage quartz, on the other hand, is often present in such quantities that it does not seem possible that all of it could have a local[2] origin.

The post-consolidation minerals of the second group occur chiefly in an interstitial matrix originating in veins which first penetrate along the boundaries between the original grains and then, widening and sending off arborescent branches, attack the primary minerals and tend to completely destroy them. The resulting texture, which will be described in detail below, at times closely resembles well-known cataclastic textures (including motar-texture) but it is distinguished from them by definite and readily recognizable criteria. For lack of a more apt expression this texture is provisionally designated as the "pseudo-cataclastic " texture.

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1. This perhaps represents an extension of the term as proposed by Mrs. Knopf. See Knopf, E.-Retrogressive Metamorphism and Phyllonitization, Amer. Journ. Sci., 5th Ser. Vol. 21, 1931, pp. 1-27

2. It is necessary for convenience sake to adopt a term for these minerals which have been found in the late stages of or after the consolidation of the intrusive mass. Sederholm's term "deuteric" is not quite applicable in its original sense (Sederholm, on Synantetic Minerals; Bull. Com. Geol. de la Finlande, No. 48, 1916, pp. 141 -142)because it is restricted to changes tak-

PLATE LXIX

Description of the figures.

Fig. I - Perthite. The dark grain filling most of the field is an orthoclase "host" containing patches and veins of replacement albite in which the twinning lamellae are clearly visible. A "Vein" containing chiefly quartz and myrmekite is clearly visible in upper left quadrant. Crossed nicols. X22.

Fig. II - Orthoclase in an advanced stage of albitization. The streaks and patches are of albite. Crossed nicols. X22.

Fig. III - Myrmekite attacking potash feldspar. The grain at extinction is orthoclase. The light grains are quartz. A replacement vein penetrating along grain boundaries extends diagonally downward across the field from right to left. This represents an initial stage in pseudo-cataclastic texture. Crossed nicols. X10.

Fig. IV - Myrmekitic intergrowths on border of potash feldspars. Crossed nicols. X22.

Fig. V - Myrmekite penetrating and attacking orthoclase. Crossed nicols. X22.

Fig. VI - The large grain at extinction in the center of the field is orthoclase. It is bounded above by microcline, on the right by another grain of microcline and below and on the left by albite. The light grain included in the orthoclase is also microcline. The large orthoclase grain, according to Gillson's criteria, has the appearance of being of deuteric origin. Running diagonally across it from upper left to lower right is a seam of sericite. On all contacts, including those with the enclosed microcline, as can be seen by close examination even at this magnification, it is fringed with myrmekite. The occurrence strongly suggests deuteric orthoclase, or at least orthoclase which crystallized after the microcline, subjected to later attack and incipient albitization by solutions penetrating along all contacts with adjacent grains. Crossed nicols. X10.





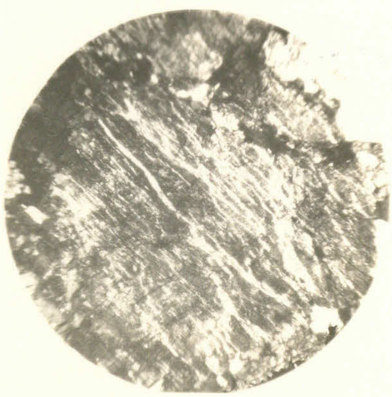
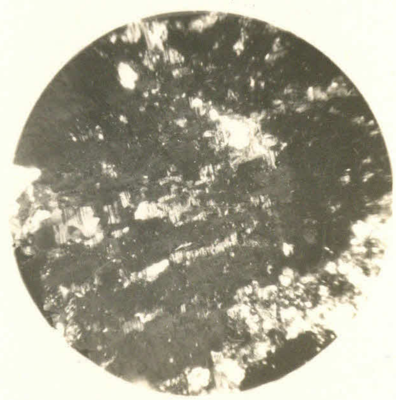

PLATE LXIX

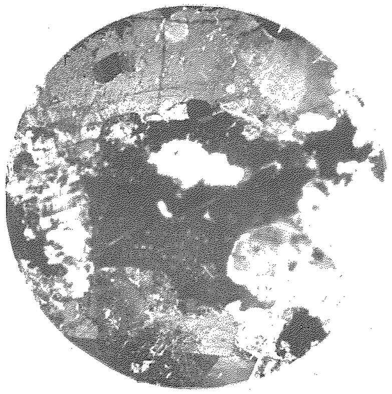

Fig. I

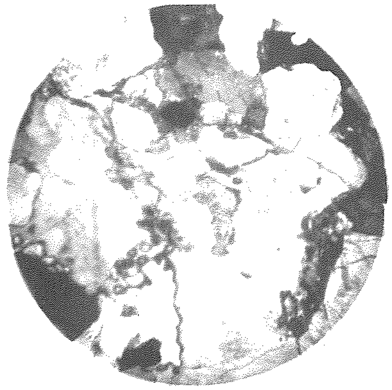

Fig. II

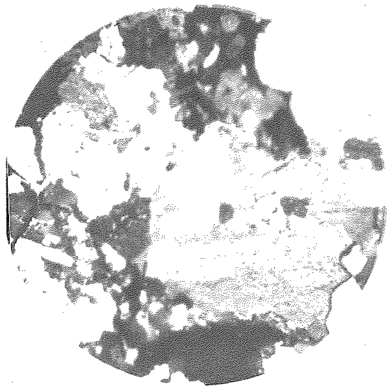

Fig. III

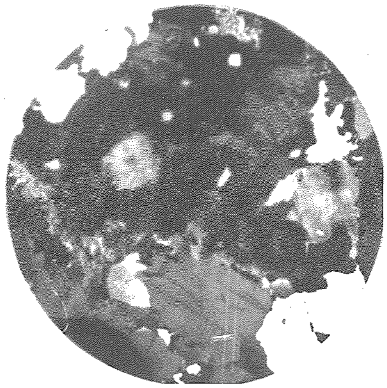

Fig. IV

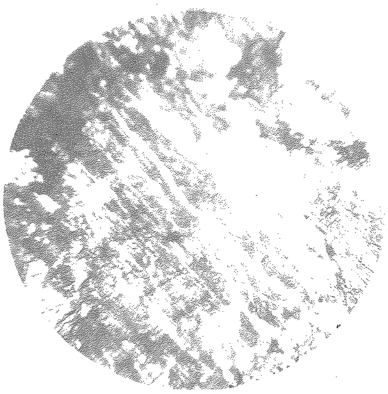

Fig. V

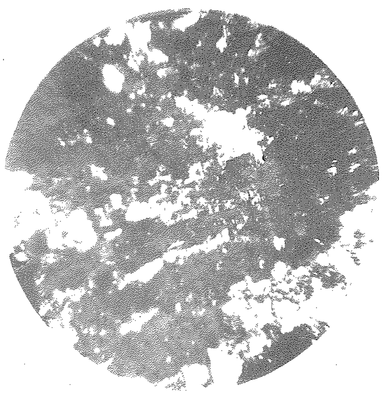

Fig. VI

Most of the minerals which are found in the matrix, however, have a second mode of occurrence. Thus sericite and epidote are frequently found as alteration products within primary feldspars. Quartz and biotite both occur as primary minerals in most of the rocks. The post-consolidation quartz is usually distinguishable from the primary variety not only by its different occurrence but also by its much finer grain size and by its characteristic illumination which is identical with or closely related to that known as "flamboyant" illumination.[1] Post-consolidation biotite differs in color and pleochroism from that of the original rock.

Conversely, albite occurs in the veins as well

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ing place during or immediately after the latter stages of the consolidation of an igneous rock and in direct continuation of the consolidation of the magma itself. Colony(Colony,R.J.-Final Consolidation Phenomena in the Crystallization of Igneous Rocks, Jour. Geol. 31, 1923, pp. 169-178) and Gillson(Gillson,J.L.-On the Use of the Term Deuteric, Econ.Geol. Vol.24,1929,pp 100-102), have proposed extensions of the term, Gillson expressly including under it albitization and similar changes, but such extensions do not seem justified, especially since Sederholm himself has objected to some of them. (Sederholm,J.L.- On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland, 11. Bull.Com.Geol.Finlande,No.77,1926,pp. 88-89) Evan's term "paulopost" (listed by Holmes in the Nomenclature of Petrology, 1920, p.177 but without reference to original use) is similarly restricted. Inasmuch as the writer is by no means willing to agree that it is certain that these changes are all closely related in time to the final stages of consolidation of the magma, he is unwilling to apply either term here. Although the they are admitted to be somewhat awkward and inexact, the expressions "post-consolidation changes" and "post-consolidation minerals will be applied in this thesis for want of better ones.

1.See Adams,S.F.-Microscopic Study of Vein Quartz,E.C Geol. Vol XV,1920,pp. 629-630. Flamboyant quartz closely resembles quartz exhibiting undulatory extinction.

as in metasomatic, perthitic and mermekitic replacements of the potash feldspars.

REPLACEMENT PHENOMENA:

Metasomatism, it is clear, has played a most important part in the genesis of the White Mountain batholith. The products of the reactions as we can now observe them are in some cases pseudomorphs while in others they are such intricate structures as myrmekites or vein and patch perthites which are probably to be interpreted and indicative of incomplete corrosion or replacement. New and independent mineral grains have also been formed on an enormous scale. These occur chiefly in the secondary matrix. Often their formation may have involved only simple recrystallization but more commonly it was accomplished by a recombination of chemical units which in many instances may all have been already present in the rock but in others were undoubtedly carried in at least in part by solutions from an outside source.

Albite has replaced potash feldspar in a variety of ways and with correspondingly different results. Often the substitution has taken place so delicately and yet so completely that the altered grain contains all of the characteristics of the original except in optic sign and in index. It looks fresh and unchanged. Such pseudomorphs can be distinguished only by careful and painstaking testing of all possibilities. Some undoubtedly escape detection because they are not correctly oriented for interference figures or properly situated for index comparisons. Such a grain (albite pseudomorphic after orthoclase) appears in the upper part of the field of Fig.2, Plate LXX.

A second type of substitution, possibly an incomplete form of the first, is that which confers a "sick look" upon the grains of orthoclase or microcline. It is a condition of which the cause, in the absence of chemical analyses, is hard to estimate and understand. Something has happened to the potash feldspar to render it streaked and spotted and dull looking and to obscure such optical properties as interference figures and indices. Occasionally, especially in aplites, instances are found in which a similar appearance is to be attributed to the presence of multitudes of inclusions almost sub-microscopic in size, which are probably in part bubbles of gas or liquid, in part microlites. Such cases, however, can often be readily and quickly distinguished by examination and high magnification from those in which no included bodies can be discerned. (Notice, for example, the large microcline grain in Fig.3, Plate LXVII.)

In the absence of more definite evidence, grains of this kind are interpreted as being ones in which a replacement of potash feldspar by albite had been interrupted before completion. Various gradations are to be observed from cases in which the alteration is slight, to others in which the typical microcline twinning has almost disappeared.

The end product seems to be a grain with an appearance very similar to that of the "chess-board" albite described below. It often gives a definite positive sign.

A third method of substitution of soda feldspar for potash is by the formation of perthites of the patch and vein types. These are perthites in which albite occurs in irregularly shaped patches and in anastomosing veinlets throughout the potash feldspar. Although Vogt[1] and others[2] have argued in favor of an origin by ex-solution of all common types of perthites, there seems little doubt that the patch and vein varities have originated by replacement.[3] In the specimens which have been examined from the White Mountain batholith, there are all degrees of replacement of the potash feldspar by the albite of this type of occurrence from the very beginning to virtual completion. The end product of this process is the peculiar chess-board ("schachbrett") albite described by Becke.[4] In some slides albite exhibiting this structure is the only feldspar. Examples of this type of replacement are to be

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1. Vogt, J.H.L.-On the Feldspar Diagram, Det Norske Videnskaps-Akademi i Oslo Skrifter, I. Mat.-Naturv.Kl., No.1, 1926.
2. Alling, H.L.-The Potash-Soda Feldspars, Jour.Geol.Vol.34, 1926, pp. 591-611.
3. See Andersen, Olaf, Genesis of Feldspar from Granite Pegmatites Norsk Geologisk Tidsskrift, Bind X, 1928, pp.166-171; also Schaller W.T.-Mineral Replacements in Pegmatites, Amer. Mineralogist, Vol.12, 1926, p.62. Schaller says, "In a recent paper on feldspars by Alling, he is surprised that petrographers have often failed to recognize in perthites two distinct generations of the sodium feldspar and I would add that I am surprised that petrographers have failed to recognize that the second type which constitutes the great bulk of perthites is a secondary replacement, for it is not difficult to find in many pegmatites examples where the micro cline contains a varying quantity of the perthite lamallae which reach a percentage of almost one hundred. In other words, the microcline has been practically completely perthitized." See also Gillson, J.L.-The Granite of Conway, New Hampshire and its Druse minerals,-Am.Min. Vol.12, 1927, p. 316.
4. Becke; Physiographie der Gemengteile der Krystallinen Schiefer.

found in many of the photomicrographs. Refer especially to Figs. 2 and 4, Plate LXVIII, Figs, 1 and 2, Plate LXIX and Fig. 1, Plate LXXVIII.

I have also frequently observed in these rocks perthite of the kind called "injection perthite" by Colony[1]. Gillson has likewise described it in the Conway granite.[2] This probably is to be considered as a variety of the vein type of perthite and formed in the same way.

Not all of the perthites which are found in the specimens from the White Mountain batholith are to be regarded as of replacement origin. In many sections, even in the same grains which show the vein and patch type, other varieties occur. These are the "film", the "rod" and the "string" types which are probably of ex-solution origin.[3] The proportion which the ex-solution albite of these perthites bears to the replacement albite, however, is small. "See, for example, Plate LXVIII, Figs. 3 and 6.

Denkschriften der Kaiserlichen Academie der Wissenschaften, Band 75, p. 124, 1906.

1. Colony, R. J. - The Final Consolidation Phenomena in the Crystallization of Igneous Rock, Jour.Geol.Vol.31, 1923,pp 169-178. See especially illustration Fig.1, p 171. The structure comprises a rim of albite surrounding more or less completely a grain of microcline which is penetrated through and through by veins of albite continuous with the rim. The term "injection perthite" is an unfortunate choice because it gives an incorrect idea of the origin of the structure.

2. Gillson,J.L.- The Granite of Conway, N.H. and its Druse Minerals. Amer. Min. Vol. 12, 1927, p. 317.

3. Warren, C.H. - Proceedings Amer. Academy of Arts and Sciences, Vol. 51,1915,p. 144. Andersen, Olaf,-Genesis of Feldspar, Norsk Geologisk Tidskrift, Bind X, 1928,pp. 116-205.

PLATE LXX

Description of figures.

Fig. I - This is an enlargement of Fig. I, Plate LXVIII. Crossed nicols. X 25.

Fig. II- Myrmekites in granite. The large light-colored grain showing cleavage is orthoclase of very latest crystallization. All other primary grains, fringed with myrmekite, are albite. Note that the convexity of myrmekitic intergrowth is always toward the orthoclase. Crossed nicols. X 50.

Fig. III - Perthite lamellae, probably of ex-solution origin, in orthoclase. Crossed nicols, X 60.

Fig. IV. - This is an enlargement of a part of the upper right quadrant of Fig. VI, Plate LXVIII, showing how the "veins" are fringed with myrmekites which attack the orthoclase. Crossed nicols, X 50.



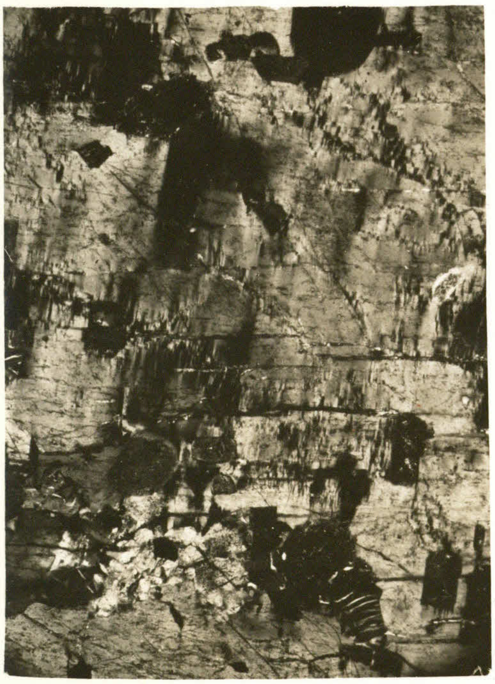


PLATE LXX.

Fig. I

Fig. II

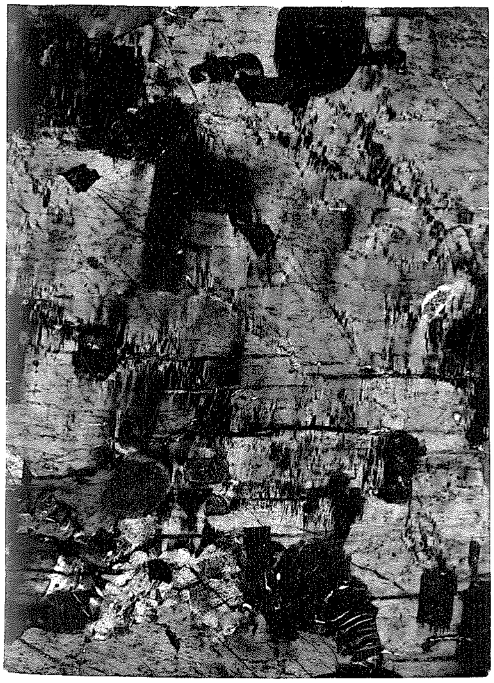

Fig. III

Fig. IV

In what may be termed a "corrosion type" of replacement the potash feldspar grain is seen to be the object of a direct attack from its margins. In many cases the attacking mineral is a homogeneous feldspar clearly demonstrable as albite (though often untwinned). Less often it is an indistinctly-zoned plagioclase (that is, a continuous variation or "progressive" type) with albite border.[1] Very commonly it is the vermicular intergrowth of quartz and feldspar known as myrmekite. As frequently the apparent aggressor is a broad interstitial vein containing a complex mineral assemblage including finely divided quartz and feldspar (probably albite), tiny fragments of myrmekite and shreds of sericite. Epidote and biotite or chlorite are also frequently present. All of these are illustrated in the accompanying photomicrographs. (See especially Plate LXVII, Figs. 1, 3 and 4 and Plate LXX, Fig. 4.

The replacement phenomena which have been described above may be classified as complete and incomplete. Among the former are those occurrences which represent the final products of the metasomatic processes. These include the albite pseudomorphs and the grains of chess-board albite. Among the occurrences which indicate interruption of replacement before the stage of completion are to be placed the various types of replacement perthite, the myrmekites and the general group of the "corrosive type of replacement.

1. This type of replacement has also been described by Gillson, J.L. - The Granite of Conway, N.C. and its Druse Minerals, Amer. Min. Vol. 12, 1927, p. 317.

MYRMEKITES.

The formation of myrmekites deserves special discussion both by reason of its exceedingly common occurrence in the rocks of the White Mountains and because it has for years attracted the attention of petrographers many of whom have speculated on its origin.

Myrmekite, it will be recalled, is a worm-like intergrowth of quartz in plagioclase. From my point of view, it is to be considered as a special kind of albitization, for it seems always to involve the substitution of soda for potash feldspar. Frequently it appears to form a continuation of a primary plagioclase where the latter is in contact with potash feldspar; just as frequently, however, it has been observed to be independent of any pre-existing plagioclase grain. It frequently is found fringing the veins of the pseudo-cataclastic texture where these cross or are contiguous to microcline or orthoclase.

The first description of myrmekite appears to have been made by Michel Levy in 1874 in which he applied the name "quartz vermicule" to the quartz of the intergrowth.[1] He later expressed a belief that the quartz had infiltrated into cavities formed by corrosion by late feldspar with which the silica was associated.[2] Fouque and Levy in 1879 proposed the

1. Michel Levy, Structure Microscopique des roches acides anciennes. Bull. Soc. Geol. de France, Tome III. 1874, pp.201-222.
2. Michel Levy, Contribution a l' etude du granite de Flamanville, Bull. Carte geol de France, no. 36, 1875, p. 27.

name "structure vermiculee" for myrmekite and ascribed its origin to replacement (corrosion) of the feldspar by the quartz.[1]

Becke at first regarded the structure as being due to simultaneous crystallization of its constituents from the molten magma.[2] He was followed in this opinion by Graber,[3] Bergt,[4] Petraschek,[5] Kalb,[6] Reinhardt,[7] and Eskola[8]. The last two writers, however, indicate their belief that it is an end-stage product of a consolidating magma. Reinhardt especially emphasizes the influence of escaping gases and vapors.

Somewhat later, however, Becke revised his opinion in favor of the view that myrmekite formation represented a replacement of the potassium in the potash feldspars by the sodium and calcium of the plagioclases. Since anorthite contains less silica than orthoclase or microcline the substitution of the former for one of the latter would set free $Si\ O_2$ which would form the quartz of the myrmekite. The richer the feldspar of the myrmekite in anorthite, the more silica would be set free. Acting in pursuance of this reasoning he

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1. Fouque and Levy, Mineralogie micrographique, Roches eruptives francaises, Mem. Carte geol. de la France, 1879, p. 193.
2. Petrographische Studien am Tonalit von Rieserferner. Tschermaks Min. und Petr. Mitt. 13, 411-414, 1892.
3. Graber, H.V. - Die Aufbruchzone von Eruptiv - und Schiefergesteinen in Sud-Karnten. Jahrb d K.K. geol. Reichsanst 1897, 47 Bd. 2 h. p. 225.
4. Bergt, W. - Zur Geologie des Coppenaume etc - Sep Abdr. aus Samml. d Geol. Reichs. - Mus. in Leiden. Ser. II. Heft. II, 117-187, Leiden, 1902.
5. Petraschek - Uber Gesteine der Brixener Masse-Jahr. K.K. Geol. Reichsanst 54. Bd. 1904, p. 50 and 70-74.
6. Kalb, Georg. - Petrographische Untersuchung am Granit von Bornholm, Inaug. Diss, Greifswald, 1914, p. 45.
7. Reinhardt, M. - Der Coziagneiszug in den Rumanischen Karpathen-Inaug Diss. Bukarest, 1906, pp. 78-79 and 100.
8. Eskola, Pentti - Petrology of the Orijarvi Region - Bull. Com. Geol. de Finlande, No. 40, 1914, pp. 27-28.

attempted to measure the ratio; quartz / feldspar, in myrmekites having different kinds of plagioclases and thought that he obtained confirmation of these views.[1] He expressed the view, furthermore, that the reaction took place after the consolidation of all or most of the rock and was favored by the presence of aqueous solutions or vapor. Hence it is very common in igneous rocks near contact zones. He was also led to think that the extensive formation of mica (both biotite and muscovite) in deep seated rocks which often takes place after their consolidation, may be due in large part to the potash set free by formation of myrmekite, and that the giving off of potash in contact aureoles of plutonic rocks may be explained in the same way.[2]

Meanwhile other investigators, observing the intergrowth developed to a high degree in metamorphic rocks, have attempted to assign its origin to metamorphic processes. Among these were Futterer[3], Backlund,[4] and Holmquist.[5] Tronquoy, on the other hand, believed that it was due to a process which he called "auto-pneumatolysis" and that it took place soon after the consolidation of the rock mass. Alkaline emanations or circulations, he thought, proceeding from the

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1. Becke - Physiographie der Gemengteile der Krystallinen Schiefer Denkschriften der Kaiserlichen Akademie der Wissenschaften. Band 75, pp.97-151, 1913, aber vorgelegt in der Sitzung vom 12, Juli 1906.
2. Becke, F. - Über Myrmekit. Mitt der Wiener Mineralog. Gesellsch, Tschermaks Min. u. Petr. Mitt. 27, 371-391, 1908.
3. Futterer, K.- Über Granitporphyr von der Greisscharte in der Zillerthaler Alpen, N. Jahrb. fur Min. IX Beil Bd. 1894-5,pp. 541-544.
4. Backlund, Über ein Gneissmassiv in nordlichen Siberien- quoted by Sederholm in Bull. Com. Geol. de Finland, No. 48.
5. Holmquist, P. J. - Granites of Sweden, also quoted by Sederholm.

unconsolidated part of the magma acted upon the already consolidated part to produce such alterations. He considered it, therefore, to be a special kind of albitization.[1]

The foregoing are only a few of the petrographers who have observed and written upon the subject. Among others might be mentioned Romberg who thought the structure was produced by weathering.[2]

The foremost authority upon the subject at the present time is J.J. Sederholm. It was he who proposed the name "myrmekite" in 1897.[3] In the same paper he expressed the belief that such intergrowths were formed at least in part after the complete solidification of the magma by processes comparable to those of contact metamorphism and likewise requiring increased temperatures and the presence of abundant solution media.

More recently Sederholm has reviewed the entire subject of myrmekite at length in his bulletin "On Synantetic Minerals and Related Phenomena." [4] He reaches the conclusion, from a multitude of observed facts, that myrmekites may form in a number of ways and at various stages in the history of the rock mass, both before its final consolidation and at a much later time but usually by circulating solutions and gases after the primary consolidation of the rock. It is rarely primary, he thinks, though it may have an early origin - that is, after the crystallization of the microcline but before the escape of the

1. Tronquoy, R.R. - Origine de la Myrmekite, Bull. de la Soc. Franc de Min. Tome 35, 1912, pp. 214-223.
2. Romberg, J. - Petrographische Untersuchung an Argentinisch Graniten, Neues Jahrbuch fur Min. 8, p. 314, 1892.
3. Sederholm, J.J.- Uber eine archaische Sedimentformation sudwestlichen Finlande- Bull Com. Geol. de Finlande No.6, pp. 108 and 111-114.
4. Bull. Com. Geol. de Finlande, No. 48, 1916.

end-products of the magma, which may often supply the material for its formation. In other places he has found evidence that it was formed after mechanical metamorphism of the rock. He reiterates his belief, however, that in most cases it is associated with contact processes, especially when these involve the melting in and assimilation of large fragments of basic rocks. He says:

> "If the formation of the symantetic minerals, as seems to me without doubt, is caused, not only by an interchange of material between the neighboring minerals but also of material carried in from without in solution, then a difference in the mineralogical composition of the neighboring rocks must have been of great influence. Rocks rich in plagioclase have delivered solutions rich in the constituents of this mineral, which have reacted on the minerals of the neighboring granite rocks . . . during the processes of assimilation and crystallization."

The quartz of the myrmekite, he thinks, either formed simultaneously with the feldspar in some cases, or, in others, corroded the feldspar after its formation. The exact process is not clear.

The study of the rocks of the White Mountain batholith has convinced me that Sederholm is correct in his conclusion that myrmekite may form in a number of ways and at various stages in the history of the rock. As Becke and others have emphasized so strongly, the intergrowth frequently appears at the contact between a primary plagioclase grain and one of potash feldspar and in such location the plagioclase of the myrmekite usually appears to be in optical continuity with the earlier plagioclase or with its outer rim if it is a zoned feldspar. On the other hand, I have many times seen the structure corroding orthoclase or microcline where no grain of primary plagioclase was contiguous to it. This happens most often in the veins of the pseudo-cataclastic texture. In such cases the myrmekite usually occurs in clusters of small individuals fringing the veins where they cross or touch the potash feldspar.

Becke, in an effort to establish a generalization concerning the mode of occurrence of myrmekite, assumed that in all sections in which plagioclase is not found in the vicinity of the myrmekite the plagioclase actually was present in the specimen before grinding and lay just below the plane of the section. I consider this explanation, although at first glance reasonable, to be untenable. Since it has been observed that when the intergrowth occurs on the border between primary plagioclase and microcline grains the quartz threads always radiate toward the replaced feldspar, a section which by accident does not include any part of the plagioclase should be perpendicular or oblique to the long direction of the quartz threads. This should give sections of the latter approximately circular or elliptical. Such cases may often be seen but in the great majority of cases in which plagioclase is absent the section is parallel to the elongation of the quartz.

Becke's idea that the quartz in the myrmekite originates from the liberation of silica which must be set free when anorthite is substituted for potash feldspar is a very attractive one but it also is unacceptable. The metasomatic, i.e., volume for volume replacement of a molecule of orthoclase (or microcline) by one of anorthite would involve the liberation of one about 0.85 molecule of $Si\ O_2$. By weight the latter would equal about 18.5 % of the anorthite. The substitution of albite for orthoclase, however, would yield no free silica but on the contrary represents an addition of about 10% to the Si_2O_2 already present in the orthoclase. Now if we assume that the feldspar of the myrmekite is rarely more basic than an oligoclase andesine with composition $Ab_{70}An_{30}$, as has been admitted by Becke and all other observers, the silica liberated would not exceed 2.5% of the replacing feldspar. Since the specific gravity of oligoclase is almost exactly equal to that of quartz (Dana gives 2.65 to 2.67 for the former and 2.66 for the latter) the volume realtions would be very nearly equal to the weight relations. Therefore the quartz of a myrmekite should never exceed 2.5% by volume of the feldspar with which it is intergrown. This is certainly not in accordance with observed facts for, although the proportion of silica in the myrmekite is variable, I have seen many cases in which it certainly was not less than 30% and was very probably as much as 50% of the plagioclase. Moreover, if nearly pure albite is the replacing feldspar, as often happens, almost no quartz should be present under this hypothesis. Although I have rarely been able to determine exactly the composition of the myrmekitic feldspar, for it is usually untwinned, its index in the great majority of the cases I have seen, is much below that of the accompanying quartz though above that of the orthoclase, and its sign, where determinable, is usually positive. This would indicate that it is albite or acid oligoclase, and that its composition varies within rather narrow limits. Nevertheless the quartz content of the myrmekite is both quite variable high.

I cannot, therefore, accept Becke's explanation for the presence of the quartz - at least in its entirety. Neither have I seen any cases in which I can be sure that it has corroded and replaced the feldspar of the myrmekite, as Sederholm has indicated. From the many occurrences which I have observed I am inclined to the belief that the two constituents have separated out simultaneously from replacing solutions carrying soda and silica, but as to the controlling conditions which cause such simultaneous precipitation or the explanation of the characteristic wormlike structure, I can as yet offer no suggestion. An alternative hypothesis which has occurred to me is that under the original conditions of the replacement an unstable sodium silicate with an abnormally high silica content, possibly in complex association with other ions, may have been formed which, under changing conditions of temperature, pressure or escape of gaseous or liquid material, may have broken down leaving sodic plagioclase and free silica.[1]

I am strongly disposed to doubt whether myrmekite is ever of primary origin, as many writers have claimed and Sederholm has rather reluctantly agreed it may be. The latter has urged that it is nearly always formed under conditions similar to those which prevail in contact metamorphism - namely, rather high temperatures and pressures and the presence in abundance of vapors and solutions. This is the

1. That such high silica, sodium-bearing minerals exist in nature is shown by the example of Leifite (9Si O_2 Na F.Al_2O_3) See Dana-Ford, Text book of Mineralogy 4th Ed., p. 535.

view I also hold but I would add that such conditions may not only exist during and shortly after the consolidation of the magma but may recur long afterward through the sufficient reheating of a rock mass accompanied by the circulation of solutions through channelways created by any process. It is indeed possible that such a reheating may proceed so far as to produce in the presence of aqueous solutions a partial solution of the outer edges of the mineral grains. Such a condition would greatly increase the permeability of the mass to solutions and vapors under pressure from without. The process would approach what Sederholm has termed anatexis. Whether we call it solution or remelting is immaterial. Refusion and solution at high temperatures, as may be pointed out, in the modern concept are not distinguishable processes. Penetration of solutions and vapors along the boundaries between grains would probably lower the temperature necessary for partial fusion. It is reasonable to suppose that such minerals as microcline or orthoclase and quartz, which crystalize last in the normal sequence, would be the first to yield to the attack and would show the most pronounced effects.[1] On the other hand, other minerals might be particularly reactive to the solutions and hence be affected to an equal degree. In either case additions and recombinations would take place which would be improbable in the solid state.

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1. It must be remembered, however, that the fusion point of quartz, for example, under normal conditions is much higher than that of any one of a number of minerals which ordinarily crystallize before it in magmas. The condition usually seen igneous rocks has commonly been ascribed to the presence of mineralizers but, as Bowen has shown, it may also be due to the operation of the Reaction Principle.

What must be emphasized is that the peculiarities observed in the White Mountain rocks, including albitization, the formation of myrmekites and the pseudo-cataclastic texture, are all closely related in the method of their formation and that they may have originated either soon after the consolidation of the mass or at a time long subsequent to it. If the former case is true, the changes are deuteric in the sense of Sederholm; if the latter interpretation is correct they are post-consolidatiin changes but no suitable term has yet been designed to describe them. In either case they are secondary but, as Holland[1] has pointed out, "the use of the term 'secondary' when applied to rock alterations is but relative . . . . The minerals of early consolidation may be attacked and altered soon after their formation by the vapors originally present in the magma and excluded to the mother liquid or they may become attacked at a distant and subsequent period. In the former case the processes of primary crystallization and secondary alteration are continuous and, in reality, phases of the same process"

In the White Mountain batholith intrusives I am inclined to favor a development of these changes at a time considerably later than the final consolidation of the rock mass. They have been seen here to involve pegmatites, usually considered to be end-stage magmatic products. In parts of the batholith it is clearly seen to have followed mechanical deformation which must have taken place long after the mass solidified. It must, moreover, be frankly recognized that these are peculiar

1.Holland, T.H.- On a Peculiar Form of Altered Peridotite in the Mysore State, Mem.Geol. Survey of India, 34, Part 1, 1901.p. 8.

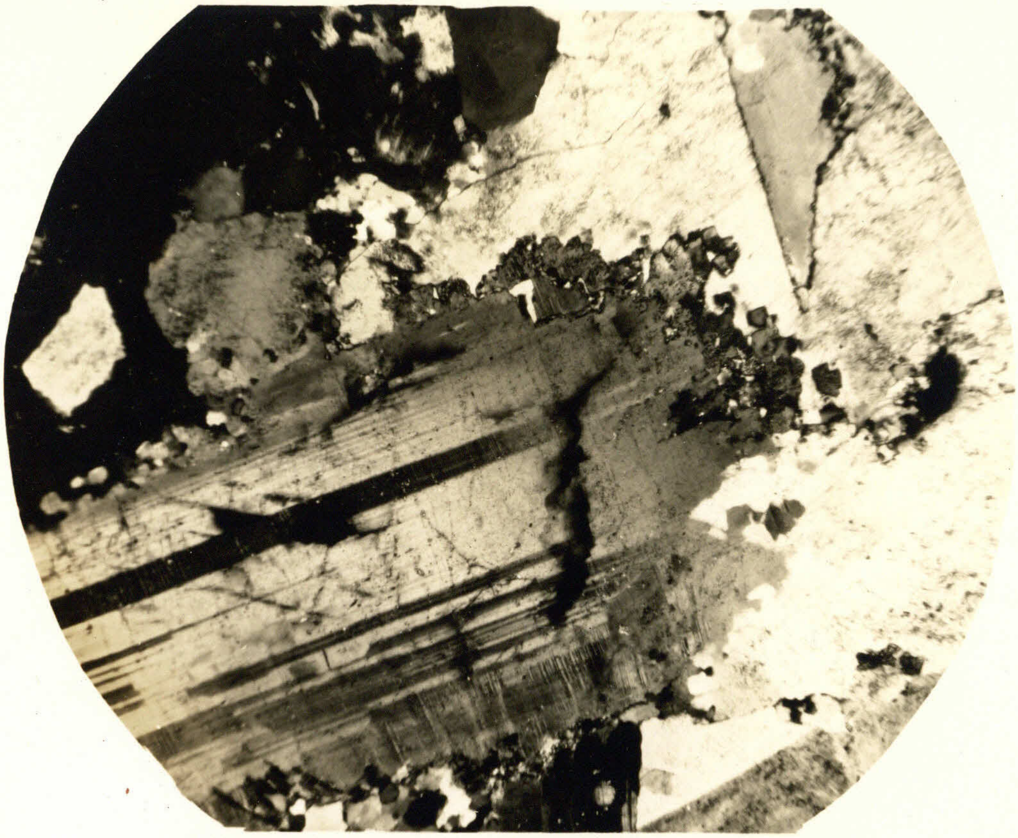
PLATE LXXI

Description of figures.

Fig. I. - Initial stage of pseudo-cataclastic texture. The grain of zoned plagioclase (oligoclase-albite) is fringed with a narrow border of fine-grained material deposited by replacing solutions. On the contacts of the plagioclase wth the microcline (light gray grain occupying the right side of the field) myrmekite has developed. Elsewhare as at the bottom of the field along the contact with another grain of plagioclase, the "vein" is composed chiefly of quartz with a little biotite. The wedge-shaped grain enclosed in the microcline is quartz. Notice the frayed border. Crossed nicols. X 40.

Fig. II - Initial stages in the development of pseudo-cataclastic texture, following in this case, an earlier period of slight mechanical crushing of the rock. Crossed nicols. X 25.

33-34



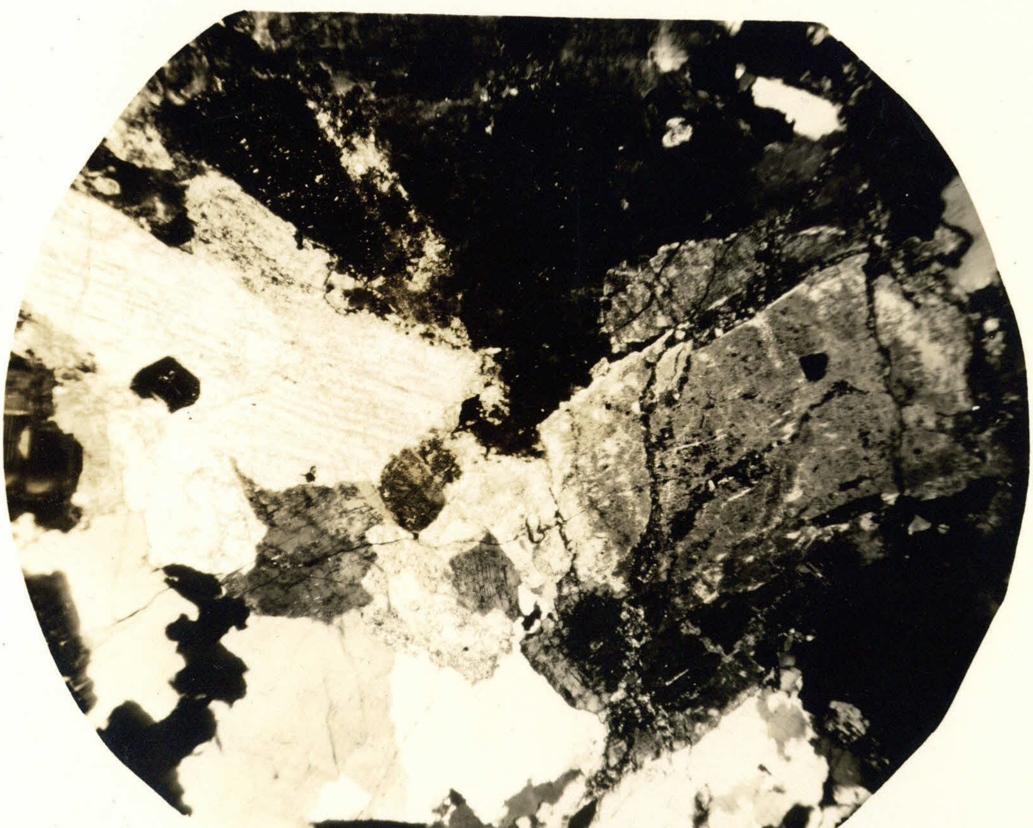


PLATE LXXI

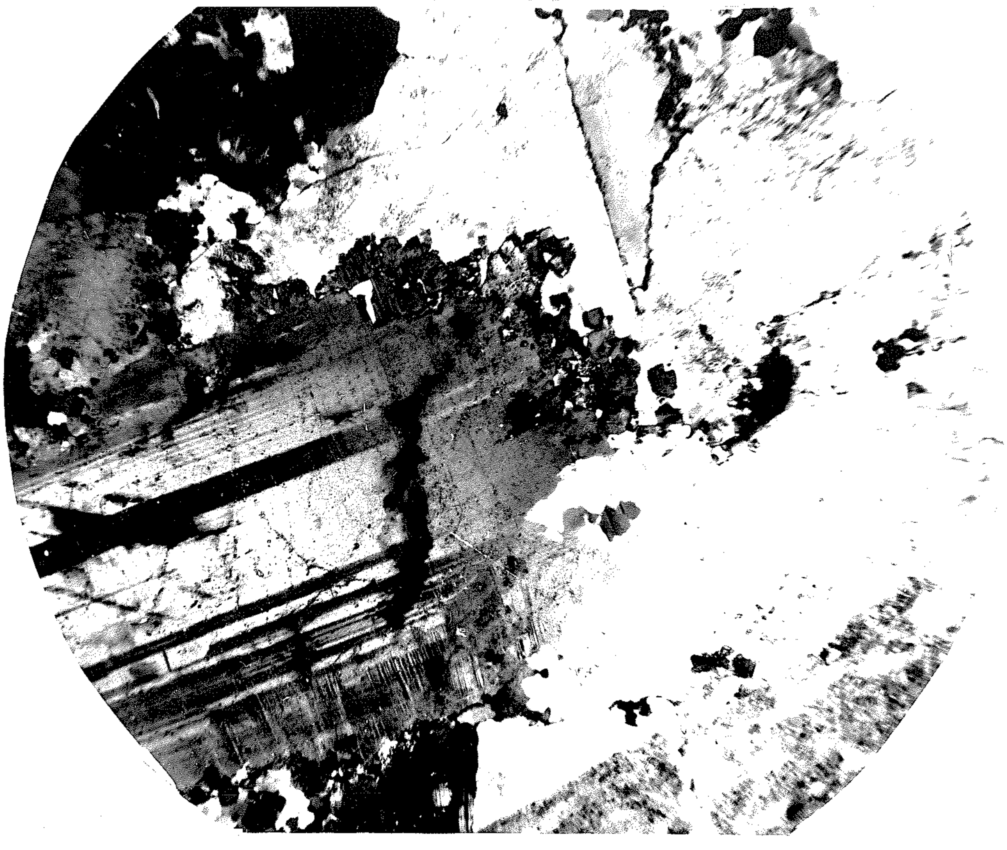


Fig. I

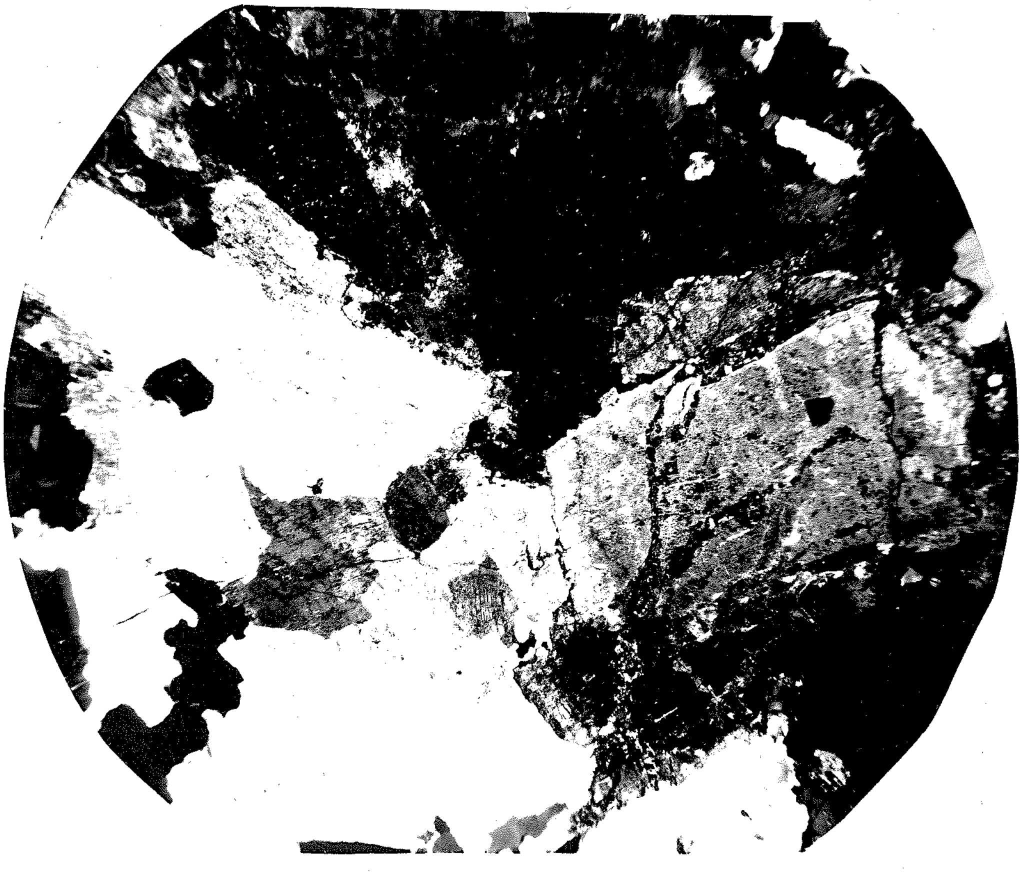


Fig. II

characteristics which are not common to all rocks and demand special explanation which may well have to do with unusual events in the later history of those that contain them. All igneous rocks, according to our present conceptions, were once fluid and became solid upon cooling; we cannot, therefore, explain albitization, myrmekitization and the like by merely saying that they are deuteric phenomena normal to a crystallizating magma. They are exceptional, not normal, though at the same time, not rare. We must attribute them to circumstances which are out of the ordinary but not so much so as to be rarely attained. We must seek, moreover, a source of the necessary new materials, especially soda, as well as the conditions which make it possible for them to permeate the igneous body and replace its minerals. This phase of the question will be more fully discussed below.

Before we leave the subject of myrmekites we must emphasize again that wherever they have been observed in the White Mountain rocks they always replace potash feldspars. Inasmuch as their feldspar is albite or oligoclase, they are to be considered, as has been said, a special form of albitization. They are often intimately associated with the veins of the pseudo-cataclastic texture and to these as well as to the metasomatic replacement of microcline and orthoclase they are without question closely related in origin. In many cases, it is true, the feldspar of the myrmekite seems to represent a continuation of an adjacent plagioclase of primary origin but it is often apparent and always probable that even here the myrmekite is of post-consolidation development. Very frequently, depending, perhaps, upon the proper orientation of the section, the contact between the earlier plagioclase and the original potash feldspar is seen to be along the course of one of the veins of the pseudo-cataclastic texture which has carried, besides sodic materials, the constituents of epidote, titanite, sericite, biotite, quartz and other minerals. The particular development of myrmekite along the contact between plagioclase and orthoclase has taken place because the same processes which produce continuous crystal growth in a solidifing magma make this an especially favorable place for the deposition of sodic feldspar. For illustrations refer to Plate LXIX, Figs. 3, 4 and 5, Plate LXX, Figs, 2 and 4, Plate LXXVIII, Figs. 6 and others.

PSEUDO-CATACLASTIC TEXTURE.

We must now consider in more detail the pseudo-cataclastic texture to which reference has frequently been made above. In varying degree this texture is so universally present in the White Mountain intrusive rocks that it can almost be said to be charmacteristic of them.[1] Often it might readily be mistaken for mortar (murbruk) texture; in its

1. Pseudo-cataclastic texture is illustrated in Plate LXX, Figs. 1 and 4; Plate LXXI, Figs, 1 and 2; Plate LXXII, Figs. 1 and 2; Plate LXXIII, Figs. 1 and 2; Plate LXXIV, all figures, Plate LXXVI, all figures and Plate LXVII, all figures. In several of these cases, as is indicated in the descriptions of the photomicrographs, the development of the pseudo-cataclastic texture took place after an earlier period of mechanical deformation.

advanced development it may resemble a mylonite.[1] In all cases, however, it presents differences which indicate that it has originated in a different way, although there is evidence in places that it has developed after a period of mechanical deformation.

Essentially the texture consists of a number of large grains, representing the original minerals of the rock, set in an interstitial groundmass made up of a greater number of grains, much smaller for the most part but variable in size. The interstitial material may be very small in amount or it may make up the greater part of the rock. The resulting appearance in microscopic section approaches that described and illustrated by Iddings under the designation "seriate intersertal fabric" or " seriate porphyritic fabric" depending upon the proportion of interstitial material.[2] With increasing degree of alteration the larger original crystals may nearly disappear, their former presence being indicated by skeleton outlines or by tattered remnants.

Between the pseudo-cataclastic texture, however, and those which have been cited above for comparison there are several very pronounced differences. These are most evident in the incipient stages but are present throughout its

1. Knopf defines a mylonite as a rock which has been completely crushed under conditions where it cannot lose coherence; this differs somewhat from the original definition by Lapworth. See Knopf, E.B. - Retrogressive Metamorphism and Phyllonitization, Amer. Jour. Sci. 5th Ser. Vol.21, 1931, pp. 1-27; alsoJJohnannsen, Petrography, Vol. 1, Chicago, 1931,pp. 220.
2. Iddings, Igneous Rocks, Vol. 1. New York, 1909, p. 197.

development. Perhaps the most noticeable of these differences is that the interstitial material of the pseudo-cataclastic texture exhibits a decided flow structure. This is in part indicated by a parallelism in arrangement of the minerals in respect to their elongation. This parallelism does not extend entirely across a rock section, however, as might be expected if the minerals had arranged themselves in response to directed pressure. On the contrary, the direction assumed is irregular and occasionally may swing through 45 or 50 degrees in a short distance.

That movement of material took place is further indicated by the presence in the interstitial material of minerals not represented among the original grains.

If we trace the texture by gradations back to its beginning phases we find that these are in the form of a few small, sub-parallel veins which wind between and around the older grains. As the texture develops the veins begin to embay and corrode these grains, so that they take on frilled and ragged outlines. This is particularly true of the microcline and orthoclase which, where bordered by the vein, are usually attacked by myrmekite.

Impressive evidence of the influence of incoming solutions upon the rocks is the presence of very large quantities of quartz in the interstitial material. The amount is often much too large to be accounted for by assuming that it was derived from the immediate vicinity. Its

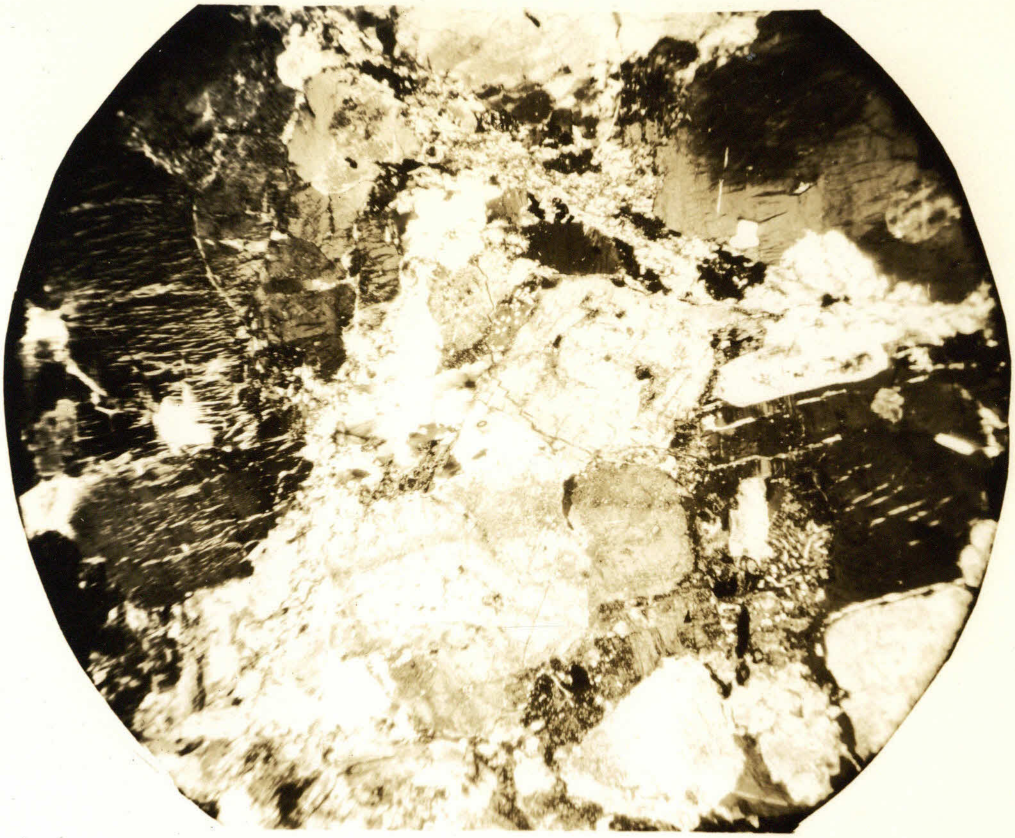
PLATE LXXII.

Description of figures.

Fig. I - The light grain inthe center of the field is potash feldspar. The grains at extinction right and left are perthites. Note the "veins" which follow the grain boundaries. Myrmekites have developed at the expense of the potash feldspars in many places. Crossing the upper part of the field diagonally is a "vein" containing almost exclusively quartz and sericite. Crossed nicols. X 25.

Fig. II - Another area showing replacement proceeding along grain boundaries. The "veins" are compose of quartz, sericite, and chlorite. The primary grains are quartz, plagioclase and perthite. The light-colored grains are in approximately the same optical orientation but of different minerals. Crossed nicols. X 25.

36-37



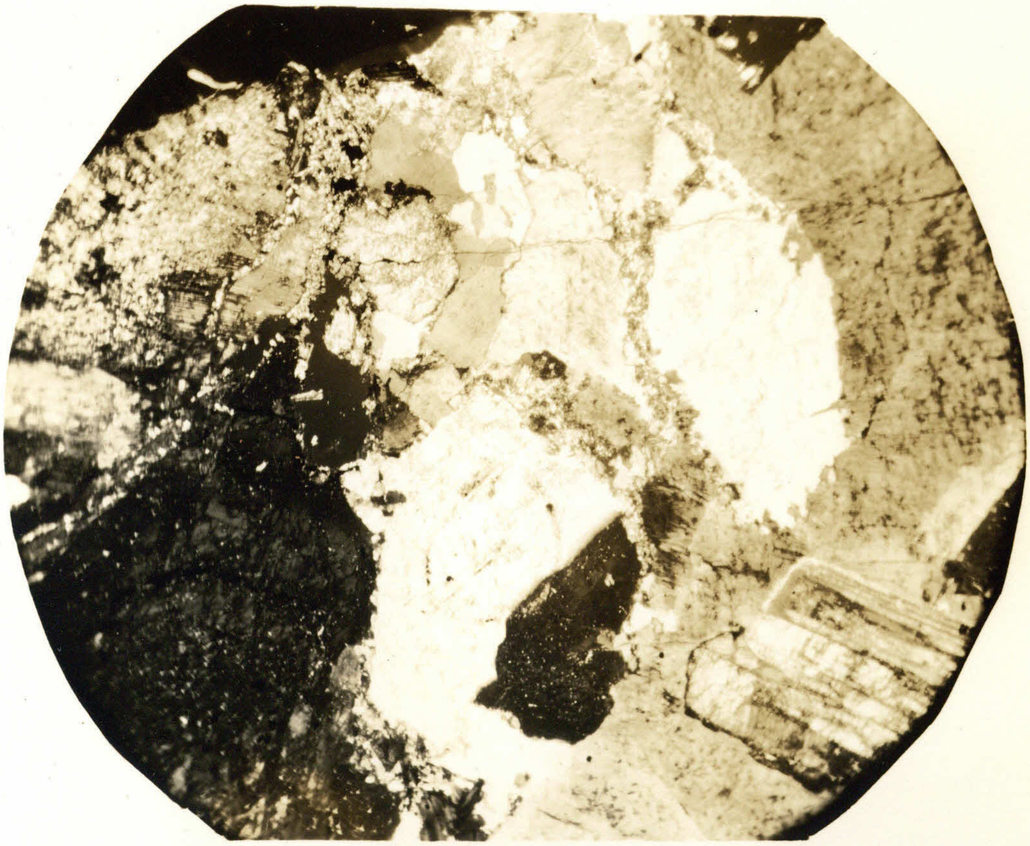
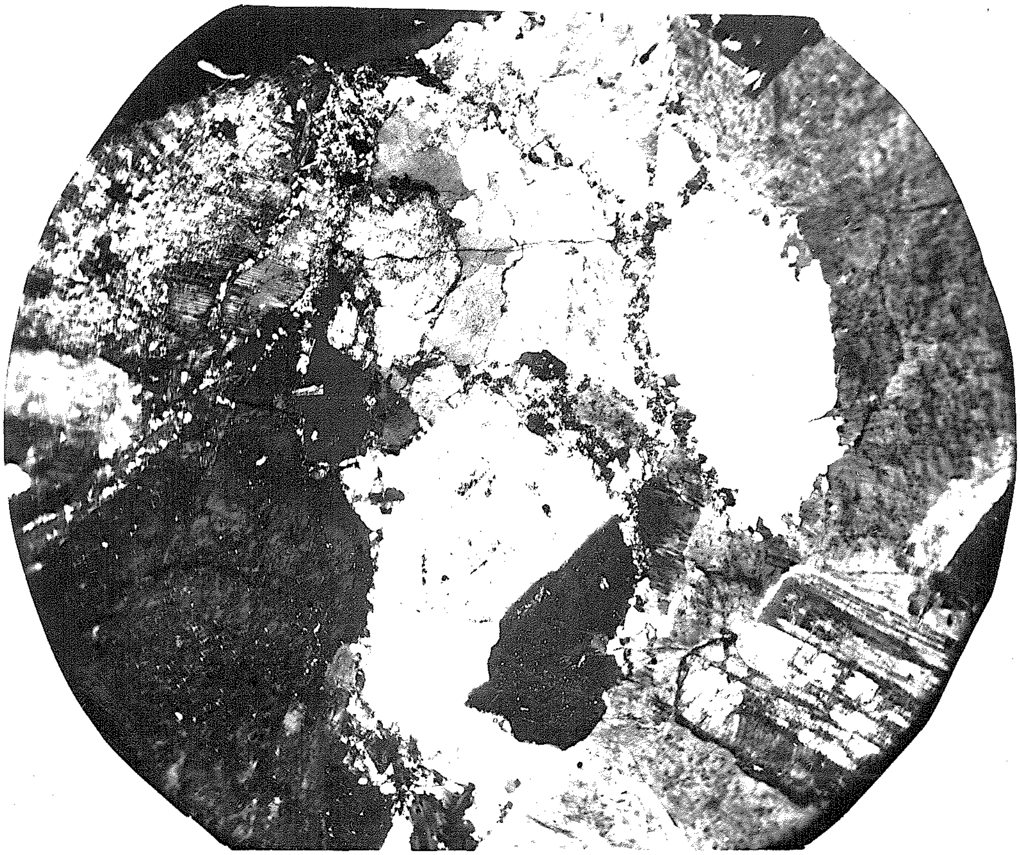


PLATE LXXII



addition can be explained only by assuming that the rock has been permeated by solutions rich in silica obtained from an outside source.

The presence in the intergranular material of such minerals as sericite, epidote, biotite and chlorite which either require water for their formation or have a recognized hydrothermal origin is significant evidence of its origin.

In studying sections from the White Mountain batholith I was confronted again and again with phenomena which most convincingly indicated that circulating solutions had entered the rock and worked their way through it, altering, dissolving, substituting, re-combining, re-precipitating as they went. My first impression was that I was dealing with a cataclastic texture but this opinion could not be maintained in the face of so much adverse testimony. Some of the characteristics which serve to distinguish the pseudo from the true cataclastic texture are summarized herewith:

1. The "fragments" which compose the intergranular veins or the secondary matrix are seldom at any spot composed of the minerals of the large grains contiguous to the intergranular material at that spot. This is exactly the reverse of what might be expected if this material were composed of true fragments produced by the crushing or abrasion of the original grains. For example, a vein passing between or crossing grains of microcline may be composed almost exclusively of small, highly interlocking grains of

"flamboyant" quartz or of albite or biotite. Often, especially where the vein is of quartz or of biotite, the grains are much elongated parallel to the course of the vein and are often sinuous in outline. Frequently, also, there is an increasing fineness of grain from the wall to the center of the vein.

Very often a vein is composed of a multitude of small grains of various minerals, usually of quite a large range of size irrespective of species. Typically, a vein might be composed of quartz, microcline, albite, biotite, sericite and epidote and this composition retained with little or no change in proportions as the vein crosses or penetrates between grains of quartz, microcline and plagioclase.

Commonly the veins of the type just described show a definite arrangement of minerals amounting to a paragenetic succession. In such cases the vein may have its walls lined with albite or biotite in elongated fibers with long axes parallel to the vein direction. Next may come a zone of potash feldspar or of plagioclase. The innermost part or core may be composed of quartz or epidote or sericite or of a mixture of these.

It is very common to find minerals in the interstitial material which do not compose or occur in any of the larger grains.

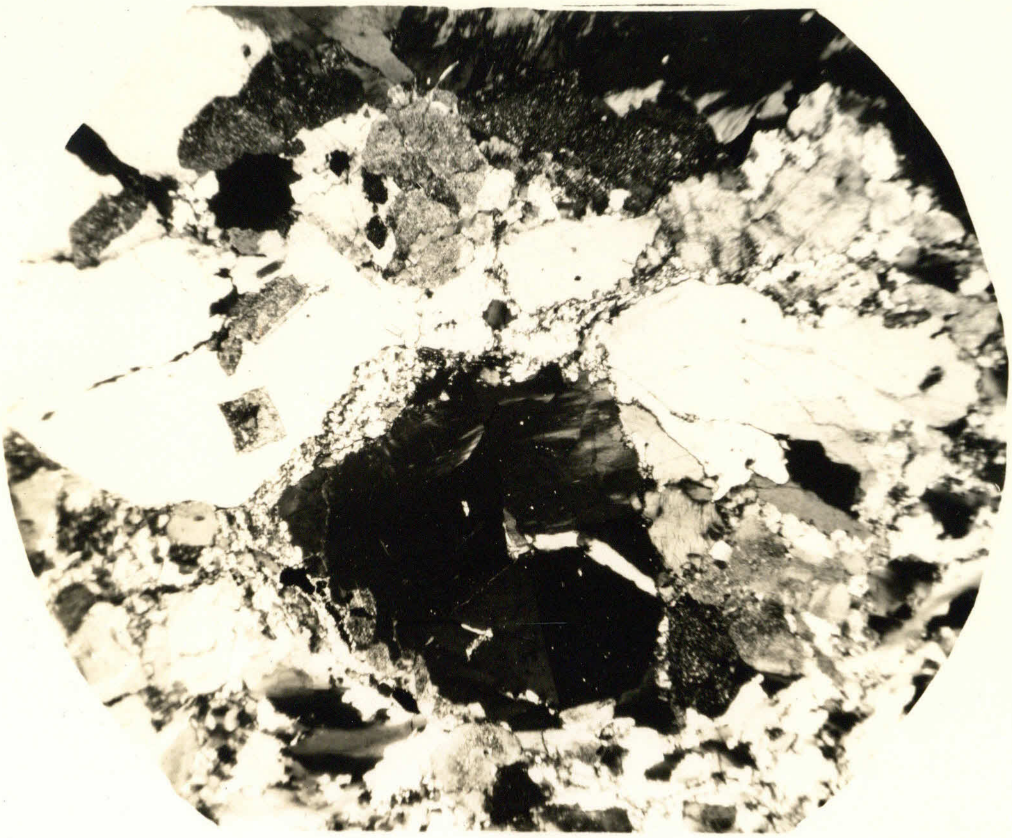
2. The veins sometimes coalesce to form larger and larger veins so that the pattern may approach the arborescent or dendritic zones. Conversely, a vein may become

PLATE LXXIII

Description of figures.

Fig. I - The large dark grain in the lower part of the field is potash feldspar in optic axis orientation. The other large grains are orthoclase. The "veins" consist of quartz and sericite with no other minerals except a little chlorite. Note the myrmekite in the dark grain near its left border. Crossed nicols. X 25.

Fig. II - This section, like Fig. I, above, shows pseudo-cataclastic texture developing after an earlier period of slight mechanical crushing of the rock. The veins consist of q uartz, sericite, and chlorite. The light-colored, fine-grained aggregate in the dark grain to the right of the center consists of sericite. The dark fibrous material near the bottom of the field is chlorite. A grain of fresh-looking biotite appears just above the quartz at the top of the field. Crossed nicols. X 25.



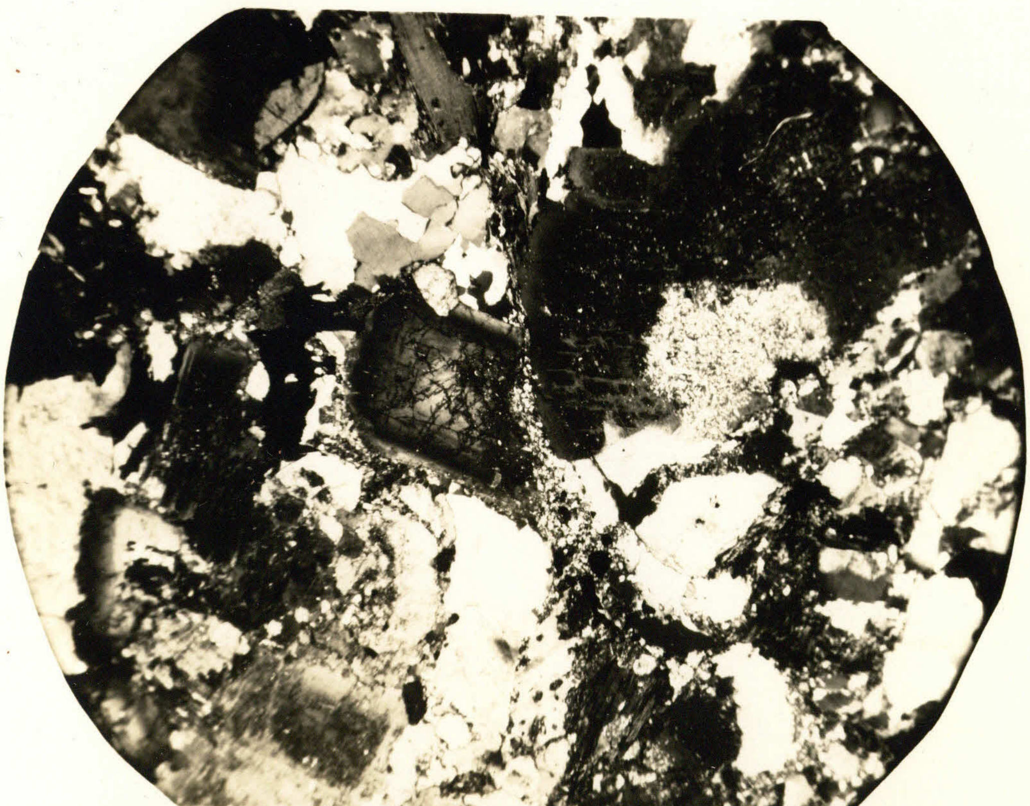
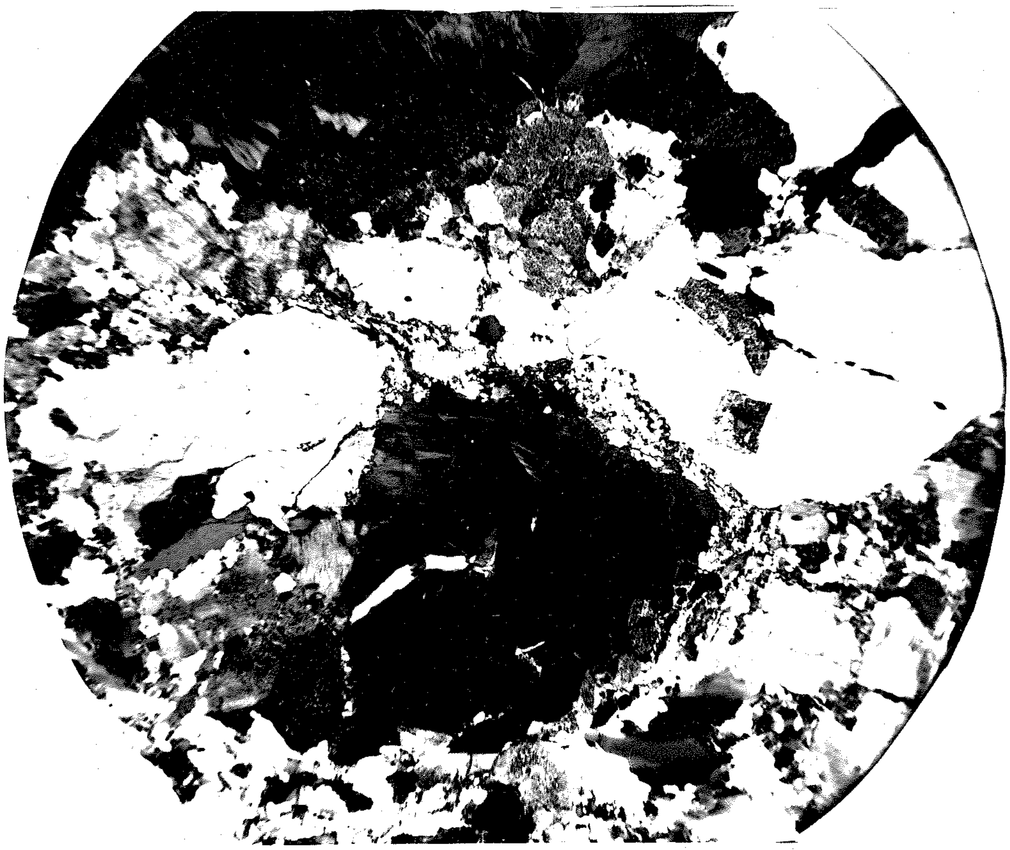
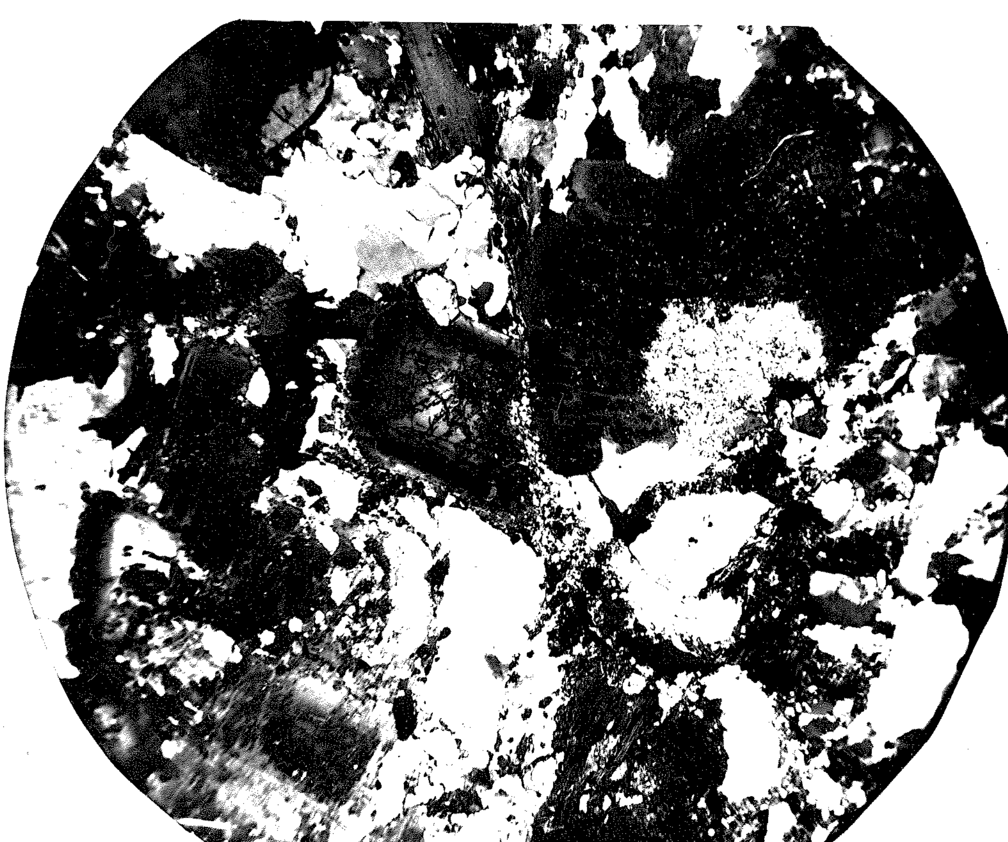


PLATE LXXIII





narrower and narrower until it finally dwindles out to a rather indefinite termination within a grain or along grain contacts.

3. Usually a rock shows no other evidence of crushing or of mechanical deformation. Large grains may exhibit no cross-fractures, the twinning lamellae of plagioclase may not be bent or broken, primary minerals may not be cracked or torn. The interstitial quartz usually shows a peculiar uneven extinction which, however, is often typical of "flamboyant" quartz of true veins which has undergone no great pressure. The quartz of the veins is usually in aggregates of small interlocking grains. These aggregates are usually elongated but the individual grains are as frequently round as elongated.

On the other hand, pseudo-cataclastic texture may be accompanied by indications of an earlier period of crushing or shearing. Sometimes the veins appear to follow or be directed by fractures formed in this way. In such cases we find bent or broken twinning lamellae, tears in feldspar healed by sericite or albite or quartz, primary quartz with abnormal biaxial character and similar criteria. It is evident, therefore, that this texture, and probably also the phenomena associated with it, was developed after the igneous mass had assumed sufficient rigidity to offer resistance to forces of deformation. It should be borne in mind, however, that this degree of solidification may have involved only a comparatively thin outer crust of the magma which, of course, would be the first to be chilled and crystallized. There seems to be good reason for believing that nowhere in the batholith are rocks exposed which may be relied upon to represent even approximately its inner composition and structure. Except in the central part of the range intrusive rocks are nowhere exposed which are far removed from contacts with the earlier sediments. The extensive development of aplite and of fine grained granite everywhere along the crest of the mountains indicates that this was the approximate position of the batholitic roof, now stripped of its cover by erosion. If this is true, and if we can consider that the crests of the interstream ridges are likewise approximately representative of the transitional slopes to the margins as now exposed near the flanks of the range, the greatest distance from the borders of the intrusive mass at which it would be possible to obtain a specimen would not be far from that represented by the depth of the deepest canyons. At most this cannot be considered to be more than two thousand feet and it may be less.

I have hoped to make clear and to emphasize in the foregoing descriptions that in the White Mountain rocks we are dealing with a profound alteration of a large igneous mass of which the cause, if known, would have important bearing upon our fundamental theories of petrogenesis. The metasomatic replacement of albite for potash feldspar, the formation of myrmekite, the development of the pseudo-cataclastic texture with the associated influx of sericite, epidote, biotite, quartz and other minerals either alterations of the primary feldspars or as independent interstitial occurrences, are part and parcel of the same or continuous processes. These processes, so far as we can estimate in the absence of analytical data, involve chiefly the addition of large amounts of soda, silica and mineralizers, including water, possibly also some calcium and iron, and the liberation of potash, part of which was probably consumed in the formation of sericite and biotite.

The statement has been made that changes of this sort and their resulting textural peculiarities, while not rare, are not common in intrusive rocks. This must be qualified by the admission that many more cases may occur than have been correctly described and interpreted. Fenner, for example, has pointed out that most writers in this country have described true myrmekites as micropegmatites.[1] I also regard it as probable that examples of pseudo-cataclastic texture have frequently been mistaken for true mortar or mylontic texture.

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1. Fenner, C. N. - The Katmai Magmatic Province, Journ. Geol. Vol. 34, 1926, p. 754. Note

DISCUSSION OF THEORIES OF REPLACEMENT.

The importance of alterations and replacements (other than those brought about by weathering) in the history of igneous rocks has only recently been fully recognized. It has only been within the last few years that we have heard of "deuteric phenomena" and of "post-consolidation processes". The hydrothermal origin of serpentime and epidote has not long been established. Yet now we have men like Schaller[1] and Hess[2] who suggest an origin entirely by replacement for pegmatites. Schaller even is inclined to believe that the "pre-existing graphic granite" from which the pegmatites he describes are said to have originated is itself the product of another type of replacement of a still earlier formed rock, and he goes on to suggest that pure albite, hornblende and mica as well as aplites have a replacement origin.[3] He asks; "Is replacement in rocks in general a much more widespread feature than is now believed?"

Fenner also has advocated a very large role for replacement in the origin and differentiation of igneous

1. Schaller, W.T. - The Genesis of Lithium Pegmatites, Amer. Jour. Sci. 5th Ser. Vol. 10, 1925, pp. 269-279.
2. Hess, F.L. - The Natural History of Pegmatites, Eng. & Min. Jour. Vol. 120, No.8, 1925.
3. Schaller, W. T. Loc. op. cit. pp. 276 and 279.

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3. Schaller, W. T. Loc. op. cit. pp. 276 and 279.

PLATE LXXIV

Description of figures.

Fig. I. This is part of the same field shown in Plate LXXI, Fig. I. The myrmekitic structure is somewhat more clearly shown than at the higher magnification. Crossed nicols. X 10.

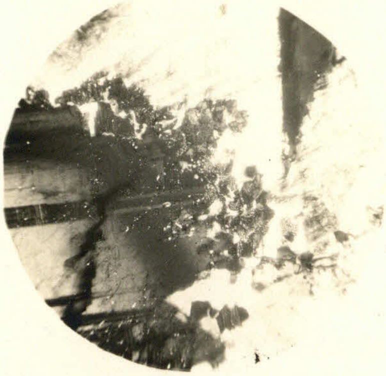
Fig. II - This is the same field shown in Plate LXXIII, Fig. I, included here inadvertently. Crossed nicols. X 10.

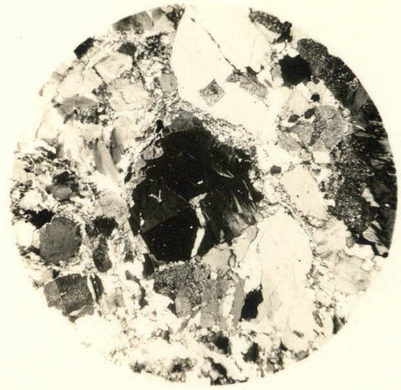
Fig. III - Because of incorrect orientation this photomicrograph doesnot show clearly the relationships apparent in the section itself. The two large grains at extinction which occupy the left half of the field are perthites in which the albite patches and lamellae are clearly of replacement origin. These, as may be faintly seen in the photomicrograph, all exhibit typical albite twinning. Crossing the perthites are "veins" which coalesce with the larger "vein" nearly vertically across the field. These veins all contain quartz, microcline, and biotite, and where they are contiguous to microcline, they are fringed with myrmekites. To the right of the large vein is a zoned plagioclase. Crossed nicols. X 10.

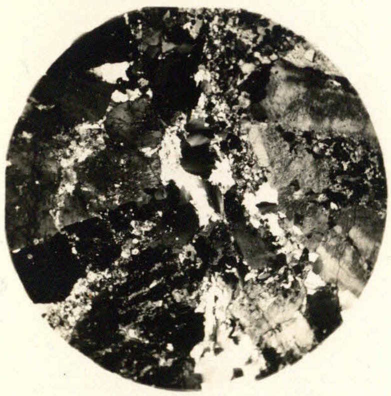
Fig. IV - In the upper left quadrant is a grain of microcline in the earliest stage of albitization. In the upper right is a grain of orthoclase. Below and to the left are grains of quartz. The vein passing through the center of the field is composed mostly of sericite with a little quartz and a few grains of magnetite. Notice how the "vein" narrows down and almost pinches out near the center of the field, and expands, divides, and ramifies above and below. This is characteristic of the "veins" of the pseudo-cataclastic texture. Crossed nicols. X 22.

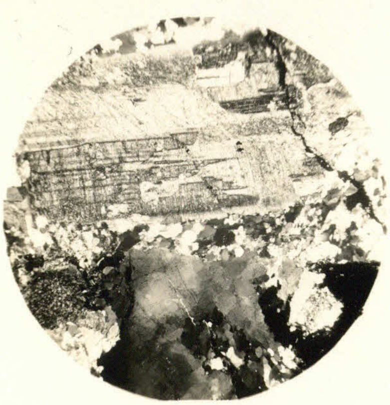
Fig. V - In the upper part of the field is a large grain of plagioclase; below is another of quartz. Between the two and extending across the field from left to right is a "vein" composed entirely of fine-grained quartz except that where it borders the large quartz grain there is a thin stringer of sericite along its entire length. Outside of the field the vein also contains epidote. Crossed nicols. X 10.

Fig. VI. Perthite below, sericitized plagioclase in upper right. Across the field from upper left to lower right is a "vein" of quartz, biotite, and magnetite. Crossed nicols. X 10.









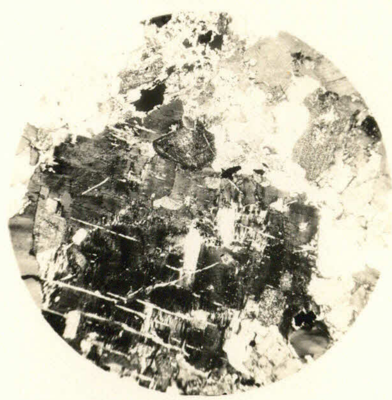


PLATE LXXIV

Fig. I

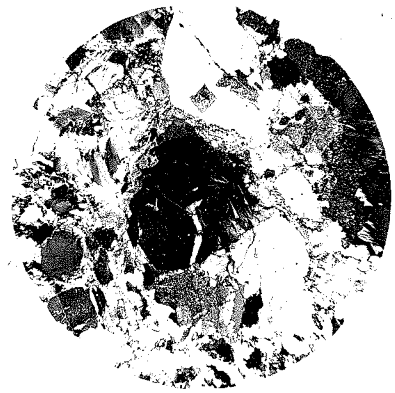


Fig. II

Fig. III

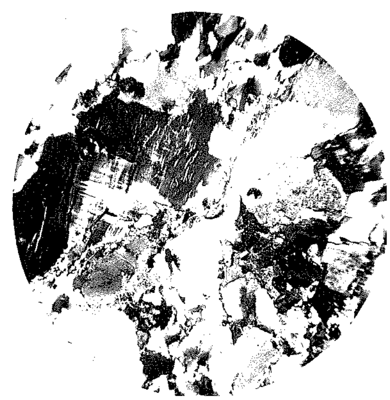


Fig. IV

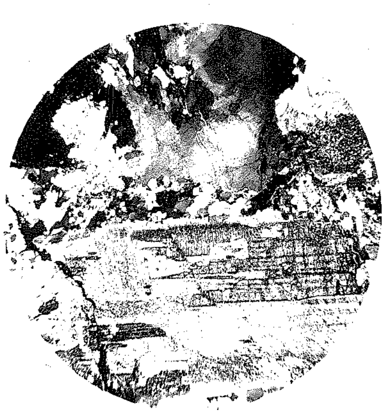


Fig. V

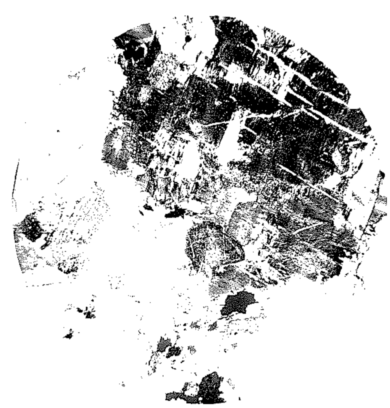


Fig. VI

rock types. Circulation of solutions and the transfer of materials and maintenance of heat by the "streaming of gases" have been assigned a prominent place in this process, which involves also the assimilation of contact rocks.[1]

Many writers have considered such intergrowths of quartz and feldspar as micropegmatites and graphic granites to be of eutectic origin. Vogt makes use of this structure in an attempt to substantiate his view that granites are of "anchi-eutectic" composition and represent a simultaneous crystallization at the ternary eutectic SiO_2; or Ab+An.[2] Lindgren, however, has noted in the study of polished surfaces of ores that mineral intergrowths of similar appearance are of replacement origin.[3] Other authors, including Warren and Palache,[4] Bastin,[5] and Fenner[6] have questioned the eutectic origin of these intergrowths in igneous rocks.[7] The idea

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1. Fenner, C.N. - The Crystallization of Basalts - Amer. Jour. Sci. 5th Ser. Vol. 18, 1929, pp. 225-253; The Katmai Magmatic Province, Jour, Geol. Vol. 34, 1926, pp. 718-760.
2. Vogt, J.H.L. - Die Genesis der Granite, physiochemisch gedeuted Zeitsch der Deutschen Geol. Gesellschaft. Band 83, Heft 4. 1931. Seite 193-214. See also Vogt, Die Sililatschmelzloesungen, Christiania, 1904, Vol. II. p.123.
3. Lindgren, W. Pseudo-eutectic Texture, Econ. Geol. Vol. 25, 1913 pp. 1-13.
4. Proceedings of the American Academy of Arts and Sciences, Vol. 47, 1911, p. 147.
5. Bastin, E.S. - Origin of the Pegmatites of Maine, Jour, Geol. 18, 1910, p. 132.
6 Fenner, C.N. - Significance of the Word Eutectic, Jour. Geol. 38, 1930, p. 164; 1910, p. 132.
Also Fenner, The Katmai Magmatic Province, Jour. Geol. Vol. 34, 1926, p. 750.
7. It is interesting to note that even Vogt in the article on the origin of granites in attempting to explain certain departures in observed occurrences from expectable conditions assumes that silica may in part exist in magmas in combination as $SiO_2 \, nH_2O$ and as such does not enter into or influence primary cry-

Of a eutectic origin for graphic and micropegmatitic textures seems to have been borrowed from metallography. Although the possible importance of eutectics in petrogenesis is not to be denied, graphic intergrowths and similar textures may certainly often be of replacement origin.

Students of ore deposits have long recognized the importance of replacements in their field of study. The fact being no longer questioned, effort is now directed toward establishing criteria for distinguishing between "hypogene" and "supergene" replacements. Butler has recently ventured to suggest the physico-chemical processes connecting wall rock alteration and deposition in veins with the formation of intrusive bodies,[1] and to explain these in the light of modern petrogenic theory.

As a further indication of the place which replacement is coming to assume in petrogenic thought we may point to the fact that Gillson has recently suggested that albitization may be the key to the origin of alkaline rocks, concerning which there has been so much controversy in recent years. Gillson believes[2] "that the process of albitization, now known to be a common accompanying feature of granitic intrusion, furnishes a key to the genesis of alkaline rocks.

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stallization but that with relief of pressure during the late stages of consolidation the water may escape and the silica be set free to form pegmatites or to produce such changes in the rock itself as myrmekitization. This would seem to indicate that he believes in a replacement origin for such structures as myrmekite.

1. Butler, B.S.- Influence of Replaced Rock on Replacement Minerals Associated with Ore Depositions. Econ.Geol. Vol. 27, 1932, pp. 1-25

2. Gillson, J.L.-Origin of Alkaline Rocks, Jour, Geol. Vol.36, 1928, pp. 471-474.

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the passage of emanations rich in soda and alumina, which albitization phenomena show have occurred, may in favorable instances have desilicated a granitic magma and so enriched it in soda and alumina that nephelite would crystalize, and, after consolidation, soda-rich deuteric minerals form."

SOURCE OF MATERIALS:

If we are to assign such important effects to albitization and similar phenomena we must inquire, first, from what source soda, silica and other materials may be derived in sufficient quantities to produce such changes and, second, how and why the transformations have been produced.

At least three possible sources of material have been suggested by different authors. The first view, which is probably the one most generally held in this country, is that the chemical substances in question are normally concentrated as a result of the ordinary course of crystallization and differentiation in the end-stage liquids of the magma until, reaching such a concentration that they become highly corrosive, in some manner not made entirely clear, they begin to attack and replace the earlier formed minerals during or shortly after the final consolidation of the rock. This has been called "autometamorphism."[1]

A second view, advanced by a large group of eminent geologists and petrographers, is that the necessary

1. Sargent, H.C.- Quat. Journ. Geol. Soc. Vol. 73, 1918, p.19.

PLATE LXXV.

Description of figures.

Fig. I - Just above and to the left of the center of the field is a grain of microcline crossed by tiny veins of albite. Below, left and right, are grains of plagioclase with only a faint suggestion of twinning, considerably sericitized. On the right side of the field is recrystallized quartz. All of the primary grains are bordered by "veins" or secondary matrix containing sericite, quartz, epidote and magnetite. Note the frayed, regged outlines of all the primary grains. Crossed nicols. XIO.

Fig. II - Primary grains of microcline, orthoclase and albite with interstitial "veins" (secondary matrix) chiefly of sericite and albite with little quartz and no myrmekite. There has been some mechanical crushing of the rock preceding the replacements, as is indicated by fracturing of some of the grains and the bending and breaking of the twinning lamellae of some of the plagioclases. Crossed nicols. XIO.

Fig. III - Grains of microcline (dark, upper left) orthoclase and plagioclase in a secondary matrix consisting chiefly of quartz, chlorite, epidote and microcline. Fringes of myrmekite border the matrix where it touches primary potash feldspar. Crossed nicols. XIO.

Fig. IV - "Injection perthite" in syenite. The albite rim (white) of the grain of microcline (dark) in the center of the field is continuous with the interstitial veins of the pseudo-cataclastic texture. The primary minerals of the rock are chielfy orthoclase, microcline and albite. The secondary matrix contains albite, chlorite and calcite. There has been some mechanical crushing of the rock preceding the infiltration by replacing solutions. Crossed nicols, XIO.

Fig. V - Advanced stage of pseudo-cataclastic texture in granite. The primary grains are potash feldspar and plagioclase with a little quartz. The secondary matrix contains quartz, sericite and chlorite with a little magnetite. The middle of the veins is quartz; the borders are chlorite or sericite. Crossed nicols. XIO.

Fig. VI - The large grain at extinction in the middle of the field is a perthite orthoclase in a secondary matrix consisting of quartz, epidote and a little microcline. The grain has been fractured, apparently by mechanical pressure and the fracture healed with quartz and epidote. Crossed nicols. XIO.

~~Photomicrographs~~ by the author.

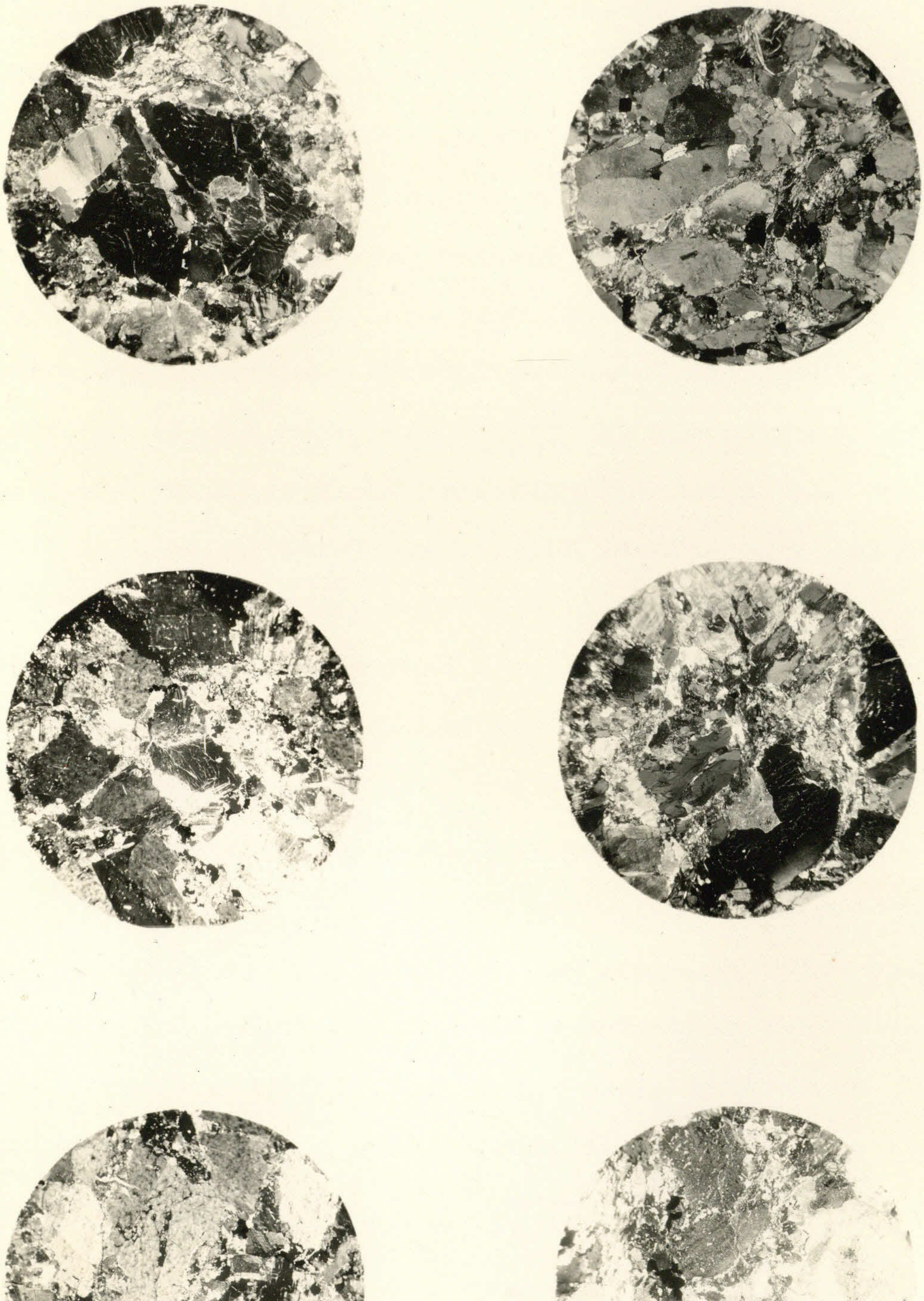

PLATE LXXV.

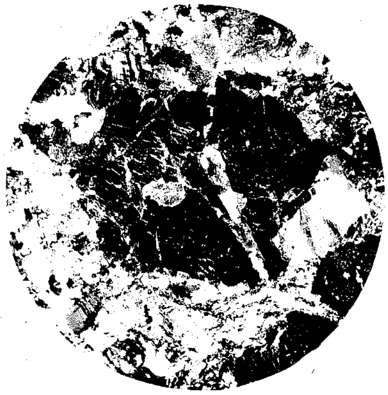

Fig. I

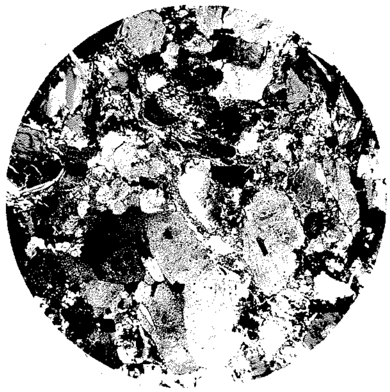

Fig. II

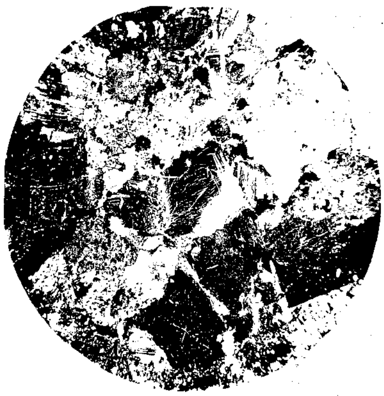

Fig. III

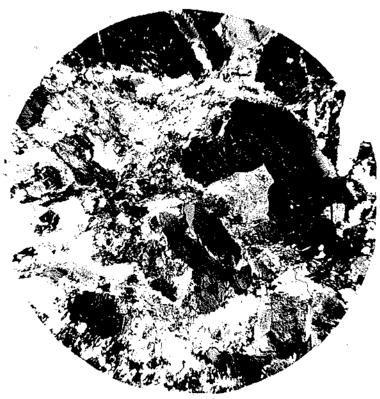

Fig. IV

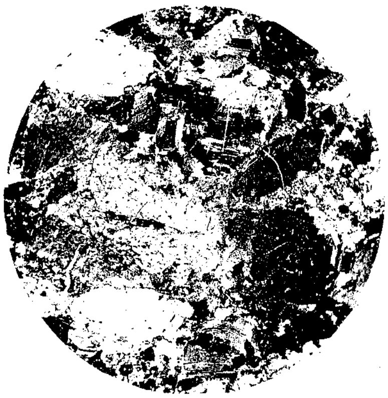

Fig. V

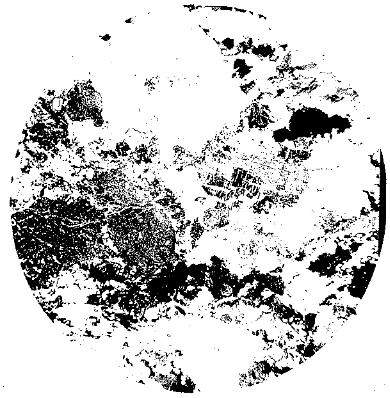

Fig. VI

materials are obtained by the assimilation into the molten magma of sediments or older igneous rocks rich in whatever substances appear to have been added. Thus, for example, sandstones or conglomerates might directly yield silica, or, less directly, the absorption of calcareous rocks, particularly carbonates, might result in the desilication of the magma, by using up the available supply of silica to form basic palgioclases and, setting free alkalis which would otherwise go to form the polysilicic feldspars, make them available either for the albitization and sericitisation of the already solidified portions of the rock mass or for the formation of the nephelite and leucite of the true alkaline rocks.

A third possibility is that many large masses of granite are really results of replacement and that what we observe in textures and structures of the type we are considering are in fact either the initial or the incomplete or interrupted stages of such replacement. Such a process might be preceded or accompanied by a partial refusion of the earlier rock.[1] In such cases the new materials might have been either original components of the replaced rocks themselves, leached and redeposited by the penetrating solutions, or they may have been derived from a subjacent molten mass. This process would be in some degree related to the anatexis of

1. See Sederholm, J.J.-On Migmatites and Associated Pre-Cambrian Rocks of Southwest Finland, Parts I and II. Bull. de la Com. Geol. de Findlande Nos. 58 and 77; Quirke, T.T. and Collins, W.H. -The Disappearance of the Huronian, Can. Geol. Surv. Mem. 160, 1930, pp. 1-112; Grout, Frank F.-Petrography and petrology, New York, 1932, pp. 188-189.

Sederholm.[1] It might also be considered to represent an extension of the view of Barrell, who held that recrystallisation in schists and gneisses is largely the result of reaction with the emanations from subjacent batholiths.[2]

Let us return now to consider the first of these possibilities in more detail. Bowen has shown that in a melt from which mix-crystals (if we may use this somewhat misleading term) of the albite-anorthite series are forming at a given temperature the liquid is always very much richer in albite than the crystals with which it is in equilibrium.[3] If the cooling of such a melt is slow enough and viscosity is not too great, the crystals will be worked over as the temperature falls so that they are brought into equilibrium with the liquid at each new point on the thermal diagram. Crystallisation will finally cease at the point at which the crystals formed represent the composition of the original liquid.

This ideal situation, however, is seldom realised in a magma. Cooling may proceed so rapidly that there is not time for the liquid to react with the earlier formed crystals and to bring them into equilibrium under the new conditions and and zoning of crystals will result unless the fall of temperature is so fast that undercooling takes place and a porphyritic texture is developed. On the other hand, if cooling is so slow

1. Sederholm, J. J. -On Regional Granitisation (or "Anatexis") Comptes Rendus, 12, 1913, p. 319-324.
2. Barrell, J. -Relation of Subjacent Igneous Invasion to Regional Metamorphism- Amer. Journ. Sci. 5th Ser., Vol. 1, 1921, pp. 1-19, 174, 186, 255-267.
3. Bowen, N. L. -The Melting Phenomena of the Plagioclase Feldspar- Amer. Jour. Sci. 4th Ser. Vol. 35, 1913, pp. 583-597.

that there is no zoning there is a considerable opportunity for the sinking of the heavier more basic plagioclases into the deeper parts of the magma chamber.[1] In either case, whether by zoning or by the sinking of the earlier formed plagioclases, the composition of the liquid is continually offset toward pure albite. It is normal, therefore, for an increasing enrichment in albite liquid to take place as solidification proceeds.

Concentration of silica in the residual liquors also commonly occur. It has long been stated that the presence of mineralizers, including water, tend to keep silica from crystallizing out as quartz until the end of the magmatic period is reached and it may in some cases keep it in solution even in the presence of orthosilicates such as olivine.[2] Vogt postulates the existence of a compound $SiO_2\ _nH_2O$ which remains liquid and stable until sufficiently low pressure is obtained to permit escape of the water, (See above, page footnote). Iddings reached a similar conclusion.[3] Bowen, however, questions the importance of water and other volatiles in keeping silica in solution and points to the fact that "every dry system investigated in which SiO_2 is one of the components has shown free silica as one of the solid phases separating at the lowest eutectic . . . . In many of these cases the eutectic mixture which has silica as one of its

1. Bowen, N.L. Later Stages in the Evolution of Igneous Rocks, Jour. Geol. Vol. 23, 1915, p. 33; Bowen- The Evolution of the Igneous Rocks, Princeton, 1928, pp. 33-34.
2. Dr. Rene Engel has evidence that the aqueous silica phase has been the effective agent in the silicification of old sediments in the Elsinore region of Southern California. Personal Communication.
3. Iddings, Igneous Rocks, Vol. 1, New York, 1909, p. 142.

solid phases is the only eutectic, the realtion between the other compounds being of the reaction type, so that with fractional crystallization this composition acts as the eutectic for the whole system, including even mixtures which originally have no free silica, stoichiometrically, This reaction relation between compounds, is, of course, due to the incongruent melting of one of them and in every case yet noted the compound breaks up in such a way as to cause a separation of a more "basic" compound and consequent throwing off of free silica into the liquid."[1]

The degree of enrichment will depend upon such factors as rate of cooling and viscosity. In any case, however, it is logical to expect that the changes in the composition of the magma toward the end of the consolidation period may produce important reversals in paragenetic relationships.

If the process proposed and advocated by Bowen is the chief reason for the concentration of albite, silica and other residues in the end-stage liquids, two conditions may exist. Either these liquids may remain disseminated throughout the igneous mass, penetrating everywhere between the earlier formed grains, as water in a sponge, or, by the earlier complete solidification of parts- perhaps the outer margins - of the intrusive body or perhaps by some form of filter-pressing they may become concentrated in some

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1. Bowen, W.L. The Evolution of the Igneous Rocks, p. 298.

part of the magma chamber remote from the earlier formed portions of the rock. Here they remain under constantly increasing pressure until the stresses become so great that they are forced out either along newly formed joints or fractures, where they crystallize as pegmatites or along the contacts between the mineral grains of the surrounding rock. Grout states that "Just as the gaseous emanations from the deep parts of a chamber may be introduced into the earlier upper rocks of the chamber, so this late, residual, filter-pressed magma may modify some of the earlier rocks by a sort of introduction, hardly to be distinguished from deuteric reaction."[1]

The former condition is apparently the one pictured as existing by most of the men who have written on "deuteric" or "post-consolidation" phenomena. It is the simplest and most direct method by which end-stage reactions may take place. It may be the process actually followed in many or even most cases. In the problem we are considering, however, it does not apply, for the evidence clearly shows that the reactions did not take place until after the formation of pegmatites and until after a moderate amount of dynamic metamorphism had taken place - that is, until long after the final consolidation of at least the parts of the batholith now exposed to view. Moreover, there is every reason to believe that the solutions which produced such profound changes carried in considerable amounts of material

1. Grout, Frank F.- Petrography and Petrology, New York, 1932, p. 252.

PLATE LXXVI.

Description of figures.

Fig. I - All of the field except the veins is microcline partially replaced by albite in "patch perthite" arrangement. The "veins" are of quartz, sericite and albite. Crossed nicols. X10.

Fig. II - The light grain in the upper part of the field is an almost completely albitized microcline with only faint vestiges of microcline twinning remaining. The degree of albitization seems to become more complete as the outer borders are approached. The "vein" which crosses the field from upper left to lower right is composed of sericite, epidote, albite and a little quartz and is fringed with myrmekite where it borders the (primary) potash feldspar. Crossed nicols. X22.

Fig. III - Early stage pseudo-cataclastic structure. The veins which are seen crossing the field are composed of quartz and albite and are fringed with myrmekite. The primary grains are albitized potash feldspar, plagioclase, biotite and quartz. The fibrous grain just above and to the left of the center of the field is biotite. To the right of the biotite is a grain of plagioclase. Most of the other grains are replacement perthites. The "veins" cross all the primary grains without change in composition or character. Crossed nicols. X10.

Fig. IV - Pseudo-cataclastic texture in pegmatite. Most of the field consists of potash feldspar, partially replaced by albite (patch and vein perthite). The light-colored grains in the upper half are quartz. The large "vein" descending from the upper left to the bottom of the field is of quartz bordered with sericite. The veins in the right side of the field contain only sericite. Crossed nicols. X10.

Fig. V. - All of the large grains in the field are of almost completely albitized potash feldspar. The interstitial matrix ("veins") contain quartz, albite and a large amount of biotite in small flakes. Crossed nicols. X10.

Fig. VI. - The large grains are mostly "patch and vein" perthites in which the albitic portions are seen under the microscope to possess albite twinning. The interstitial "veins" consist of albite and quartz with some myrmekite on the borders. Two quartz aggregates are seen at the right and left. Crossed nicols. X10.

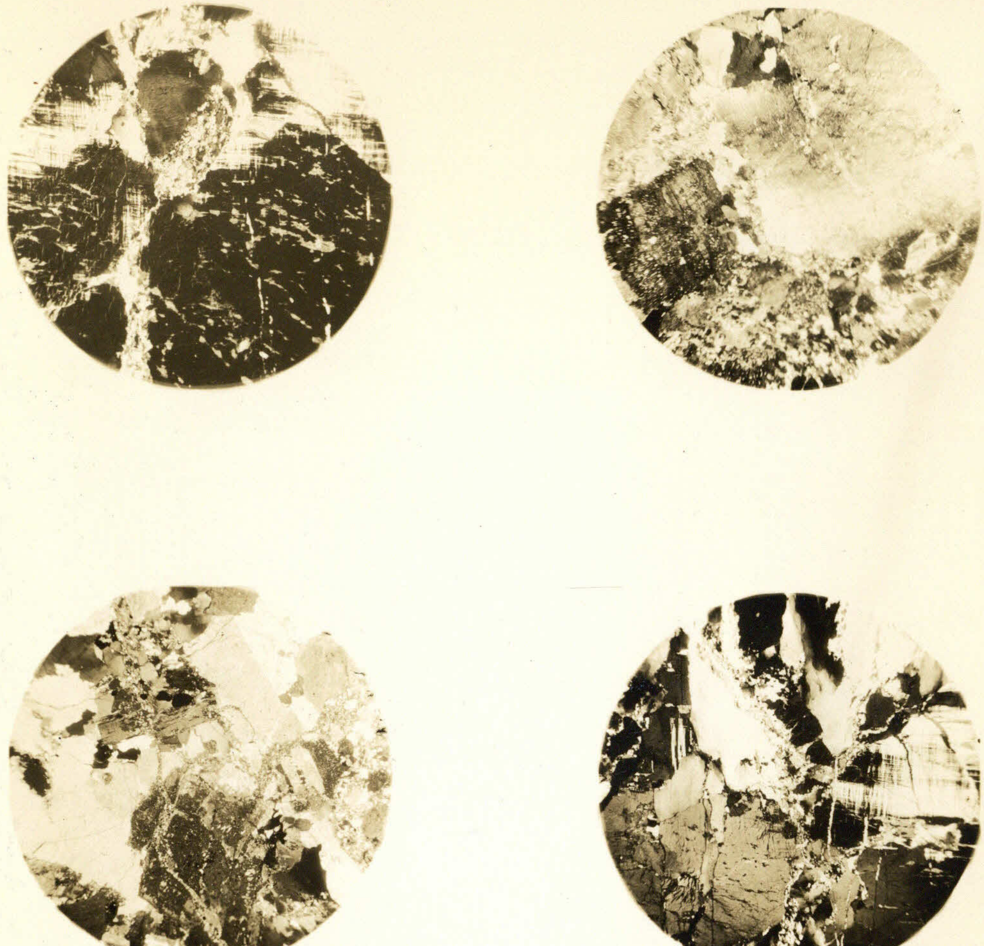

PLATE LXXVI

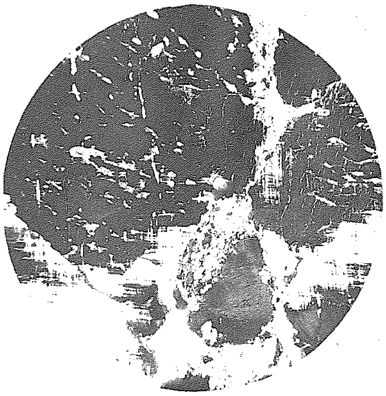

Fig. I

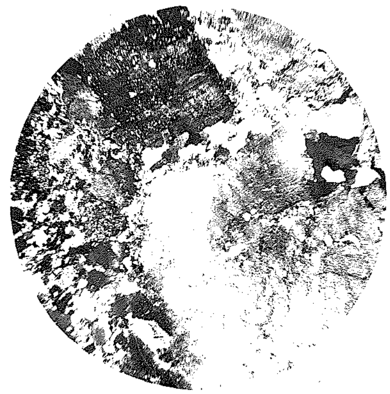

Fig. II

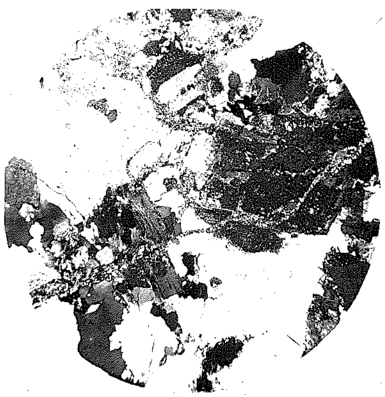

Fig. III

Fig. IV

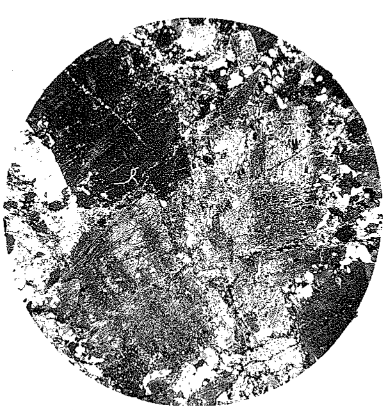

Fig. V

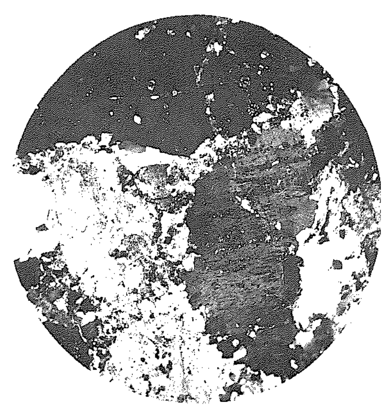

Fig. VI

from some source outside the field of reaction.

It is not easy to obtain a clear conception of how the concentration of end-stage materials in some remote portion of the magma chamber takes place. Crystals cannot contime to grow to completion except in the presence of liquid. If they are less dense than the liquid with which they are in equilibrium they might use up all available space in a given part of the batholith before all the liquid was exhausted and so force the remaining part out. This would have to be accomplished against tremendous pressures, for it seems probable that the magma fills its entire chamber under great hydrostatic head. If the crystals have a greater density than the liquid, which is more likely, their formation would increase rather than decrease the available space. Bowen states that solution of silicates usually takes place with increase of volume.[1] Crystallization, therefore, would be accompanied by a decrease of volume. Additional fluid material would then be forced in to fill the voids until crystallization became complete. If this holds true, then the last crystals to form in any part of the mass would be representative of the composition of the end-stage liquids for that particular stage of development. If crystallization proceeds from the batholithic margins inward toward the center it would be possible, then, to distinguish zones across a section of an intrusive body, each characterized by a particular kind of composition of last-formed minerals.

1. Bowen, N.L.- Evolution of the Igneous Rocks. p. 183.

White Mountain region, let us consider the other suggestions which have been advanced to explain occurrences somewhat similar to this one.

Daly has long argued for the assimilation of basic sediments as a process leading to the origin of alkaline rocks.[1] This view has been briefly summarized on page . The rocks with which we are dealing are not true alkaline rocks but, as Gillson has suggested,[2] albitization such as they have undergone may be an introductory step in the formation of alkaline rock. We cannot, therefore, neglect this as a possible explanation. The theory is an attractive one inasmuch as it provides a direct source of whatever materials are needed to complete the reaction. By postulating the absorption of arenaceous sediments or highly siliceous igneous rocks we can get any amount of enrichment in silica.[3] Similarly we can obtain alumina and sodium from shales but the quantities of the latter are probably insufficient to meet the requirements. Water, of course, may be had from nearly all rocks.

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1. Daly, R.A.-Genesis of the Alkaline Rocks.-Jour.Geol.Vol.26, 1918, pp. 97-134.
2. Gillson, J.L.- Origin of Alkaline Rocks.-Jour. Geol. Vol. 36, 1928, pp. 471-474.
3. Daly, R.A.-Secondary Origin of Certain Granites. Amer. Jour. Sci. 4th Ser. 1905, pp. 185-216.
4. Shand, S.J. -Limestone and the Origin of Feldspathoidal Rocks, Geol. Mag. Vol. 67, 1930, pp. 415-427.
5. Coleman, A.P.-The Sudbury Laccolithic Sheet, Jour, Geol. Vol. 15, 1907, p. 759.

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Daly has not been alone in defending the theory of assimilation of invaded sediments. Shand has been a particularly strong advocate of the idea.[4] Coleman has given

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1. Daly, R.A.-Genesis of the Alkaline Rocks.-Jour. Geol. Vol. 26, 1918, pp. 97-134.
2. Gillson, J.L.-Origin of Alkaline Rocks,-Jour. Geol. Vol. 36, 1928, pp. 471-474.
3. See Daly, R.A.,-Secondary Origin Origin of Certain Granites, Amer. Jour. Sci. 4th Ser. 1905, pp. 185-216.
4. Shand, S.J. Limestone and the Origin of the Feldspathoidal Rocks, Geol. Mag. Vol. 67, 1930, pp. 415-427.

If pressure from without has compelled the withdrawal of the end-stage liquids from the immediate scene of crystallization it must have involved only a part of the mass or it must have forced the fluid portion into some opening outside the main magma chamber into which the already formed crystals could not follow it. This is the method of origin which Bowen has postulated for the mono-minerallic rocks.[1] It would seem likely, though not altogether necessary, that if this process had been effective in such a case as this the effects would be apparent either in the structure of the mass or in the appearance of the last crystallized minerals approaching the composition of the end-stage fluids, for, as Bowen admits, no reasonable amount of pressure could force out all of the interstitial liquid.

Whatever the source and nature of the forces which may have acted to induce concentration of end-stage fluids in a given space, if conditions later become such as to favor the permeation of the already solid portions of the batholith by them with resulting replacements and alterations, we might reasonably expect the effects to be most pronounced in the immediate vicinity of the place of concentration and least pronounced around the periphyry of the igneous body, unless, of course, they were guided by such special structural conditions as fracture zones.

Before we attempt to decide how well this process of concentration explains the facts observed in the

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1. Bowen, N.L. Evolution of the Igneous Rock, p. 167.

normal processes possible in the absence of foreign matter. He admits, however, that magmas may incorporate considerable quantities of foreign inclusions by reactive solution and reactive precipitation and he thinks that in certain cases the process may have been important in the formation of individual rock masses, even granting that some alkaline rocks may have been so derived.

If a certain amount of melting of invaded rocks is possible for basaltic magmas, however, it is less so for magmas of granitic composition, for it is thought that the latter must be near saturation; otherwise they could not have been differentiated by the process of fractional crystallization. It must be noted, however, that this assumption rest upon the belief that differentiation took place somewhere near the surface and that no heat has been added since the splitting occurred. It is by no means certain that these beliefs are correct. But even if we admit that melting-in cannot occur, it is still possible for the magma to react with the constituents of the invaded rocks and make them over into phases similar to those with which it is saturated.[1]

In considering the phenomena of assimilation, moreover, sufficient stress has not been placed upon the solution point of view. An acidic magma has a greater reacting or dissolving power than a basic one. This arises from the

1. Bowen, N.L. Evolution of the Igneous Rocks. 1928, p. 221.

evidence for believing that impregnation and solution of conglomerates has given rise to micropegmatite at Sudbury,[1] and Bain has substantiated this view.[2] Lacroix[3] argued in favor of assimilation of sediments on a large scale. Similar absorptions seem to have taken place in the Haliburton-Bancroft Area in Canada,[4] in the West Point area of New York,[5] and in many other places. In connection with our study it is important to note that Sederholm has strongly emphasized the relationship between contact phenomena and the formation of such intergrowths as myrmekite.[6]

Bowen has opposed the idea that much assimilation of wall rock material commonly takes place on the ground that magmas in the upper part of the lithosphere do not possess a sufficient amount of superheat to effect much melting of cold border rocks.[7] He points out that reactions between the materials of the invaded rocks and the magma may take place under certain conditions, depending upon the point reached in the reaction series in the course of the magmatic crystallization, but that these would in most cases only emphasize

1. Coleman, A.P. - The Sudbury Laccolithic Sheet, Jour. Geol. Vol. 15, 1907. p.759.
2. Bain, G.W. - Amount of Assimilation by the Sudbury Norite Sheet Jour. Geol. Vol. 33, 1925, p. 5-9.
3. Lacroix, A. Le granite des Pyrenees et ses phenomenes de contact. Carte Geologique de France, Tome 10, #65, 1898-99 and Tome 11, no. 71, 1899-1900
4. Adams, F.D. and Barlow, A.E. - Geology of the Haliburton and Bancroft Areas, Can. Dept. of Mines Mem. No. 6, 1910, p. 87 ff.
5. Berkey, C.P. and Rice, Marion, - Geology of the West Point Quadrangle, New York State Museum Bulletin, No. 225, 1911, p.29, ff
6. Sederholm, J.J. - On Synantetic Minerals, Bull. de la Com. Geol. de Finlande, No. 48, 1916.
7. Bowen, N. L. - Evolution of the Igneous Rocks, pp. 174-223.

fact that the heats of reaction of orthosilicates are greater than those of metasilicates. Among the metasilicates, iron metasilicate possesses a higher heat of reaction than the sodium metasilicate. Reactions, therefore, tend to proceed toward the basic end and the acidic end of the series is accordingly more reactive.

The presence of large amounts of water and and other mineralizers in granite magmas, may greatly affect their ability to dissolve and assimilate the rocks of their roof and walls even down to 570 degrees Centigrade.[1] It is an apparently well established fact that large concentrations of mineralizers occur in the contact zones of granitic rock and these may act as a flux, greatly lowering the temperatures necessary for the fusion of the mixed magma. Grout believes that "the field evidence of assimilation in granites is so strong that it may not only show the presence of some superheat in granite magma but may even serve as evidence that granite magma may form in some other way than by crystallization and separation from basalt magma." [2]

It is interesting to note in this connection that Holmes has recently rejected the idea that granite magma can arise by diffeentiation of basaltic magma and postulates that there are at least three kinds of "parent" magma: ultra-basic, basic and acid, and that granites and associated rocks are

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1. Eskola, Pentti,-On Contact Phenomena Between Gneiss and Limestone in Massachusetts; Jour. Geology, Vol. 30,1922, p. 292.
2. Grout, Frank F.-Petrography and Petrology, New York, 1932, pp. 227-228.

PLATE LXXVII.

Description of figures.

Fig. I.-Pseudo-cataclastic texture in granite. The feldspars in the field are all plagioclases and all are highly sericitized but have clear borders. The secondary matrix consists of chlorite, biotite, hornblende and a little quartz. Crossed nicols. X10

Fig. II.- The dark grain in the upper part of the field is altered microcline, the one to the left is orthoclase. The secondary matrix consists of quartz and biotite. Note how the secondary matrix has corroded and embayed the borders of the potash feldspar. Crossed nicols. X10

Fig. III.- Advanced stage of pseudo-cataclastic texture in granite. The large grains in the field are all plagioclase, partly sericitized. The secondary matrix consists of quartz, feldspar and a considerable amount of dark green hornblende. The dark grains in the field are nearly all hornblende. Crossed nicols. X10

Fig. IV.- Mechanical pressure as well as solution and reprecipitation appear to have taken part concurrently in producing the texture of this rock. The primary grains have been fractured and the twinning lamellae of some of the plagioclases bent or broken. The fragments have been recemented, however, by outside materials. Thus in the field shown relicts of primary plagioclase and potash feldspar are inclosed in a fine grained matrix of which quartz is the predominant constituent. Weaving in and out between the older grains from top to bottom of the field are stringers of biotite and sericite. Crossed nicols. X10

Fig. V.-An almost completed stage in the development of pseudo-cataclastic texture. A few ragged grains of microcline and plagioclase in a very fine-grained secondary matrix chiefly of quartz but containing also feldspars, chlorite, epidote and titanite. The last two are usually in euhedral grains. The potash feldspars shown in both Figures IV and V are, contrary to the usual case, only slightly albitized. Crossed nicols. X10

Fig. VI.-This is an especially instructive field showing an advanced stage of pseudo-cataclastic texture. Relict grains of albitized potash feldspar, plagioclase and quartz in a fine grained secondary matrix consisting mostly of quartz but with some feldspars and chlorite. Note that the twinning lamellae of the plagioclase grain in the center of the field show no indication of bending or breaking. Note also the embayment of the quartz grain (dark) in the upper right by the secondary matrix. There is no possibility of this kind of structure being produced by crushing ~~above~~. The same is true of the potash feldspar in the lower part of the field, where actual veining is to be observed. Crossed nicols. X10

Photomicrographs by the author.

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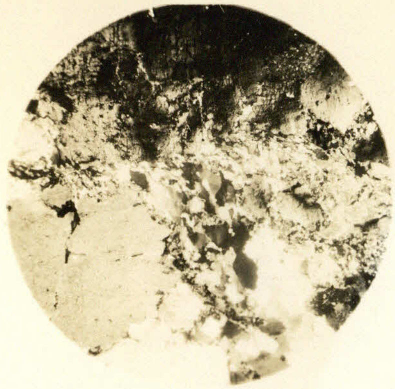
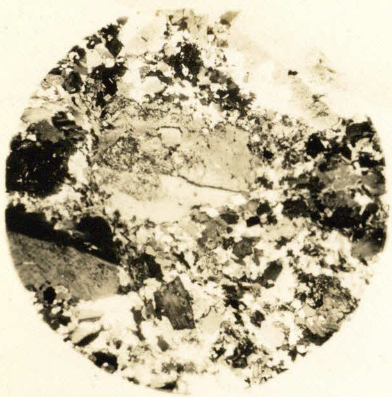
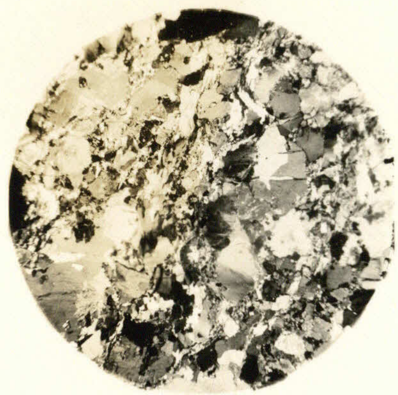
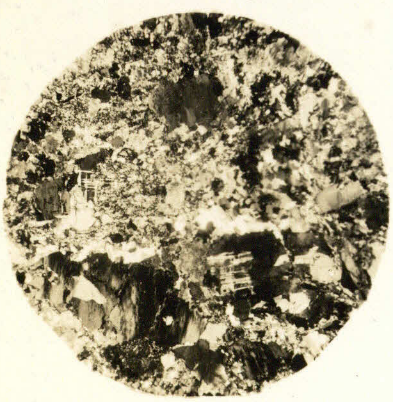
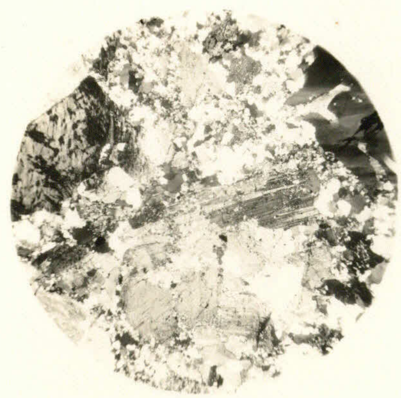






PLATE LXXVII

Fig I

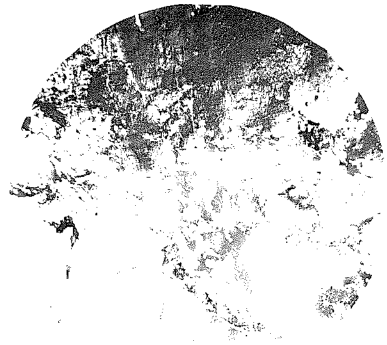


Fig. II

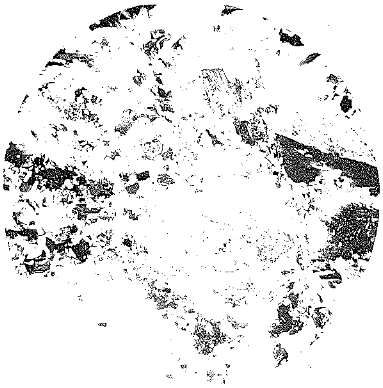


Fig. III

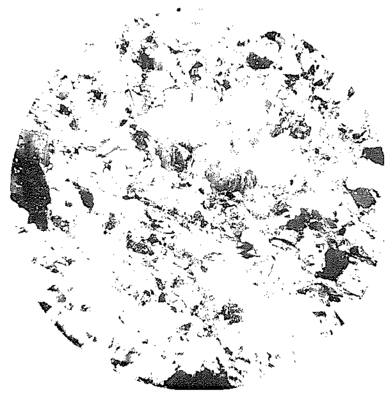


Fig. IV

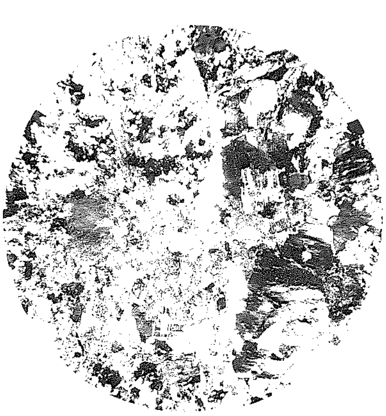


Fig. V

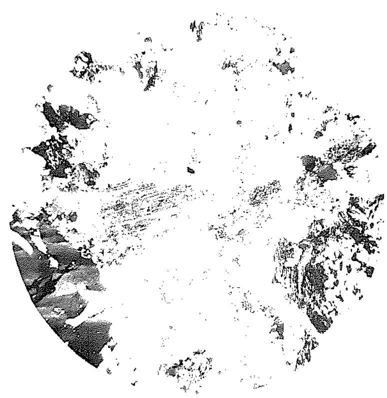


Fig. VI

derived by refusion of the upper-intermediate or upper layers of the earth's shell.[1]

Whatever opinions may be held concerning the nature of the reactions which occur at the contacts between granites and wall rocks, it is evident to any observer that profound modifications of both the invading and invaded rocks have often come into existence over wide zones and that these changes have been accompanied by very large transfers of material. This statement certainly holds true for the rocks of the White Mountain region. As has been pointed out above, it is nowhere possible to secure samples or study exposures at distances of more than two or three thousand feet from possible contacts with various types of sediments. The possibility that material derived from this source may have had much influence on the origin of the phenomena which we have observed, therefore, does not seem to be beyond the bounds of reason and is not to be neglected.

The transfer of material from magma to country rock in the contact zones, accompanied, perhaps, in some cases by a partial fusion of the latter, may grade into wholesale replacements or granitization of previously existing rocks. Sederholm has been one of the strongest advocates of occurrences of this kind.[2] The idea did not originate with Seder-

1. Holmes, Arthur,-The Origin of Igneous Rocks, Geol. Mag. Vol. 69, No. 882. (December 1932) pp. 543-558.
2. See Sederholm, J. J.-Uber eine archaische Sediment formation in Sudwestlichen Finland-Bull. Com. Geol. de Finlande, No. 6, 1899; Sederholm, Einige Probleme der prakembrischen Geologie von Fennoskandia, Geol. Rundschau, 1, 1910, pp. 126-135; Sederholm, Uber die Entstehung der migmatischen Gesteine, Geol, Rundschau, N,

holm, however, for the early geologists of the French school seem to have taught it and they were followed by Michel Levy, Lacroix, Termier, Dupac and others. It has been accepted by a number of German, Swiss and Austrian geologists including Grubenmann and Niggli.[1] It has been favorably received in America by such geologists as Barrell, Berkey, Daly, J.D.Dana, Fenner, Foye, Lawson, N.H. Winchell and many others. The theory has been accepted to some extent also in England and in Russia but most members of the German school are opposed to it.[2]

Not all of those who have been mentioned as favoring the theories of Sederholm would be willing to carry them so far as he has done. Most men, probably, would limit their application to the vicinity of known intrusive masses and would not admit that large bodies of rock with an apparently igneous origin have been formed in place from older rocks by a combined process of partial or complete fusion and replacement. Many degrees of reaction are possible, from those in which heat plays a prominent part to others in which thermal effects as such are negligible. "Even where lit-par-lit injections occur" says Grout, " pervasive emanations may extend beyond the zone of recognized igneous material." [3]

1913, pp. 174-185; Sederholm, Die regionale Unschmeltzung (Anatexis) erlautert an typischen Beispielen, Comptes Rendus, Congr. geol. internat. Stockholm, 1910, pp. 573-586; Sederholm, On Regional Granitization (or Anatexis) Comptes Rendus XII, Congr. Geol. Internat. Canada, 1913, pp. 319-324.

1. See Grubenmann, U. and Niggli, Paul, - Die Gesteins metamorphose 1, Berlin, 1924, pp. 322-368.

2. For a more complete summary see Sederholm, JJ. On Migmatites Part 1, Bull. de la Com. Geol. de Finlande, No. 58, pp. 1-17. An excellent bibliography is also contained in Grubenmann-Niggli die Gesteins-Metamorphose, 1, pp 322-324, 341-347.

3. Grout, Frank. F.-Petrography and Petrology, New York, 1932, p. 414.

PLATE LXXVIII.

Description of figures.

Fig. I. - Effects of albitization in granite. The grains in the field are "chess-board" albite, quartz and biotite. No other minerals are present in the slide except titanite in small amounts. Crossed nicols. X10.

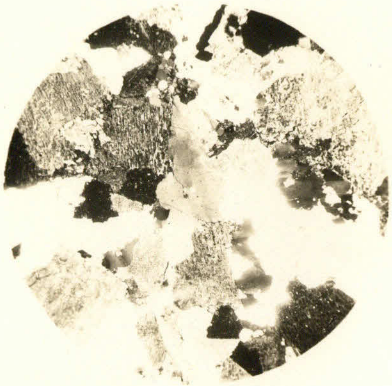
Fig. II. - Pseudo-cataclastic texture. The large (primary) grains are plagioclase highly sericitized within but each with a clear rim or border. The interstitial "veins" consist almost entirely of chlorite and epidote. Crossed nicols. X10.

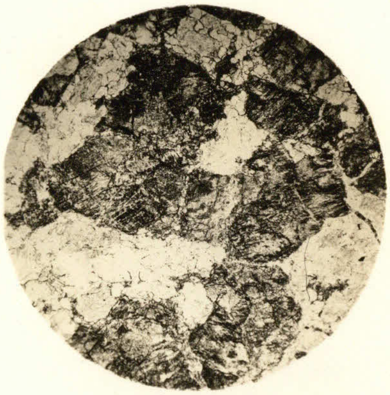
Fig. III. - Effects of albitization. The field contains quartz and potash feldspar. The latter is thoroughly streaked and spotted, probably as the result of albitization. Nicols not crossed. X10.

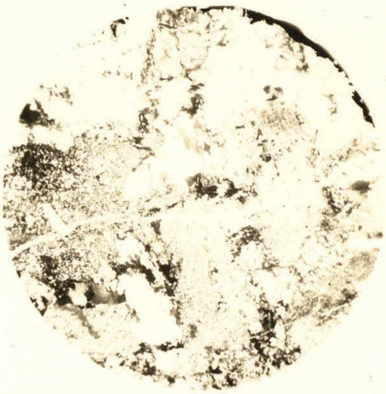
Fig. IV. - Effects of replacement in granite. The primary feldspars are so completely sericitized that their original character is no longer determinable. The interstitial "veins" (secondary matrix) consist of quartz and chlorite with a little epidote. Crossing the field from left to right is a vein of calcite. Crossed nicols. X10.

Fig. V. - Development of pseudo-cataclastic texture following mechanical crushing of the rock. Note the broken lamellae of the plagioclase above and to the right of the center. Below is a grain of microcline which has been torn and healed with albite. To the left is a typical replacement "vein". Crossed nicols. X22.

Fig. VI. - Myrmekite developing along contact between plagioclase and potash feldspar. These myrmekites are closely connected with interstitial replacement "veins" outside the field of view. Crossed nicols. X22.







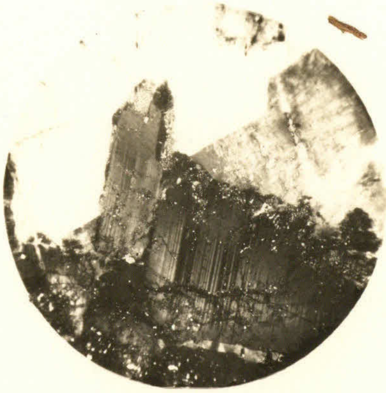


PLATE LXXVIII

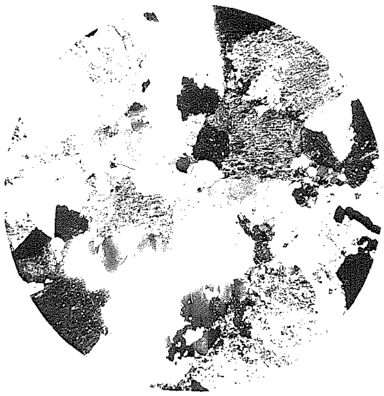


Fig. I

Fig. II

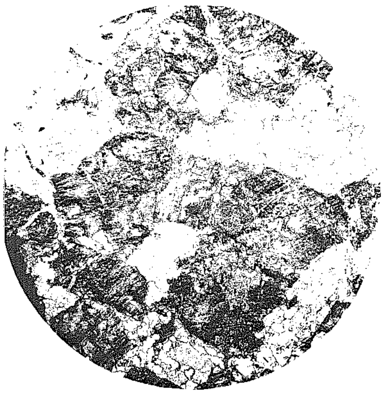


Fig. III

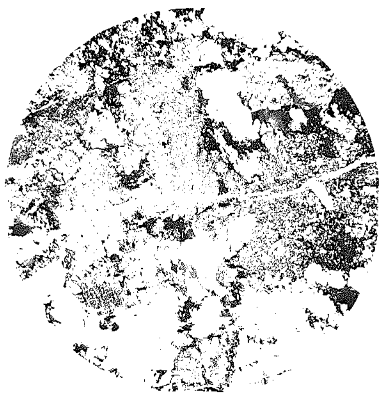


Fig. IV

Fig. V

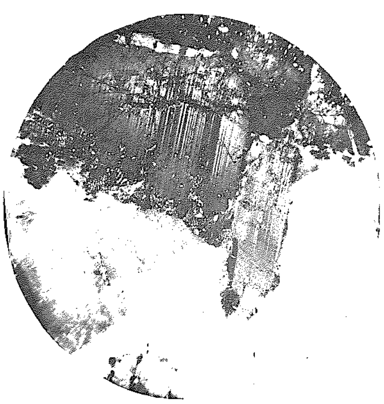


Fig. VI

Ptygmatic folding which has been held to be due to injection during a "mushy" or half fused condition of the invaded rock may, according to Campbell, result from replacement.[1]

Processes of this kind may produce mixed rocks of definitely recognizable structure such as migmatites or injection gneisses if they take place lit-par-lit in stratified deposits or in schists but if they occur in massive rocks such as quartzites or older intrusive rocks they may cause changes which are less easily recognizable as secondary. To quote Grout again,[2]

> "Much is being written of granitization as a process that takes place *near* batholiths, but it is probably more largely injection and solution than fusion . . . . As noted . . . the emanations from a magma may cause changes in the composition of the wall rocks. Where granite intrudes schists the rock is injected lit-par-lit, but in a wall rock of quartzite the changes are pervasive rather than in layers, and the altered rock is almost as massive as the granite. It is probable also that although the introduced material is commonly a dilute hydrous emanation from the magma, the emanation may be followed in some places by the main magma itself. If a granite magma is introduced into massive quartzites and so disseminated that its channels of access are not visible, it may so largely replace the original as to form a rock indistinguishable from granite. Some intermediate stages in this series of replacement effects suggests that certain large masses of granite may be really results of replacement." 3

1. Campbell, Ian. Personal Communication. This is an opinion based upon preliminary work on the pre-Cambrian complex of the Grand Canyon region and not yet fully substantiated.
2. Grout, Frank.F. Petrography and Petrology, New York, 1932, p. 188.
3. See also Quirke, T.T and Collins, W.H.-The Disappearance of the Huronian, Can. Geol. Surv. Mem.160,1930, pp. 1-112.

The distinction between assimilation and granitization or regional replacement should also be carefully drawn. The two are related phenomena and may accompany each other but they are not identical. The former concerns the addition of material to the magma with possibly important consequences upon its composition and differentiation; the latter has to do with transformations in the invaded rock brought about (presumably) by emanations from a nearby or subjacent molten mass. Whatever theory we adopt for the differentiation and crystallization of the latter, we may still admit that it may discharge large quantities of volatile material with important effects upon the country rock even though sufficient heat to produce fusion may not exist.

For the most complete statement of the injection granitization replacement theory, reference should be made to the works of Sederholm. In one of his well known treatises on Migmatites[1] Sederholm gives evidence in favor of a partial remelting and replacement of leptites and of older granites by younger acidic magmas. The following quotations are representative of his views:

> "This change of the salic portion of the leptite into granite veins is entirely in harmony with the observations on the formations of other migmatites which can be made all over the coastal regions. Their components are of a very varying character. Even when basic rocks of a uniform chemical composition but possessing a schistose texture have been invaded by granites, we are aware that they may occasionally become

1. Sederholm, J.J. - On Migmatites and Associated pre-Cambrian Rocks of Southwest Finland, Part 11, Bull. de la Com. Geol. de Finlande, No. 77, 1929.

banded, whereby the granitic juices penetrate certain layers and gradually change them metasomatically into rocks with a more or less typical aplitic composition. When this is possible even with metabasites, which are generally most refactory to the action of the granite and its "juices", it is easily understood that those portions which originally possessed a more salic composition must be easily changed, by the same process, into rocks showing a granitic character." 1

"Thus the idea which these phenomena convey to the observer is that the penetration of the younger granite into the older rocks occurred while these in a large measure retained their former position and that hereby a part of the older rock masses were never entirely solved. It has been an anatexis in situ . . . . Here the 'juices' of the younger granite permeated the older one as oil penetrates sheets of paper; a tache d'huile, according to the excellent expression of Termier, (Termier, Comptes Rendus, Congr, Geol, Intern. Stockholm, 1910,p. 510.) and later changed them 'ultra-metasomatically' into a new granite which in the final stages was able to react on the older rocks like an eruptive." 2

Discussing the geologic age of the Obbanas and Bodom granites Sederholm says:

"They are seldom homogeneous but are commonly mixed up with more or less intimately assimilated fragments of older rocks and they have seldom quite definite boundaries. The general impression which they give is that the older rocks have, all over the region in which they occur, been soaked with the magma of these granites and its ichor." 3

1. Ibid, p. 128.
2. Ibid, p. 50
3. Ibid, p. 112. "Ichor" is a word coined by Sederholm to designate the so-called "granitic juices."

Summarizing the evidence presented by the myrmekites he says:

> "These facts . . . suggest that the solutions which carried the material necessary for the formation of the myrmekite, which was formed at a time when all microcline, as well as probably all biotite, had already been crystallized, acted principally at such places where minute cracks had originated. These cracks gave access to solutions carrying soda and probably also containing a surplus of silica. These facts give additional evidence in favor of the conclusion arrived at by the writer previously according to which the myrmekite has not, as little as other synantetic minerals, been formed merely by an interchange of material between minerals lying in contact with each other. But if even such changes at the boundaries of two adjacent minerals cannot be explained without assuming the intervention of solutions, then it is still more probable that the reactions by other metamorphic changes follow the old rule; corpora non reagunt nisi fluida." 1

The general conclusions drawn by Sederholm from his observations in Finland are of particular interest here. They are well summarized in the following quotation:

> "The granulation of minerals is more often a chemical phenomena than a physical, i.e., it is due to solution. In other cases it is deuteric, not truly secondary. Cataclasis is in general a destructive process, it is not creating new minerals or rocks. The use of the term dynamo-metamorphism for every metamorphic change which cannot otherwise be accounted for should be discontinued as not warranted by facts. As has been emphasized by the present writer and many otherspetrologists, especially of the French school, a sufficient quantity of solvents seems in most cases to be an indispensable condition of metamorphic changes. These solvents are in general exudations from eruptive masses, either visible or hidden at great depths."2

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1. Ibid p. 29.
2. Ibid p. 128.

From the above quotations it is clear that Sederholm on the basis of field observation believes that the influence of an invading magma upon a pre-existing rock may extend from simple lit-par-lit injection to complete replacement with or without refusion and that he relates the formation of myrmekites in many occurrences to processes of this kind.

From what has been presented above it is apparent that we can view the changes which have taken place in the plutonic rocks of the White Mountain region in one of three ways.

1. The changes are related to the normal processes of intrusion, crystallization and cooling of a single batholithic mass without modification from outside sources.

2. The original unaltered rocks were crystallized in normal course near the borders of the batholith. Shortly after the consolidation of this portion of the magma other portions of the latter, still fluid, were enriched in certain constituents, especially soda, silica and water, by the ingestion of large amounts of country rock containing these materials. This enrichment upset the equilibrium existing between the fluid and the solidified parts of the intrusive body and led to reactions between the two phases which did not attain completion before temperatures became so low as to put an end to the process.

3. The pre-alteration minerals may have belonged to an earlier formed rock, perhaps either an arenaceous or arkosic sediment or a siliceous igneous rock which was partly or almost entirely replaced by materials derived from a later igneous invasion which took place at depths below our present field of observation. The replacement may or may not have been accompanied by a slight degree of refusion of the mass.

Emphasis has been placed on the fact that the White Mountain batholitic rocks, although not properly belonging to the alkaline clan, may represent a certain stage in the development of an alkaline rock. If this is a reasonable supposition, as it appears to be, an interesting corollary to the hypothesis set forth in paragraph 3 above is to be found in the views of Harker,[1] Becke[2] and Prior.[2] These students independently reached the conclusion that alkaline rocks occur in regions of radial dislocation- the "Atlantic" province of Suess- while sub-alkaline rocks occur in regions of tangential dislocation - the "Pacific" region. As a result of changes in the type of crustal disturbance a given area formerly underlain by a sub-alkaline magma might come to be underlain at a later time by alkaline magmas with corresponding changes in its igneous rocks.[1] If these observations are correct - about which, however, there is considerable doubt- they are of interest in view of the fact that an earlier period of deformation by tangential compression was followed in late Tertiary or early Quaternary times by one of block faulting involving radial dislocation.

1. See Iddings, J.P. - The origin of Igneous Rocks, Bull. Phil. Soc. Washington, No.12 1892, pp. 89-209. Harker, A. The Natural

3. The pre-alteration minerals may have belonged to an earlier formed rock, perhaps either an arenaceous or arkosic sediment or a siliceous igneous rock which was partly or almost entirely replaced by materials derived from a later igneous invasion which took place at depths below our present field of observation. The replacement may or may not have been accompanied by a slight degree of refusion of the mass.

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1. See Iddings, J.P.-The Origin of Igneous Rocks. Bull. Phil. Soc. Washington, No. 12, 1892, pp. 89-209; Harker, A.-The Natural History of Igneous Rocks, 1. Their Geographical and Chronological Distribution, Science Progress, 6, 1896, pp. 12-23; Becke, F. Die Eruptivgebiete des bohm. Mittelgebirges und der amerik. Andes-T.M. u P.M. 22, 1903., p. 247. Quoted by Smyth, C.H. Jr.-The Chemical Composition of the Alkaline Rocks and its Significance

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as to Their Origin. Amer. Journ. Sci. 4th Ser. Vol. 36,1913. p. 41.

APPLICATION OF THEORIES TO WHITE MOUNTAIN PLUTONIC ROCKS

If from the various hypotheses which have been advanced to explain the changes in magmatic composition which would lead to such replacements as have been noted for the White Mountain batholithic rocks we attempt to select the one which best meets all the conditions imposed by the observed facts, we at once encounter serious obstacles erected by lack of knowledge. In so far as this involves ignorance of conditions deeper within the batholith it is without remedy at the present time. Further study, however, will probably reveal much additional information upon which an intelligent opinion can be based. At the present stage of investigation no definite selection will be made, but significant circumstances will be pointed out which may affect the choice.

Of the processes which have been reviewed the one advocated by Bowen is the simplest and most direct. It would seem, moreover, to afford ample supplies of the very materials which have undoubtedly been introduced to take part in the substitutions - namely, sodium and silica - provided that the necessary conditions, such as correct rate of cooling, prevailed at the time the rocks were formed. The process, it will be remembered, involves the withdrawal of calcium from solution before it could react with the melt to form the more sodic plagioclases. This could be accomplished either by sinking of crystals rich in calcium or by zoning.

In general it may be said that the existing exposures fail to indicate directly or indirectly that either process operated. We have assumed that these rocks, being not far from the roof of the batholith, represented the earliest consolidated portions of the mass. If that is correct, their last-formed plagioclases should represent rather closely the composition of the liquid before much abstraction of calcium with resulting concentration of sodium had taken place. We find, however, that these plagioclases are usually less calcic than oligoclase. Moreover, although zoning is not infrequent in the plagioclases, it by no means affects the majority of them and it is rarely pronounced. On the other hand somewhat more calcic plagioclases, chiefly oligoclase, are frequently enclosed poikilitically in grains of more sodic plagioclase or of potash feldspar.

The suggestion that more calcic plagioclases may have settled to deeper levels in the magma does not seem to me to be acceptable. Although pyroxenes are not commonly observed in these granites a few skeleton crystals, suggesting almost complete resorption, do occur. Moreover, there are frequent aggregates of flakes of biotite or chlorite or sometimes of shreds of hornblende which so closely simulate the typical pyroxene outline as to leave little doubt that they are indicative of the former presence of that mineral. If pyroxene with a specific gravity much higher than that of anorthite did not settle, why should the latter have done so?

It must be admitted, of course, that if these are rocks which represent the uppermost and earliest-cooled phases of the batholith they give us no definite information of what may have occurred deeper within the magma. Rate of cooling, for example, may change considerably as crystallization proceeds. But samples taken from the crest of the range have been compared with others obtained from the bottoms of the glacial cirques without the discovery of any significant differences in composition and texture.

In spite of these objections, Bowen's theory still remains one which must be seriously considered.

The objections which have been expressed to the idea that changes in magmatic composition have been brought about by assimilation of foreign material have been summarized above. The problem of where the necessary superheat could be obtained for melting-in is perhaps chief among these[1].

These objections, however, depend chiefly upon the prevailing theory of a crystallization-differentiation origin for granitic magmas which, of course, may not be correct. There are, moreover, possible sources of heat which have not been taken into account. Fenner has indicated some of these[2].

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1. Heats of reaction may be considered as a possible source of the necessary heat.
2. Fenner, C.N. - The Katmai Magmatic Province Journ. of Geol. Vol.34, 1926, pp.738-740.

In favor of the assimilation hypothesis as an important factor in producing the changes in question stand a number of facts. Contact metamorphism of a very intense kind has taken place on all the borders of the White Mountain batholith. Not only have the invaded sediments been altered to a high degree but endomorphic reactions have produced striking changes within the intrusive mass. There can be no mistaking the origin of these changes, for they occur on all the contacts and increase in intensity as the batholithic margins are approached. Whatever theoretical considerations may exist concerning the slight effects of assimilation of sediments upon magmatic composition they cannot stand against such field evidence as to be observed in the White Mountain region. Whether those effects depend upon actual melting-in or upon chemical reactions is not yet clear but the results are none the less profound.

The sediments of the White Mountain contact zones are not less than twenty-five hundred feet in thickness. Roughly half of them are calcareous and half are argillaceous. The calcareous members include impure dolomitic limestones and calcareous shales. In general the most pronounced endomorphic effects occur where the limestones are not exposed at the contact, but whether this is due to the presence of shale or to the fact that the underlying limestones have been more extensively ingested into the magma is not clear. It is certain, however, that wherever limestone and shales or schists appear together at the contacts the limestone usually exhibits the stronger exomorphic effects. An exception is to be found in those cases in which the shales have been injected lit-par-lit.

Almost nowhere are the intrusive sedimentary contacts sharp and distinct. Transition zones occur between undoubted intrusives and undoubted sediments which are often a mile in width. In these zones occur hybrid rocks of a bewildering variety and complexity. Chief among the differentiated igneous masses are highly altered pyroxenites, gabbros, hornblende diorites and similar varieties.

The statement has been made that nowhere in the batholith is it possible to collect samples at points which are surely more than two or three thousand feet from a former contact zone. It is repeated here for emphasis. The addition should be made that zenoliths are very abundant in the Pellisier granite everywhere along the contacts, while as far removed from visible contact relations as we can observe it, it contains large numbers of dark inclusions which, though they may be autoliths, are more probably to be interpreted as partly or nearly digested zenoliths.

In view of such strong evidence for the influence of contact phenomena upon the White Mountain granites it would seem contrary to reason to dismiss from consideration the possibility that materials assimilated from the sediments have in some way brought about the effects we have observed. This is especially true since Sederholm so strongly emphasizes the frequent relations existing between contact zones and the formation of such structures as myrmekites.

A gainst this view, however, is the fact that the Boundary Peak phase exhibits the replacement texture to the same degree as the Pellisier granite. The Boundary Peak phase in its central portion is comparatively free from any visible contact effects, although this is not true of its border zones. It probably came into position somewhat later than the Pellisier granite. There seems to be some reason to believe that its central part may have been brought up from depth by structural movements, but this is by no means certain. The fact remains, however, that decreased contact effects are not accompanied by correspondingly decreased replaceement phenomena.

Evidence for or against the applicability of the third possible explanation for the peculiarities of our plutonic rocks is least definite. The phenomena observed and described are unquestionably due to replacement but there seems at present no way to prove that they may or may not have been brought about by emanations proceeding from a more recently emplaced magma at depth. I was at first inclined to suspect that these effects might have been produced by the intrusion into the Pellisier granite of the Boundary Peak phase. The suspicion was of necessity abandoned, however, when it was found that both granites exhibited the alterations in about the same degree. The possibility that a third and still more recently emplaced magma of alkaline character may exist not far below the present surface must be kept in mind.

Although unable as yet to express a definite conclusion as to the origin of the materials which have produced such extensive replacements in the White Mountain batholith, I am unwilling to admit that the changes are " deuteric" in the strict sense of the word - that is, they are not the result of processes which took place at the time of the final consolidation of that part of the rock mass, even though they may have been brought about by liquids and vapors derived at a later time from the same magma from which these rocks crystallized. The replacement period may have shortly preceded, accompanied or followed final solidification of the batholith - if indeed, true batholiths ever completely solidify. But for the rocks concerned the alterations and replacements are regarded as entirely secondary.

From my study of these rocks I have become inclined to look very sympathetically on the views of Fenner concerning the importance of liquids, gases and vapors, from whatever source they may be derived, in the origin and history of igneous rocks. I quite agree with Fenner's statement that:

> "In considering petrogenic processes one may doubt also whether 'filter-pressing' and 'armouring of crystals' - processes of undoubted reality in a limited sense - are really so widely

prevalent or effective in differentiation as is often assumed, or whether invoking them when required to assist in explanation does not give to the process a somewhat artificial aspect; also whether the fact that such widely different processes as magmatic crystallization on the one hand and hydrothermal metamorphism (accompanied by metasomatism) on the other frequently give the same or closely similar mineral assemblages has not led to confusion and misinterpretation of evidence."[1]

The present studies have at least tended to decidedly emphasize the following opinions expressed by the same author[2]:

" The economic importance of ore bodies of this (contact metamorphic) catagory has directed much study to their relations but chiefly to the exomorphic phenomena of which they are a part. There must, however, be equivalent endomorphic changes. In fact they illustrate a set of processes of general character by which a crystallizing and cooling mass of rock is penetrated and searched out by migrating gases and hydrothermal solutions. Some of the results of this action have been determined but it is doubtful if all the effects have yet been recognized. It seems to have been satisfactorily demonstrated by various workers that micropegmatites, myrmekites and similar aggregates have often been formed by such post-magmatic processes . . . ."

" . . . we have excellent authority for believing that pneumatolysys or a high grade of hydrothermal metamorphism frequently produces the same or very similar assemblages of minerals as orthomagmatic crystallization, and this is a source of very real difficulty in petrogenic interpretations . . . ."

" . . .in not a few descriptions, alteration effects which have been pointed out as illustrating the reaction principle in magmas, seem equally explicable as results of hydrothermal metasomatism. Processes so fundamentally unlike may lead to

1. Fenner, C.N. - The Residual Liquids of Crystallizing Magmas, Mineral Mag. Vol.22, p.550
2. Ibid, p.553-554.

almost identical results, and the implications and conclusions to be drawn are entirely at variance."

"Acceptance of the essentially magmatic origin of great bodies of plutonic rocks should not cause us to attribute everything in them to primary magmatic processes. Probably all such bodies have been subjected after consolidation to the action of autogenous (and perhaps xenogenous) vapors and solutions, and it remains to be determined to what degree such phenomena as myrmekites and micropegmatites and even larger features such as certain dike-like sheets of felsic minerals and variations of composition are derived directly from a magma and to what degree they are the result of later pneumatolytic and hydrothermal replacement phenomena in an already consolidated mass."

PROCESS OF REPLACEMENT

Our choice of a theory to account for the source of materials which have so profoundly modified the composition and textures of the rocks we have described will have little, if any, effect upon our ideas of the processes involved in the replacements. If we do not know how or where the solutions originated we do have fairly definite evidence of what happened during their invasion of the rock mass. Much quantitative work remains to be done to determine precisely what materials were brought in or carried away and what quantities were involved. From the nature of the textural and mineralogical changes produced, however, we can trace with considerable accuracy the steps by which these transformations were brought about.

It seems certain that the effective agents were solutions of very low viscosity and great penetrating power. These characteristics probably resulted from a high water content, elevated temperatures and great pressures. Possessing them, the solutions were enabled to take advantage of minute cracks and interspaces. There are indications that they may have progressed by a method of continuous solution and re-precipitation. As has been indicated, the process may actually have been facilitated by a partial resolution or refusion[1]. Whether or not

1. As has already been pointed out (page above), refusion and solution at high temperatures are not distinguishable processes in the modern concept.

the probability of such high temperatures is to be admitted, it is entirely possible that the invaded rocks may still have retained a large amount of heat or that they have been reheated by the emplacement of a large body of molten rock at depth[1].

The advance guards of the invasion consisted of tiny veinlets, perhaps sub-capillary in size, which worked their way in and out along the grain boundaries and into the interior of the crystals wherever opportunity presented itself. Constant addition of fluids broadened the veins and pushed them on farther and farther into the rock. Soon the entire mass was saturated somewhat like a sponge with water; the solutions were not stagnant, however, but in motion, perhaps forced on by almost irresistible pressures.

It is not to be thought that at any time fluids were present in a rock to the full width of the present veins or of the secondary material in the matrix. Veins and matrix grew by recrystallization along their

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1. If doubt exists as to the permeability of the rocks to solutions of this sort, it should be dismissed. "Deuteric Minerals" says Gillson (Gillson, J.L. -Granite of Conway, N.H., Amer.Min., Vol.12, 1927, p.319) "illustrate, as do the widely disseminated minerals of contact metamorphic zones, the power of these igneous emanations to pervade solid rock without visible channel or fissure, a fact to which Kemp, for example, has already called attention." It should be remembered, moreover, that previously existing channels may have become sealed and rendered indistinguishable by the very solutions which took advantage of them.

margins. The grains in the center of a vein were, in general, deposited somewhat earlier than those at corresponding points on the margins. Continuous solution and redeposition enabled a comparatively small amount of fluid to do much work.

This is the explanation of the fineness of grain of the veins and of the matrix. Commonly the assumption is made - often it is specifically stated - that recrystallization tends to increase the size of the grain, granulation tends to decrease it. But it is well known that rapid precipitation from saturated solutions produces exceedingly minute crystals, while slow precipitation from dilute ones favors large crystal growth. Rapid fall in temperature may result in quick saturation and fast precipitation. Thus are fine-grained or glassy rocks often produced. Quick saturation, however, may result from other causes, as fast evaporation or the mixing of solutions containing like ions. Thus if a solution saturated in the albite molecule comes into contact with a solution saturated with albite and microcline, the albite will be deposited in small grains if, under the prevailing conditions of temperature, pressure, hydrogen-ion concentration and the like, microcline is more soluble than albite. Processes such as these may explain the fineness of grain we are considering. In general fineness of grain is determined by the development of nuclei in the labite state.

As additional liquid was supplied or as temperatures rose, as appears to have taken place with continuation of the process, saturation was less quickly attained and grain size somewhat increased. Thus we find that, in general, the interstitial material is often finer in the middle and somewhat coarser as the primary crystals are approached.

The incoming solutions were rich in sodium and in silica. The states of combination or the ions present are unknown. The sodium may have been present as albite in solution or it may have been part of complex ions stable only under the prevailing conditions. Other substances, including iron and magnesium, may also have been present.

In some cases the solutions soaked through the potash feldspars, dissolving and replacing them more or less completely with albite. In other cases, the sodium-rich solutions penetrated along irregular cracks formed, perhaps, as Andersen has postulated[1], during the cooling of the primary feldspar, thus forming the patch

1. Andersen, Olaf. Genesis of Feldspar from Pegmatites, Norsk Geologisk Tidsskrift, Bind X, 1928, pp.116-207.

and vein replacement perthites. Completion of this type of replacement resulted in the chess-board albite, so often observed in these rocks. In still other cases the solutions, penetrating along the contacts between primary plagioclase and microcline, produced myrmekite. These structures also often fringe the albite-rich veins where they border microcline or orthoclase.

The exact conditions leading to the replacement of potash feldspar by sodic plagioclases are as yet unknown. They are related, undoubtedly, to concentration, to temperature, to pressure and possibly also to such factors as hydrogen-ion concentration. We can observe the effects and we can speculate on the conditions involved but no definite information on stability relationships appears to be yet available.

Goldschmidt has discussed the general circumstances under which certain metasomatic replacements occur[1]. For these, in which he specifically includes the

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1. Goldschmidt, V.M. - On Metasomatic Processes in Silicate Rocks-Econ. Geol. Vol. 17, 1922, p. 106.

Goldschmidt's definition of metasomatism differs from that of Lindgren. The latter would apply the term only when the composition of the "whole rock" is changed. Goldschmidt, however, considers metasomatism as "a process of alteration which involves enrichment of the rock by new substances brought in from the outside. Such enrichment takes place by definite chemical reactions between the enriching minerals and the reacting substances." See Tyrrell, G.W. - Principles of Petrology, 1926, p. 322.

albitization of potash feldspars and the formation of structures such as myrmekite, he considers freely circulating hydrothermal solutions to be necessary, stating that they cannot take place in a closed system. He refers these processes chiefly to relative concentrations and applies the law of mass action to their interpretation.

With progress of the reactions the solutions, now enriched in potash, penetrated the primary plagioclases and absorbed calcium, depositing sericite in its place. If the solutions were iron-rich, epidote was formed instead of or along with the sericite. Part of the calcium, however, was carried into the veins where at least some of it went into the formation of the epidote of the interstitial matrix. Similarly part of the potash was used up in the formation of the vein sericite, as well as that of the plagioclase.

Concurrently with these processes, primary quartz, particularly susceptible to attack of hot aqueous solutions, was dissolved and as rapidly reprecipitated. Likewise, the silica brought in from outside sources was added to the quartz content of the matrix. This secondary quartz, partly of local and partly of foreign origin, may usually be distinguished from the primary quartz by the fineness and the highly interlocking character of its grains and by its characteristic flamboyant illumination.

From the same solutions biotite was crystallized, utilizing potash derived from the primary microcline and iron and magnesium either from foreign sources or from earlier pyroxenes. The secondary biotite is easily distinguished from the primary by its color, which is a lighter and more yellowish green and by differences in pleochroism.

Chlorite is also usually abundant in the veins and secondary matrix material, drawing its materials probably, from the same sources as the biotite. It is of two kinds, of which one is probably penninite and the other is an unidentified variety characterized by an especially beautiful old rose interference color.

Finely divided untwinned albite also forms a considerable part of the matrix material, where it appears to have been formed from the excess sodium of the veins after complete or partial replacement of the potash feldspars.

It is significant that all of the minerals that form the secondary matrix are either usually or frequently of hydrothermal origin. There seems to be a growing tendency to consider the sericite, epidote and chlorite of igneous rocks to be always of hydrothermal origin[1].

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1. See Gillson, J.L. - Granodiorites in the Pend Orielle District of N.Idaho, Journ.Geol.Vol.35, No.I, 1927, pp.1-31; Winchell, W.H. and A.N. - Optical Mineralogy, Part II, 1927 ed., p.357 and p.379.

Sericite and chlorite have been shown to form during the consolidation of recent sediments[1], but they are more commonly due to the action of hydrothermal waters[2]. Doelter, quoting from the writings of a number of observers, concludes that epidote is among the minerals formed only by hydrothermal processes[3], although Butler thinks that it may occur as a pyrogenetic mineral[4]. Fenner has shown that chlorite, sericite and epidote are products of hydrothermal action in the Watchung basalt[5]. Similar conclusions covering the origin of these minerals have been reached by Shannon[6] and by M'Lintock[7]. Serpentine which is very closely related in occurrence and origin to the chlorites[8],

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1. Leith, C.K. and Mead, W.J. - Metamorphic Geology, 1915, p.105.
2. Kirk, C.T. - Mineralization in Copper Veins at Butte, Montana, Econ. Geol. Vol.7, 1912, p.58; Lindgren, W. - Mineral Deposits, 1919, pp.74, 441, 580, 623.
3. Doelter, C. - Handbuch der Mineralschemie, Band II, Teil. II, 1917, p.857.
4. Butler, B.S. - Pyrogenetic Epidote. Amer.Journ.Science. 4th Ser. Vol.38, 1909, pp.27-32.
5. Fenner, C.N. - The Watchung Basalt and the Paragenesis of the Zeolites and other Secondary Minerals, Annals N.Y. Acad.Sci. Vol.20, Part II, 1910, pp.93-287.
6. Shannon, E.V. - Mineralogy and Petrology of Intrusive Triassic Diabase at Goose Creek, London Co., Virginia, Proc. U.S.Nat.Museum, Vol.66, 1924, pp.1-86. In the same article Shannon shows that the presence in the diabase of large masses of albite and quartz, both as separate individuals and as graphic intergrowths, are due to hydrothermal introduction and replacement.
7. M'Lintock, W.F.P., On the Z eolites and Associated Minerals from the Tertiary Lavas around Ben More, Mull, Trans. Royal Soc. of Edinburgh, Vol.51, 1915, pp.1-33.
8. Winchell, Optical Mineralogy, Part II, 1927, p.373.

has been considered to be of late magmatic or hydrothermal origin by many authors, including De Launay[1], Benson[2], Dresser[3], Graham[4], and others. Maxson has related serpentinization to hydrothermal action in the Western Siskiyou Mountains[5].

Schaller has suggested that several minerals of igneous rocks, including the micas, may always be of hydrothermal origin[6]. Quartz is readily attacked and carried in solution by hot aqueous solutions, especially of an alkaline character, while albite is similarly affected.

Thus the evidence presented by both the textural and mineralogical features of the rocks which compose the White Mountain batholith indicates that those features and the replacements which produced them are of hydrothermal rather than of strictly deuteric origin[7].

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1. DeLaunay, H.L. - Contributions a l'etude des gites metallifers, 1897, p.25. Cited by R.J.Colony, Journ.Geol., Vol.31, 1923, p.173.
2. Benson, W.N. - The origin of Serpentine, Amer. Journ.Sci., 4th Ser. Vol.46, 1918, pp.693-731.
3. Dresser, J.A. - Preliminary Report on the Serpentines and Associated Rocks of Southern Quebec - Mem.Can.Geol.Surv.22, 1913, p.66.
4. Graham, R.P.D. - Origin of Massive Serpentine and Chrysotile Asbestos, Black Lake - Thetford Area, Quebec, Econ. Geol. Vol.12, 1917, pp.162-183.
5. Maxson, J.H. - Geology of the Western Siskiyou Mountains, Doctor's Thesis, California Institute of Technology, 1931, pp.172-173.
6. Schaller, W.T. - Genesis of Lithium Pegmatites, Amer. Journ. Sci. 5th Ser., Vol. 10, 1925, p.279; Schaller, W.T. - Mineral Replacements in Pegmatites, Amer. Mineralogist, Vol.12, 1926, p.63.
7. Attention should again be called to the fact that Colony and Gillson have proposed extension of the term "deuteric" to cover alterations in the already solidified part of a batholith produced by hydrothermal emanations from the still liquid portions at depth. In this sense the changes described above may be deuteric.

AMOUNT OF MATERIAL NEEDED FOR REPLACEMENTS.

In weighing the merits of any or all of the theories which have been advanced above we must keep constantly in mind some idea of the amount of material which must have been introduced to bring about the changes we have observed. It is impossible, of course, to arrive at definite figures because, first, we do not know how deep into the batholith the alterations extend and, second, in the present absence of analyses we cannot judge accurately how completely sodium has been substituted for potassium in those individual grains of orthoclase and microcline in which the replacement is incomplete. My estimate is that so far as erosion has exposed the batholith not less than fifty percent of the potassium originally present in the potash feldspars has been replaced by sodium. Inasmuch as these feldspars originally probably made up more than 35% or 40% of the entire rock, the concentrations of sodium must have been very large - too large, certainly, to have existed in interstitial liquids throughout the rock in the last stages of consolidation.

To the quantity of imported sodium which has actually taken part in the replacements we must add that which has gone to form the albite of the secondary matrix. It is to be remembered that this matrix, formed by the widening of the interstitial replacement veins at the expense of the older grains, is composed largely of quartz and albite with varying amounts of biotite, sericite, epidote, chlorite and sometimes calcite and titanite. Since, like most of the interstitial material, the albite occurs in very fine grains the problem of determining how much is present is not an easy one, especially since the proportions are highly variable. Moreover it is frequently untwinned and hence difficult to recognize. My estimates run from 25% to 75% in different cases.

The situation is further complicated by the fact that the proportions of recrystallized matrix to original material are likewise not constant. The interstitial matter may make up as little as 5% of the total rock in the early stages of the replacement or as much as 80% or more where the process is nearly complete.

Much of the secondary albite has probably been derived from the original sodic plagioclases of the rock, dissolved and redeposited at short, though varying, distances from its source. The plagioclase content of the relatively little altered parts of the rock, however, indicate that only part of it could have been derived in this way. Moreover it is frequently to be observed that the replacement of the potash feldspar has proceeded almost to completion while the original plagioclase grains are almost intact.

The albite of the myrmekite, of the secondary matrix and of the chess-board type does not appear to be pure albite. As has been pointed out, this secondary albite is rarely twinned and, in the absence of analyses, estimates of its composition must depend upon relative index, upon birefringence and upon optic sign, supplemented by observation of extinction angles of the few twinned grains. It seems probable that in most cases it is 90% to 95% pure albite.

The amount of secondary quartz present in the rocks is still more difficult to estimate with any degree of accuracy, because of the variability in the proportions of original quartz, because it does not commonly take part in metasomatic replacements, and because solution and reprecipitation of the primary quartz appear to have almost kept pace with the introduction of new material. In many cases, however, the total quartz content of the altered rock is nearly 50% in contrast to an average content of 15% to 25% of quartz in the relatively unaffected rocks.

It is possible that some calcium and some iron may have been introduced, the former entering into the composition of the secondary sodic plagioclases and into that of the epidote, the latter taking part also in the formation of the epidote and in that of the biolite and chlorite. For the last two a source of magnesium is also necessary. Unquestionably part, perhaps all, of the calcium has been derived from the original plagioclases, while magnesium and iron may have come from pre-existing pyroxenes or amphiboles.

The rough estimates which have been made would in the writer's opinion seem to indicate that unless the effects which have been observed are confined to a small portion of the batholith the amount of new materials necessary for the replacements, especially sodium and quartz, are too large to be explained by normal processes of crystallization as is so ably advocated by Bowen.

ALBITIZATION AND THE SPILITIC SUITE

The rocks of the White Mountain batholith may be considered to belong to the spilitic suite. Although the first-described spilites were the British pillow lavas, the term has since been extended to cover various kinds of rocks with certain common characteristics. For a definition of what it now includes reference may be made to the study by Dewey and Flett:[1]

> "We have, then, a long and varied suite of igneous rocks belonging to the spilitic association. The commonest are always spilite and diabase; next in abundance are keratophyres and quartz keratophyres; less frequently we find soda-granite, minervite and picrite . . . . Their chief characteristic is the abundance of soda, even in the basic types . . . . The spilitic suite is always richer in soda and shows as an additional characteristic the almost universal and often complete albitization of the lime-soda feldspars."

To include the White Mountain batholith in this catagory we need only add to this definition the words, " or of the potash feldspars."

Chlorite, epidote and calcite are also common minerals in spilitic rocks; pyroxenes, on the contrary, are rare.[2]

Albitization of basic feldspars may be brought about in a number of ways. Calcium may be leached out from the calcic plagioclases, leaving albite.[3] Termier has

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1. Dewey, H. and Flett, J.S. - On some British Pillow Lavas and the Rocks Associated with them. Geol. Mag. 1911, p.209.
2. Dewey and Flett, op. cit.; Wells, A.K. - Nomenclature of the Spilitic Suite, Part II. Geol. Mag. 1923, pp.62-74.
3. Termier, Bull. Geol. Soc. France, Vol. 26, 1898, pp.165-192.

ascribed albitization to percolating surface waters rich in soda which replaced soda for lime in the plagioclases. Saussuritization, a process by which feldspars are changed into a mixture of albite, zoisite, epidote, quartz and sericite has long been known.

In their study of the spilitic lavas, Bailey and Grabham were able to show that the albitization probably belonged to the category of juvenile reactions which igneous rocks undergo while they are still hot and richly charged with volatile ingredients.[1] They based this conclusion on a number of facts including (1) that the more basic the feldspar the more likely it is to be albitized, (2) that in a given feldspar the more basic portions are albitized first, but (3) that the more basic lavas are less altered than the less basic ones. On these and other considerations they advanced the hypothesis "that in some volcanic centers . . . some portions of the magma were discharged exceptionally rich in carbon dioxide . . . , that during crystallization of the lava an unusual portion of soda was thus retained in solution; and that the residual liquors then began to react with the minerals which had been crystallized. Olivine was converted to serpentine and chlorite while the more basic feldspars were replaced by albite . . . . The lava at this stage was stewing in a concentrated solution of sodium carbonate."[2]

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1. Bailey, E.B. and Grabham, G.W. - Albitization of Basic Plagioclase Feldspars - Geol. Mag. 1909, pp.250-256.
2. Bailey and Grabham, loc.cit. p.253.

Other descriptions of albitization of feldspars in intermediate or basic rocks have been published by Becke[1], Geijer[2], Sundius[3], Shannon[4], Fenner[5], Reynolds[6], and others. Grubenmann and Niggli have discussed albitization in basic rocks and their contact zones[7].

Replacement of potash feldspars by albite may be a process distinct in cause or in governing conditions from that of the albitization of the basic feldspars. This is indicated in the plutonic rocks of the White Mountain area by the fact that in sections showing the most complete replacement of microcline or orthoclase the primary plagioclases are either apparently unaltered or are sericitized. What changes in temperature, pressure or concentration may be necessary to produce albitization of the plagioclases is not known. It is evident, however, that albitization of the potash feldspars proceeded more readily than that of the plagioclases and that, furthermore, sericitization of the plagioclases proceeded more readily than their albitization,

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1. Becke, F.: Petrographische Studien am Tonolit der Rieserferner - T.M.P.M. Vol.13, 1892, p.420.
2. Geijer, P. - Geology of the Kiruna-District, 2, Stockholm, 1910 - quoted by Grubenmann-Naggli, Die Gesteinsmetamorphose, I, 1924, p.439.
3. Sundius, N. - Beitrage zur Geologie des sudlichen Teiles des Kirunagebietes, Upsala 1915, - Zur Frage der Albitisierung irn 1916, Bd.38, S 446 - both quoted by Grubenmann-Niggli, op.cit, p.439.
4. Shannon, E.V. - Mineralogy and Petrology of Intrusive Triassic Diabase at Goose Creek, Louden Co. Virginia, Proc. U.S. Nat. Mus. Vol.66, 1924, p.83.
5. Fenner, C.N. - The W achtung Basalt, Annals N.Y. Acad.Sci. Vol.21. No.2, 1910, p.121.
6. Reynolds, S.H. - Igneous Rocks of the Tortworth Inlier. Q uart. Journ. Geol. Soc. London, Vol.80, 1924, p.107.
7. Grubenmann and Niggli - Die Gesteinsmetamorphose, Vol.I, 1924, pp.220 and 289-291.

(in both cases, of course, under the conditions of temperature and pressure prevailing in the rocks at that time.) Thus albitization of plagioclases could not take place so long as unreplaced potash feldspar remained in the vicinity.

Albitization of microcline has been described by various investigators, including Becke[1], Spencer[2], Brögger[3], Landes[4], Schaller[5], Hess[6], Colony[7], Warren[8], Gillson[9], and Grubenmann and Niggli[10].

Bowen after a thorough study of albite-bearing rocks in the Gowganda Lake district of Quebec concluded that

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1. Becke, F. - Zur Physiographie der Gemengteile der Kristallinen Schirfer Wien K.K. Akad.Wiss.Deukschr. 75 28.
2. Spencer - Treadwell Ore Deposits, U.S.G.S. Bull.259, 1904, p.74; The Juneau Gold Belt, U.S.G.S. Bull.287, 1906, p.211.
3. Brogger, W.C. - Die Mineralien der Syenitpegmatitgange der sudnorwegischen Augit - und Nephelinsyenite, Zeit.Krist Vol.16, 189-, p.559.
4. Landes, K.K. - The Paragenesis of the Granite Pegmatites of Central Maine, Amer. Min. Vol.10, 1925, p.373.
5. Schaller, W.T. - Genesis of Lithium Pegmatites, Amer. Jour. Sci. 5th Ser., Vol. 10, 1925, pp.278-279.
6. Hess, F.L. - The Natural History of the Pegmatites, Eng. Min. Jour-Press Vol.120, 1925, p.293.
7. Colony, R.J. - Final Consolidation Phenomena in Igneous Rocks, Journ.Geol. Vol.31, 1923, pp.170-175.
8. Warren, C.H. - Petrology of the Alkaline Granite and Porphyries of Quincy and Blue Hills, Mass.-Proc.Amer.Acad.Arts & Sci. Vol.49, 1913, p.214.
9. Gillson, J.L. - The Granite of Conway, N.H., Am. Miner. Vol.12, 1927, p.316.
10. Grubenmann and Niggli - Die Gesteinsmetamorphose, Vol.I. 1924, pp.312, 316, 434-436.

the albite was introduced by processes of replacement. The rocks are for the most part associated with gabbros which are often intruded into argillites. Water included in these sediments, he believes, may have played a part in the transfer of the soda-rich solutions[1]. This is in accordance with Daly's ideas[2].

More recently Bowen[3] has favored an origin by replacement for all albite-rich rocks. This stand is taken on the basis of the fact that glassy rocks corresponding to granite very rich in albite do not occur. Albitization is considered to be "the result of a secondary process of impregnation of a solid rock with albite by circulating aqueous solutions . . . . There is nothing in the manner of their occurrence to warrant belief in their formation by simple consolidation of a magma.[4]"

Other investigators, however, have regarded some occurrences of this sort as primary. Knopf appears to consider albite at Engels, California[5], to be primary. In the albitite and albitite porphyry (called soda syenite and soda syenite porphyry by Turner and soda syenite granophyre

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1. Bowen, N.L. - Diabase and Granophyre of the Gowganda Lake District Quebec; Journ.Geol. Vol.18, 1910. pp.658-674.
2. Daly, R.A. - Igneous Rocks and their Origin, New York, 1914, p.339.
3. Bowen, N.L. - Evolution of the Igneous Rocks, Princeton, 1928, p.132.
4. Idem.
5. Knopf, A. and Anderson, C.A. - The Engels Copper Deposits, California, Econ. Geol. Vol.25, 1930, p.18.


44-a


37-a

PLATE LXXIX

Knotted Schist (Knotenscheifer) from Queen Canyon. Natural size.

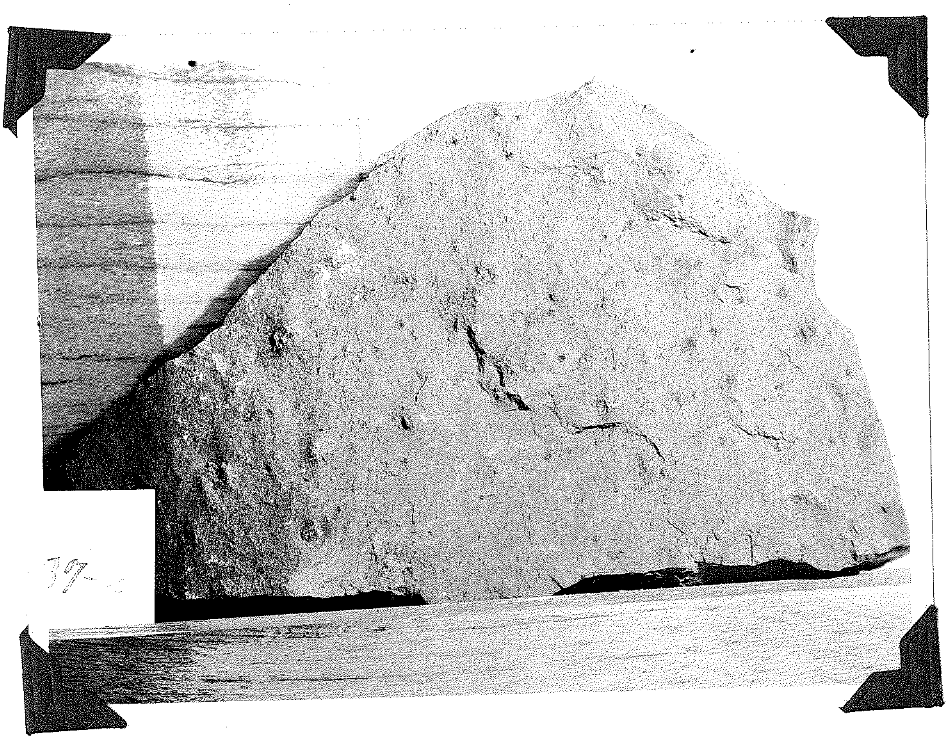

Figure II

Carbonaceous shale, showing beginning of contact metamorphism, from south of Indian Canyon. About 9/10 natural size.

by Ransome) of the Mother Lode system[1], Knopf considers the albite to be primary, although he suggests a deuteric origin for the aegirite. In his study of keratophyres at Rochester, Nevada[2], Knopf rather doubtfully refers the albite to primary processes of development. Campbell has likewise postulated a primary crystallization for albite in the volcanics at Tonopah[3].

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1. Knopf, A. - The Mother Lode System of California, U.S.G.S. Prof. Paper 157, 1929, pp.21-22.
2. Knopf, A. Geology and Ore Deposits of the Rochester District, Nevada, U.S.G.S. Bull.762, 1924, p.21.
3. Campbell, Ian. - The Petrography of Tonopah, Nevada, Doctor's Thesis, Harvard University, 1931, pp.156-157.

CONTACT METAMORPHISM

An adequate study of contact metamorphism in the White Mountain Quadrangle would in itself provide sufficient material for a doctor's thesis. In the following pages the subject will be presented only in a general way; a more detailed discussion is planned for a later paper.

Important effects of this kind appear to be almost entirely limited to the intrusive contacts. The modifications produced by the lava flows upon the underlying formations are either slight or they have been concealed by later accumulations or obscured by more recent hydrothermal activity. Within the contact aureoles of the White Mountain batholith, however, profound changes are to be observed. These may be divided into two groups; first, endomorphic modifications affecting the composition and texture of the intrusive; second, exomorphic changes in the invaded sediments. Hybrid rocks whose origin it is difficult if not impossible to determine are exceedingly common.

The outer limits of the contact aureole are not determinable because to the east and west they lie beyond the fault zones which delimit the mountain block and thus are deeply buried beneath the valley detritus; to the north and northeast the more remote zones are likewise concealed by the thick accumulations of Tertiary volcanics. Everywhere within the area the McNett formation has been at least mildly

- and often intensely - affected by contact metamorphism.

The intensity and extent of the metamorphic effects are easily understood when one considers the composition of the sediments and of the intrusive mass as well as the size of the latter. The members of the McNett formation, as will be recalled, are chiefly calcareous and argillaceous deposits. Arenaceous material is of minor importance. Intruded rocks of this composition might reasonably be expected to show the most pronounced as well as the most varied effects. Goldschmidt[1], for example, has differentiated ten classes of hornfels each with a characteristic mineral assemblage and arising from sediments ranging in composition from shales to marls.

The results are intensified by the fact that the intrusive body is granitic in composition, for in the first place, acid magmas are usually considered to be more highly charged with chemically active gases and liquids than are intermediate or basic ones, and, in the second, the chemical contrast between such magmas and the components of the more basic sediments is favorable to the production of pronounced changes. The comparatively large size of the

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1. Goldschmidt, V.M. - Die Kontaktmetamorphose im Kristianiagebiet 1911, pp.146-197. They are, respectively, andalusitecordierite - hornfels, plagioclase-andalusite-cordierite-hornfels, plagioclase-cordierite-hornfels, plagioclase-hypersthene-cordierite-hornfels, plagioclase-hypersthene-hornfels, plagioclase-diopside-hypersthene-hornfels, plagioclase-diopside-hornfels with or without biotite, grossularite-plagioclase-diopside-hornfels, grossularite-diopside-hornfels and vesuvianite-grossularite-diopside-hornfels.


56 a


51 a
Indian Creek

PLATE LXXX.

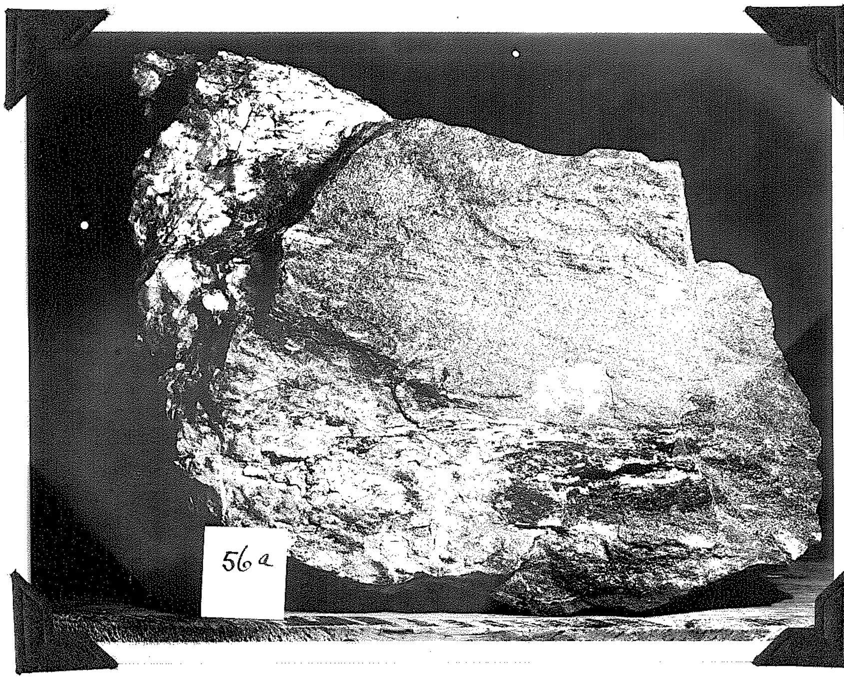

FIGURE I.
Schist injected with igneous material. Indian Canyon at south end of Davis Mountain. Slightly more than one half natural size.

FIGURE II.
Lens of granite material in injection gneiss from Indian Canyon near Post Meadow. About 5/6 natural size.

batholith is of importance both because of its high thermal capacity and because of its large content of fluid and folatile substances.

Three or more stages of contact metamorphism are commonly recognized. These are classified by Grubenmann and Niggli[1] as follows:

a) Normal or ordinary (thermal) contact metamorphism[2].

b) Pneumatolytic to hydrothermal contact metamorphism with addition of material.

c) Injection metamorphism to fusion and assimilation.

All of these types are represented in the area under consideration but the last two are vastly more important than the first.

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1. Grubenmann and Niggli, Die Gesteinsmetamorphose, Vol.I, Berlin, 1924, p.248.
2. Tyrell, however, prefers to use " thermal metamorphism" as a general term, including pyrometamorphism, contact metamorphism, optalic metamorphism, pneumatolytic metamorphism and injection metamorphism. Only in the last two cases is there considered to be a positive increment of material to the rock whereby its composition is altered. In ordinary contact metamorphism "magmatic emanations . . . merely increase the molecular mobility of the interstitial solutions and thus facilitate the mineral changes." (See Tyrell,G.W. - Principles of Petrology, New York, 1926,pp.253-254; 289-302; 321-336.

METAMORPHISM OF THE ARGILLACEOUS SEDIMENTS

Except in one locality the exomorphism of the argillaceous sediments in this area has not proceeded beyond the initial stages of the "normal"[1] contact metamorphism. The rocks belong for the most part to the zone of the Knotentonschiefer and that of the Knotenglimmerschiefer of Rosenbusch. In some localities, as along the mountain front south of Indian Creek and also at an elevation of about 9000 feet in the bottom of Dry Canyon the slates which are carbonaceous in character, are filled with little bodies suggestive of grains of wheat. These rocks are properly "fruchtschiefer". The little bodies appear to be aggregates of biotite in minute flakes admixed with considerable amount of carbonaceous material. Elsewhere, as north of Queen Canyon, the included bodies are larger and consist in some cases of aggregates of sericite and quartz or in others of chiastolite. The groundmass is often a sericite or chlorite schist. The carbonaceous material has greatly diminished. To these the term Knotenglimmerschiefer may be correctly applied[2].

The Knotenschiefer often contain much iron which may confer upon them a green or bluish tint when they are fresh, or a rusty brown color where they are more weathered.

True hornfels occur in various localities in the immediate vicinity of the smaller intrusive masses. These

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1. The term "normal or ordinary contact metamorphism" is not an apt one. It implies that the other types are in some way abnormal or extraordinary.
2. Grubenmann and Niggli, Die Gesteinsmetamorphose, Vol.I, p.254.

consist of quartz, orthoclase or microcline albite or oligoclase and an abundance of biotite together with andalusite or in some cases sillimanite. Cordierite has not been noted but may be present in some cases.

To the south and southwest of Davis Mountain addition of material from the magma has played a large part in the metamorphism of the argillaceous sediments. In some localities these have obviously been thoroughly injected and converted into injection gneisses and migmatites; in others they appear to have been soaked as a whole in magmatic "juices" and more or less completely recrystallized. The end-products of the latter process are rocks which are difficult to distinguish in the field from true igneous rocks. In many cases the uncertainty continues even after microscopic examination. For the most part, however, they possess a characteristic porphyroblastic texture with porphyroblasts of potash or soda feldspar set in a fine grained groundmass of quartz, feldspars, biotite, sericite and hornblende in linear arrangement. In some instances it is questionable whether we are not dealing even here with palimpsest structures in which phenocrysts are inherited from a pre-existing igneous rock.

The injection of igneous material to form the gneisses evidently took place in two stages. In the first of these the material from the magma was introduced lit-par-lit with the production of bands of igneous material which alternate with other bands of sedimentary material in parallel arrangement. The contacts between adjacent bands is usually gradational. This suggests that the introduced solutions were of low viscosity. At a later time aplitic material was introduced in dikes, varying in width from less than an inch to several feet, which always trend obliquely across the earlier bands. These dikes invariably possess sharply defined borders irrespective of the character of the adjacent material and they are granular to their margins.

These observations are thought to be of considerable importance as suggesting for this locality, at least, that igneous emanations preceded rather than followed the invasion of the molten mass. This is in keeping with the theories of Sederholm.

The evidence at least definitely indicates that the introduction of magmatic material into the sediments took place in two stages. In the first stage the more volatile constituents penetrated along the bedding planes of the earlier rocks, producing lit-par-lit structure. In the later stage more viscous intrusive material formed the aplite dikes which cut obliquely across the earlier structures. Opportunity for the introduction of this material was probably afforded by the formation of fractures in the sediments by the upward movement of the main intrusive mass.

METAMORPHISM OF THE CALCAREOUS SEDIMENTS

The calcareous sediments intruded by the White Mountain batholith have in general been metamorphosed to a higher degree than those of argillaceous composition. The chief results of this metamorphism are summarized below.

1) Conversion of the limestones to pure marbles and dolomitic marbles in the immediate vicinity of the contacts.

2) Formation of tactites containing various minerals characteristic of contact zones in calcareous rocks. These include epidote, garnet (chiefly grossularite and andradite) diopside, wollastonite, vesuvianite, apatite, tremolite, actinolite, magnetite, pyrite, quartz and sodic feldspars[1].

3. Impregnation of the limestones with siliceous material from the magma with various degrees of completeness of replacement according to structure and position. In some cases large masses of limestone have been entirely metasomatized to rocks consisting almost entirely of quartz. The original character of such rocks is betrayed in the field only by textural and structural features and by linear continuity with unaltered limestones. In others the replacement has been less complete.

In general it may be stated that the most striking effect of the metamorphism (exomorphism) of the limestones is the intense silicification which they have

1. Wollastonite and tremolite are not properly included under the term "tactite" but they are so placed here for convenience. See Hess, Frank - Amer.Jour.Sci.4th Ser.Vol.48, 1919, pp.377-378.

undergone in the contact aureoles. This has most commonly taken place by the process of metasomatism, but frequently granitic material has been injected along the bedding planes, producing calcareous injection gneisses. This is notably exhibited in the limestones south of Indian Creek and in the contact zone on the west scarp of the range. North of lower Queen Canyon a series of thin-bedded limestones, calcareous shales and quartzites underlying knotenschiefer derived from material chiefly argillaceous in composition have been similarly injected and intensely folded, forming contorted gneisses whose bizarre appearance at once attracts the attention of the observer who follows the trail up the canyon.

In his description of the geology of the Silver Peak Quadrangle Turner[1] describes and illustrates a series of gneisses and schists underlying the Lower Cambrian beds. The schists he divides into two groups which he designates, respectively "granite-augen-schists" and "calcareous augen-schists". Although he admits the possibility that the "calcareous augenschists may represent thin-bedded limestones and limey shales thoroughly injected and infiltrated with granitic material". Turner considers that this complex was formed in Pre-Cambrian times.

As has been indicated above, rocks exactly similar to these occur in the contact aureoles of the White

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1. Turner, H.W. - Contribution to the Geology of the Silver Peak Quadrangle, Nevada, Bull. Geol. Soc. Amer. Vol.20, 1909, pp.230-232.

PLATE LXXXI

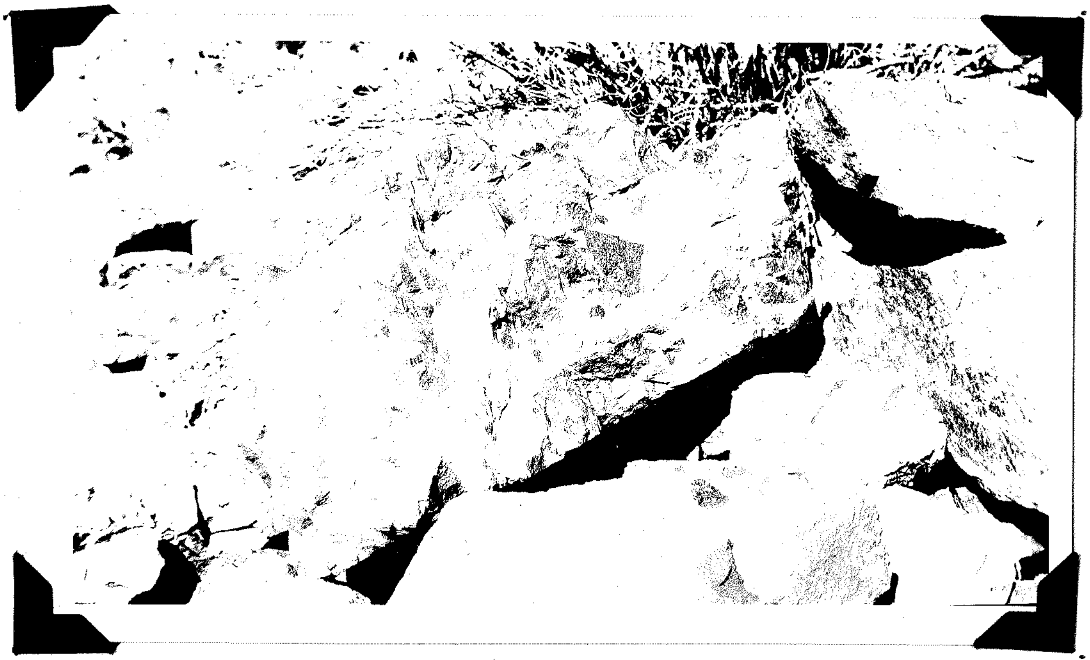

Figure I

Contact breccia, first large canyon southwest of Queen Canyon.

Figure II

Contact breccia, south branch Indian Canyon.

Mountain batholith, where they undoubtedly represent members of the McNett formation complexly injected by material from the intrusives. Turner's descriptions and illustrations fit these White Mountain rocks so closely that they are reproduced in part herewith:

> " The schists . . . . are of two kinds. One has the composition of a granite and shows under the microscope strong evidence of shearing, the feldspar and quartz grains being crushed and faulted and largely reduced to minute granules. In this schistose granulated groundmass large grains of quartz, feldspar, and muscovite form kernels or augen, around which the lines of granules and the lines of muscovite of presumably secondary origin curve. Such a rock may be designated a granite-augen-schist. The other type of schist weathers a brown color, strongly resembling sedimentary limestone. It often contains streaks and augen of the white granite, as shown by Fig.2, plate 7. . . . The streaks of granite are often several inches in diameter, producing the impression of intrusive sheets in the darker schists. The rocks are here greatly plicated, and as the streaks of granite are involved in this plication, it is evident that the plication occurred aft.r the intrusion. Some of the more massive occu.rences of this type of schist show no augen to the unaided eye. At the west base of the ridge of Lower Cambrian rocks . . . are certain dark rocks resembling shales, in which are dikelike streaks of coarse white granite at one or two points. These slate-like rocks were at first supposed to be a part of the Cambrian series, but the microscope shows them to be of essentially the same composition as the schists above described, and hence they are mapped as part of the complex. While these schists vary in macroscopic appearance, under the microscope these differences are less striking. The fine grained schists and slaty rocks are found to always contain grains or augen of feldspar or quartz, or both, and often of secondary minerals, including an epidote-like mineral, in a groundmass of minute grains of carbonate of lime. The fine grained portions of the coarser calcareous augen-schists, represented by figure I, plate 7, are an exact facsimile in some cases, as seen under the


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PLATE LXXXII

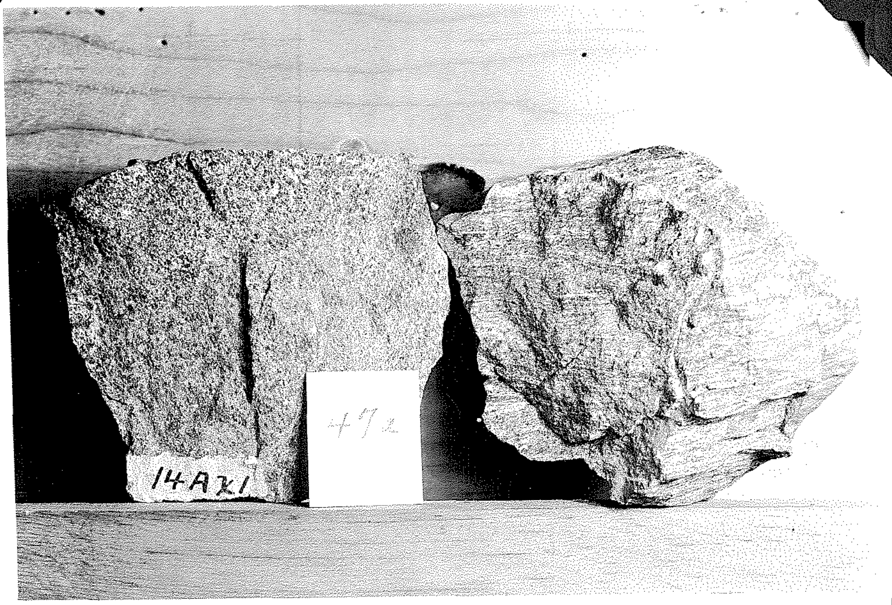


Figure I
Rocks of the contact zone, 4/5 natural size

Figure II
Hybrid rocks from the contact zones. Natural size.

microscope, of the fine grained schists, which, when massive, so strongly resemble sedimentary limestone on exposed surfaces. (See Fig. 2, plate 7.)

"Nearly all the thin-sections show evidence of strong shearing or mashing, the original grains being thoroughly crushed and arranged in parallel streaks. Such of the grains as have not been granulated are fractured and rounded and the quartzes usually show undulous extinction. Lines of mica foils, chiefly finely divided muscovite, contribute greatly to the formation of the schistose structure. While the two types of schists here described are very different in chemical composition - the granite-augen-schist having the composition of granite or arkose, and the lime-rich extreme of the calcareous augen-schists the composition of an impure limestone - at numerous points schists representing transitions from one to the other may be found. Such a series, all taken from one bluff about one mile southeast of North Spring, shows transitions from a typical granite-augen-schist composed of lines of minute grains of quartz and feldspar and of minute muscovite foils with little or no carbonate to a granite-augen-schist similar to that just described, but with lines of carbonate granules in addition."

The Hybrid Rocks

The batholith at the contacts with sediments is characterized by the presence of a complex group of rocks which appear to have been formed by a mixture of materials derived in part from the magma and in part from the sediments. In short, they seem to have been formed by a process of assimilation. They are hybrid rocks.

Such rocks are not divided sharply from the metamorphosed sediments on the one side nor from the endomorphosed intrusives on the other. Intermediate varieties, on the one hand, may retain more definitely the characteristics of sedimentary rocks, though always giving evidence of having been more or less thoroughly impregnated with magmatic material. On the other hand they pass by gradual modification in composition into the igneous mass.

Our recognition of the presence and origin of such rocks need not be affected by whatever major theory of petrogenesis we adopt. If we agree with Daly we will look on the process as one of actual melting and mingling of fluid components; if we side with Bowen we will regard a given rock of this origin as the product of one of the stages in a reaction between the fluid magma and the minerals of the invaded rock, the character of the product depending in part upon the point reached by the intrusive in the sequence of crystallization.

The process may be considered to begin with the breaking-off by stopping or other means of fragments of the intruded rock and their inclusion as xenoliths in the magma. Near the present contacts such xenoliths will occur as little-altered angular inclusions because in such locations the magma was probably near solidification at the time such fragments were broken loose from the roof or walls. Farther from the contacts such inclusions will be observed in various degrees of digestion and assimilation by the igneous mass.

Within the White Mountain batholith xenoliths of various sizes and in various stages of assimilation are

94-95

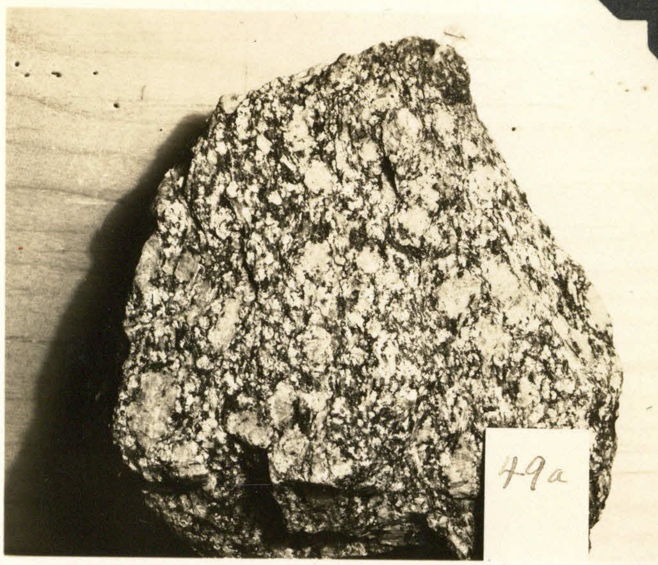


PLATE LXXXIII

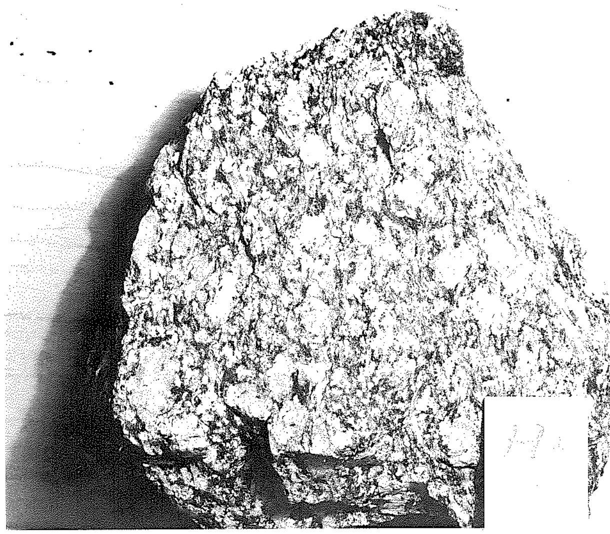


Figure I
Contact rock from Indian Canyon. About 3/4 natural size

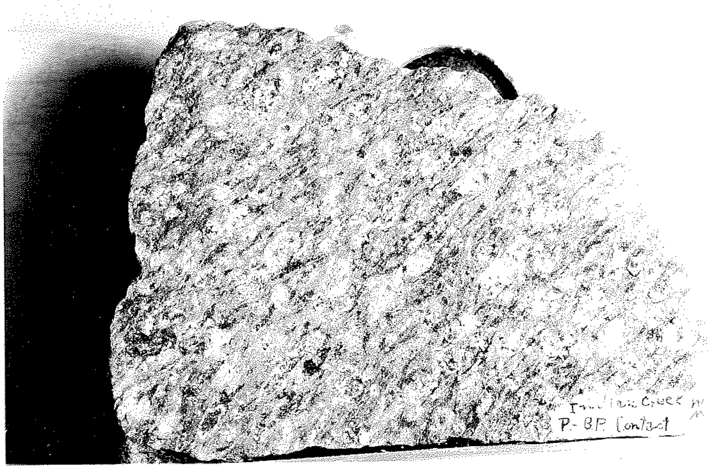


Figure II
Contact rock from Indian Canyon. Natural size.

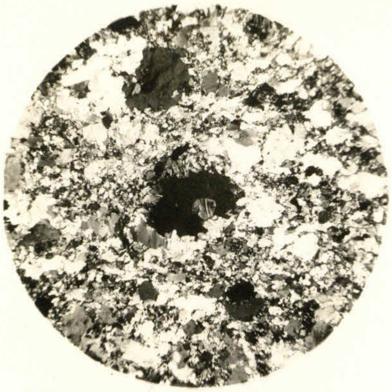
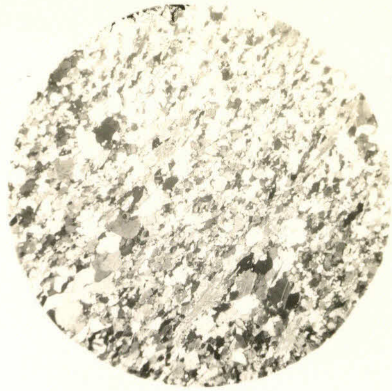
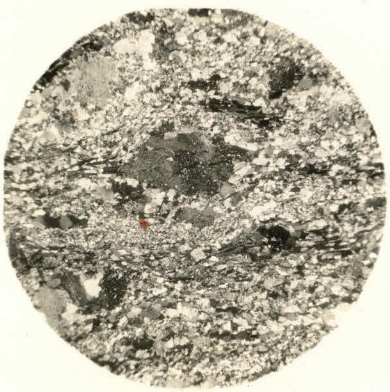
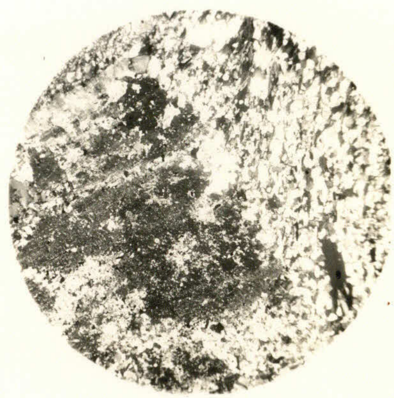





PLATE LXXXIV

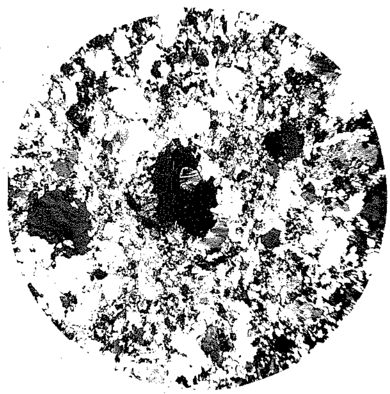


Fig. I

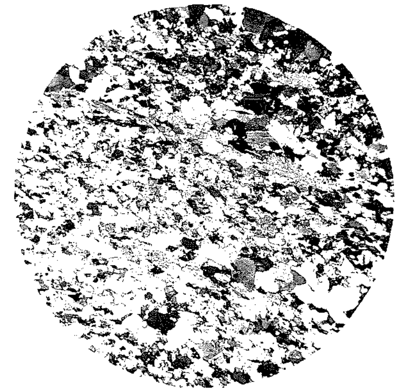


Fig. II

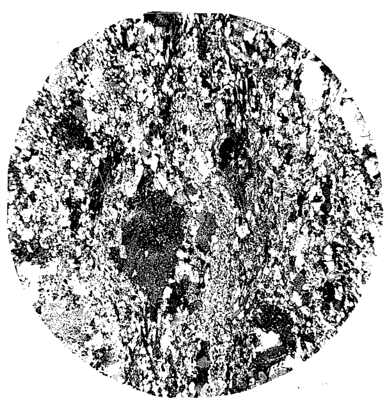


Fig. III

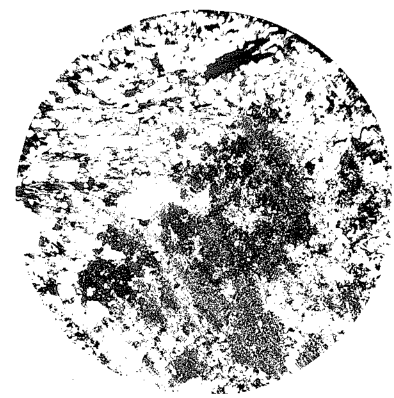


Fig. IV

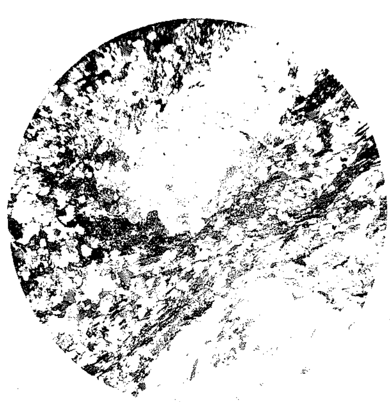


Fig. V

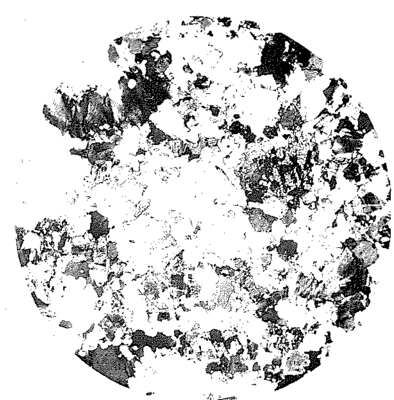


Fig. VI

to be observed in great abundance. In the Pellisier granite, especially, they are not confined to the immediate vicinity of the contacts, although they are most numerous in such localities, but are of frequent occurrence farther within the mass. This will be understood when we remember that we are nowhere far from the former batholithic roof within the area of granitic outcrops.

The xenoliths are mostly small, averaging about six inches across, but some are very large. Near a contact of biotite schist one was observed three hundred feet in length. Some have sharp borders but mostly they have gradational contacts with the surrounding igneous material and often are rather thoroughly recrystallized with loss of their original characteristics. In such cases they may be difficult to distinguish from cognate inclusions but are usually recognizable by their strong resemblance to known xenoliths.

Production of the hybrid rocks may be considered to result from incomplete incorporation of the materials derived from the xenoliths into the batholith or by the local concentration of these substances.

Various types of hybrid rocks may be recognized, differing from each other in both composition and texture. A striking feature is the uniformity of the types. A specimen taken from near the contact in one locality may be indistinguishable from a sample from a similar occurrence ten miles

PLATE LXXXV.

Description of figures.

Fig. I. - Contact rock. The large grains are relicts of plagioclase (oligoclase) and albitized potash feldspar. The dark grains of the groundmass are mostly biotite and epidote with some hornblende. The lighter grains are quartz and feldspar. Crossed nicols. X10

Fig. II. - Another field in the same section but nicols not crossed. The large grains are feldspar relicts, both plagioclase (oligoclase) and albitized potash feldspar. The dark minerals of the groundmass are chiefly biotite and epidote with some hornblende. The light colored grains of the groundmass are quartz and feldspar. X10.

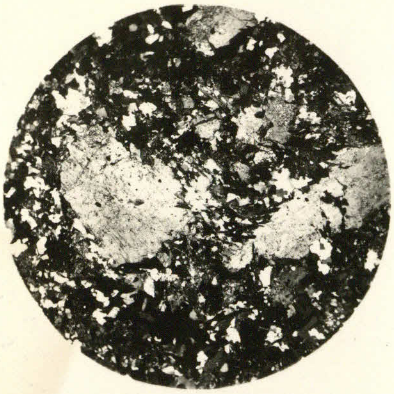
Fig. III. - Contact rock with composition of hornblende diorite. The light colored grains are andesine, the dark ones are sodic hornblende. Crossed nicols. X10.

Fig. IV. - Contact rock. The large light grains with ragged outlines are almost completely albitized microcline and chess-board albite (just outside the field shown). The larger and roughly equidimensional dark grains are sodic hornblende, the smaller ones, often somewhat elongated, are biotite. The small light-colored grains of the groundmass are quartz and feldspar. Crossed nicols. X10.

Fig. V. - Contact rock. In the field shown are grains of sodic hornblende (large dark grains), biotite (small dark flakes) and epidote (small medium dark granules) in a mesostasis of plagioclase feldspar. Between crossed nicols the latter shows vague albite twinning and it has an index about equal to that of Canada balsam. Nicols not crossed. X22.

Fig. VI. - This is a view at lower magnification of the field shown in Plate LXXVIII, Fig. VI. The dark grain in the center of the field is the plagioclase with a fringe of myrmekite where it borders potash feldspar to the left. Notice that this myrmekite fringe is continuous with a replacement zone along the border between the large biotite grain (dark) just above and the same potash feldspar. Below, right to left, is a vein lined with quartz. This is probably of later origin. Crossed nicols. X10.

Photomicrographs by the author.



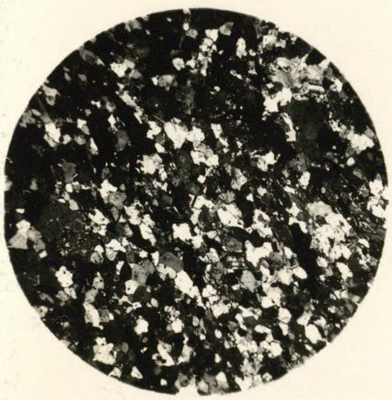


PLATE LXXXV

Fig. I

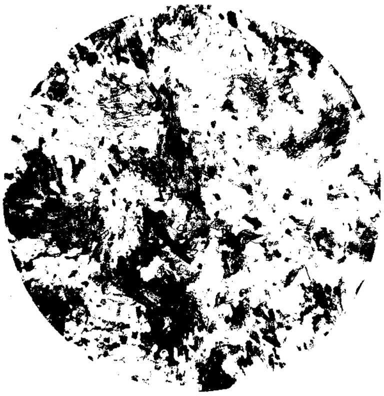


Fig. II

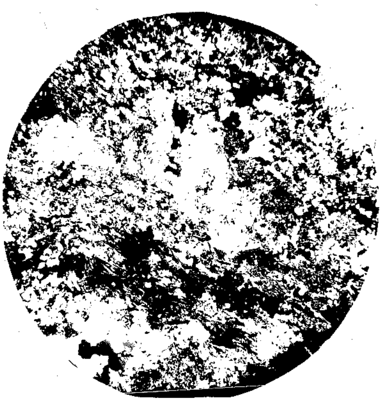


Fig. III

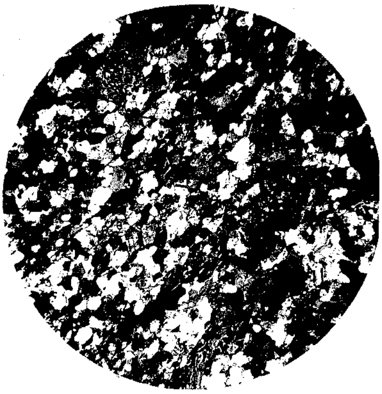


Fig. IV

Fig. V

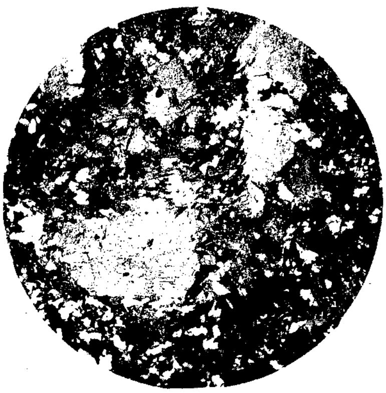


Fig. VI

away. The conditions controlling the production of the various types have not yet been worked out. They are probably related to the character and composition of the invaded sediments and to the distance from the present contacts.

The hybrid rocks may be fine or coarse-grained, even-grained or porphyritic. One of the common varieties is a fine-grained type with abundant hornblende which bestows a greenish color upon it. Another is similar to the one just described but with large grains of pink or gray feldspar set in the fine-grained matrix. A third type has a gneissic appearance with narrow bands of light and dark material in alternation. Under the microscope this structure is seen to be entirely due to the parallelism of the biotite, all other minerals being virtually equi-dimensional and without arrangement. Most types are without parallel structure.

Rocks of a mottled or spotted appearance are very common. This appearance is caused by the concentration of mafic constituents in certain small areas and of felsic minerals in others.

When microscopically examined, the hybrid rocks are seen to have as their chief constituents plagioclase feldspar, biotite, amphibole, epidote, and chlorite. in some cases a comparatively small amount of quartz may be present. Magnetite and pyrite are common constituents but occur in smaller quantities. Olivine was found in some instances. In some of the types plagioclase feldspar and

PLATE LXXXVI.

Description of figures.

Fig. I. - Sericitization of feldspars in granite. The light grain in the center of the figure is quartz. Below is a large grain of "chess-board" albite, the chess-board structure being barely discernible in the photomicrograph. Above the same quartz grain is one of primary plagioclase (oligoclase). Other plagioclase grains are to the right and left. The dark grains are quartz at extinction position. The speckled appearance of all the feldspars is due to the presence of numerous minute grains of sericite. Crossed nicols. X10.

Fig. II. - Marginal phase of granite intrusive into sediments. The minerals are quartz, microcline, albite, sericite and some garnet. Crossed nicols. X10.

Fig. III. - Amphibolite from contact zone. The minerals are sodic hornblende, tremolite, chrysotile, chlorite and rutile. Nicols not crossed. X10.

Fig. IV. - Hornblende-quartz-diorite from contact zone. The minerals are andesine, hornblende, biotite and some quartz. Epidote, biotite and chlorite occur in a second generation of minerals. The photomicrograph shows the texture. Crossed nicols. X10.

Fig. V. - Contact rock. The large light-colored grains to the left and right are completely sericitized feldspars - original composition indeterminable. The dark mineral at the lower right is chlorite filled with a very fine opaque dust. The gray minerals composing most of the field are hornblende, tremolite and chlorite. Nicols not crossed. X10.

Fig. VI. - Quartz-biotite-hornblende-diorite, near quartz monzonite. The photomicrograph shows the texture. The gray grain with good cleavage just below the center is hornblende. To the left are several grains of biotite. The plagioclase is andesine. The biotite and the hornblende are in about equal amounts in the section. Crossed nicols. X10.

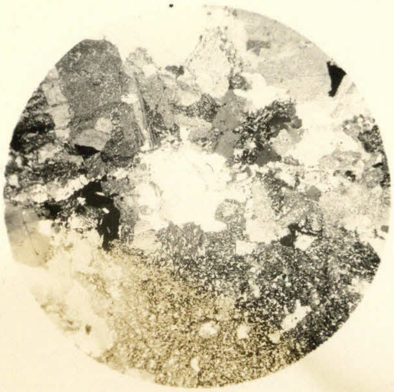
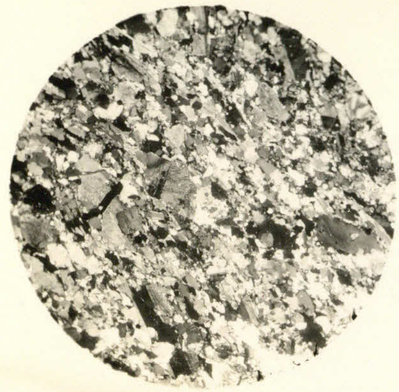
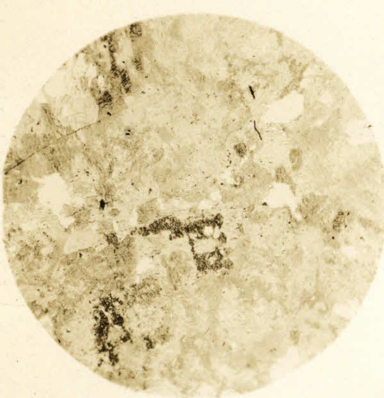
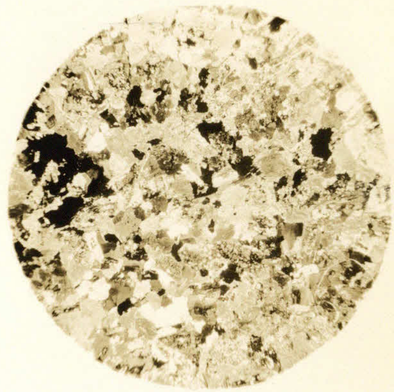
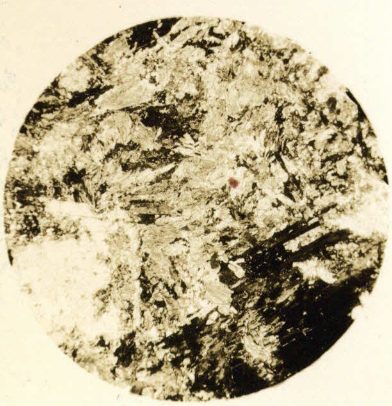
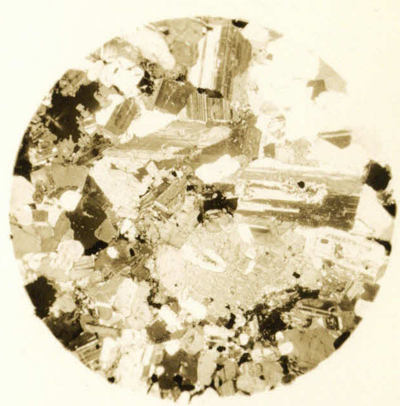







PLATE LXXXVI

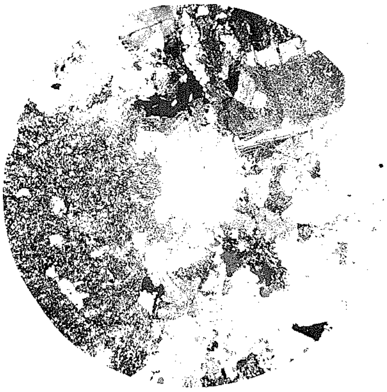


Fig. I

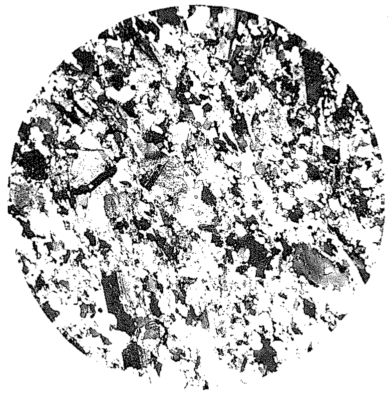


Fig. II

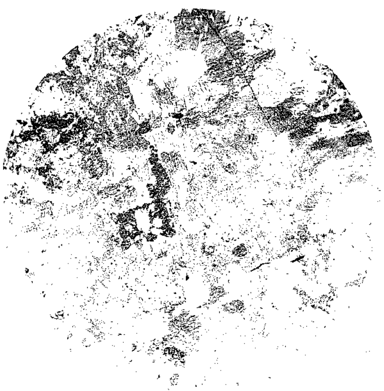


Fig. III

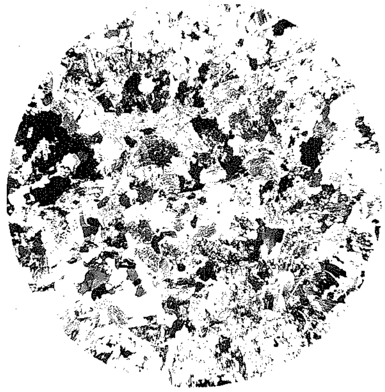


Fig. IV

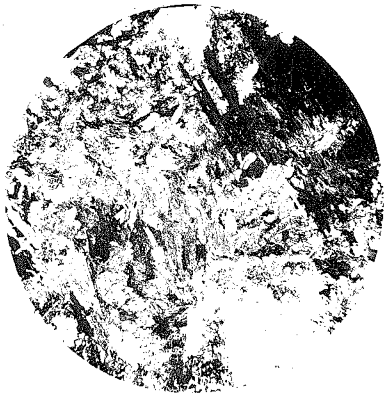


Fig. V

Fig. VI

amphibole are almost the only minerals present.

The plagioclase feldspar of the hybrid rocks is almost always andesine of approximate composition Ab_{60} An_{40}. Occasionally it may be oligoclase or albite-oligoclase. It occurs usually in small equidimensional grains.

The amphibole is remarkably uniform in character. Wherever it is found in the hybrid rocks it has an extinction angle Z on c of 20° and is strongly pleochoric with X= pale greenish yellow, Y=medium green and Z =bluish green to greenish blue. Its sodic content is probably high and it may be regarded as sodic hornblende or perhaps as an abnormal glancophane. In general it is found in rather small, short prisms but in some cases may be considerably elongated. A fibrous amphibole frequently occurs, pale green in section and pleochoric. It may be actinolite.

The biotite is likewise of uniform appearance. It is a strongly pleochroic variety with X=pale yellow, Y= pale greenish yellow or, in some cases, golden brown and Z=deep olive green, often almost opaque. It may occur in elongated grains in some cases or in short, nearly equidimensional ones in others. Both the amphibole and the biotite frequently contain great numbers of slender prisms of rutile in reticulate arrangement. Apatite also occurs, although not commonly.

Epidote is very common in many of the hybrid rocks, as is also chlorite. The former may appear as an alteration product of the plagioclase feldspars and the latter of either hornblende or biotite but both usually are found as independent grains.

Quartz, where it occurs, is usually in equidimensional grains and possesses no abnormal characters.

In most of the hybrid rocks studied the plagioclase exceeds the hornblende in amount. A typical sample contains 60% of andesine, 35% hornblende and 5% biotite. In some cases the hornblende and plagioclase were approximately equal in amount, while in a few others biotite increases at the expense of hornblende. In general it may be said that the hybrid rocks are approximately of the composition of a diorite.

Occasionally, as to the southwest of Queen Canyon, coarse-grained amphibolites are found which contain hornblende, a fibrous type of amphibole, much chlorite containing quantities of dust-like particles of magnetite or a similar mineral, epidote, calcite and leucoxene pseudomorphous after titanite. The amphiboles and chlorite compose at least 80% of the rock. Feldspar and quartz were not observed in the sections.

The porphyritic varieties are of two kinds - those in which the phenocrysts are relicts of a pre-existing igneous rock, nearly always corroded and partly destroyed, and those in which they are metacrysts. In the former case the rocks are blastoporphyritic, in the latter they are porphyroblastic[1]. The relict phenocrysts are almost invariably of altered microcline or of albite; the metacrysts are nearly all oligoclase. Both are set in a fine-grained matrix consisting of feldspars, biotite and hornblende with occasionally some quartz.

ENDOMORPHISM OF THE INTRUSIVE ROCKS

The formation of the hybrid rocks was in some degree an endomorphic process. Independently of this, however, there is a decided tendency for a gradual change to take place in the character of the intrusive as the contact zones are approached. This is especially noticeable on the eastern margins of the batholith. The changes have not been carefully investigated microscopically but from field observations there appears to be a decrease in the quartz content and an increase in the proportion of the mafic minerals.

STAGES OF METAMORPHISM

Gillson has called attention to a succession of overlapping stages in the contact metamorphism in the rocks of the Pend Oreille District in Idaho[2]. The idea of the stages of metamorphism was first suggested in the United States by Spurr, Garrey and Fenner in their report on the

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1. Tyrrell, Principles of Petrology, New York, 1926, p.270.
2. Gillson, Jos.L. - Contact Metamorphism of the Rocks in the Pend Oreille District, Northern Idaho. U.S.G.S. Prof. Paper, 158, 1929, pp.111-121.


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PLATE LXXXVII

Figure I
Knotenschiefer from Queen Canyon. About 4/5 Natural size.

Figure II
Amygdaloidal basalt. Natural size.

Dolores Mine at Matehuala, Mexico[1], and, according to Gillson, was afterwards used by several other investigators.

The stages recognized by Gillson are, first, the stage in which the magma is molten and heat is most effective; second, that in which the magma is crystallizing with the margin probably already solid and pneumatolytic emanations carrying mineralizers are most important and, third, the final stage in which the igneous rock is solid and abyssal hydrothermal emanations are chiefly active.

In the contact aureole of the White Mountain batholith no evidence for such a sequence has been observed. It is possible that it once existed but was confused or destroyed in the latter phases of the metamorphism. Without going into detailed discussion at this time, it may be stated that the observations made upon the contact phenomena in the field suggest that the magma was not emplaced as a single mass in a short space of time but that it reached the position indicated by the present batholith in a series of movements no one of which may have involved the entire molten body. As the earlier parts of it stopped or otherwise advanced into position, they appear to have assimilated parts of the country rock with consequent important modifications in their own composition. Rapid chilling by contact with these still cold country rocks produced fine-grained border phases which are representative of the early stages in crystal growth in the magma as modified by the ingestion of

1. Econ. Geol. Vol.7, 1912, pp. 471-474.

foreign material. Later, though perhaps before these advance guards of the moving magma became entirely solid, they were reinforced by additions of fluid material from below. This second surge of magma may have been followed by a third and this, in turn, by a fourth and so on to the complete emplacement of the batholith. Each succeeding uprush of molten magma was probably greater than the earlier ones, and the time between successive surges became progressively less.

The earlier emplacements, as has been stated, produced the chilled border phases. They also began the impregnation of the sediments with magmatic emanations, the degree of impregnation being dependent in part upon the character and condition of the sediments and in part upon the size of the intrusive. The later movements not only continued the processes begun in the earlier stages but brought about changes in the earlier-formed fine-grained border zones. In places these later movements broke through the border zones and brought molten material, which because of its greater amount possessed a higher thermal content, into direct contact with sediments rather thoroughly heated in the preceding stages of the intrusion. Thus we find at one place coarse-grained plutonic rocks in direct contact with thoroughly recrystallized and marmorized limestones. Nearby limestones of the same original character, impregnated with magmatic material but not recrystallized, are in contact with fine-grained border phases of the intrusive or with hybrid rocks. Either of the latter at a greater or less distance from the known sediments, may frequently be observed to form intrusive breccias with the same coarser-grained rocks. These observations likewise may serve to explain why so frequently, both in the argillaceous and in the calcareous sediments, an earlier period of impregnation and even of lit-par-lit injection of the country rocks with fluids of low viscosity and great penetrating power is followed by one in which materials more completely representative of the composition of the magma - often aplites or fine-grained granites - form dikes and other cross-cutting structures which obliquely transgress the planes of bedding or schistosity and the igneous matter injected above them.

Interpreted in the same way, the blastoporphyritic rocks may be considered as products of one of the earlier stages of magmatic invasion, with subsequent modification and partial replacement during a later influx of molten material.

If these are the processes by which the intrusion of the batholith took place, no simple succession of stages of metamorphism nor regular arrangement of zones is to be expected. These are in fact the conditions which prevail in the contact aureole of the White Mountain batholith.

Plate LXXXV111

Description of figures.

Fig. 1 - Olivine basalt. The dark phenocrysts are olivine, largely altered to iron oxide, in a pilotaxitic groundmass consisting of lath-like micrrolites of labradorite, interstitial granules of augite and magnetite. Crossed nicols. X10

Fig. 11 - Rhyolite. The phenocrysts are of quartz in a spherulitic fluidal groundmass. Crossed nicols. X10.

Fig. 111 - Reaction rim of magnetite surrounding augite in basalt. Crossed nicols. X22

Fig. lV - Contact rock, showing texture. The dark minerals are mostly sodic hornblende with a small amount of epidote in a mesostasis consisting of interlocking grains of andesine with a little quartz. Crossed nicols X10

Fig. V - Mustang Mountain basalt. The light colored elongated grains are augite, the small ones are olivine. The plagioclase phenocrysts are labradorite-bytownite in a hypohyaline groundmass. Crossed nicols. X22

Fig Vl - Basalt north of Dry Canyon. This field includes the one shown at higher magnification in Fig. 111. The phenocrysts are basic andesine set in a hyaloophitic groundmass with feldspar microlites of median andesine. Crossed nicols. X10.

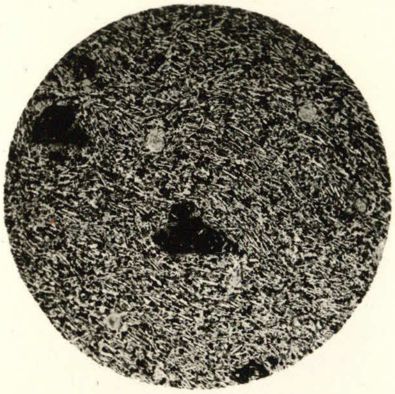
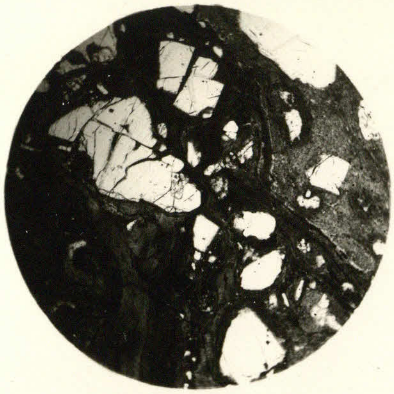
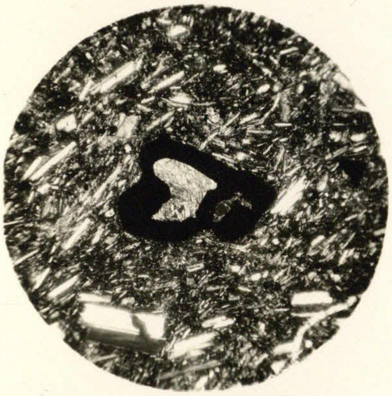
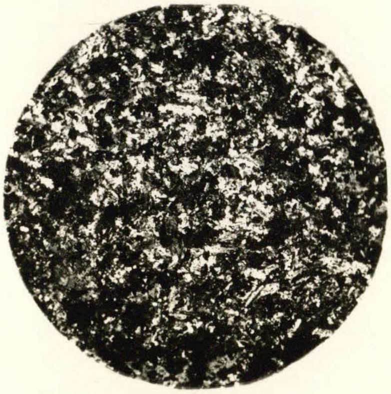
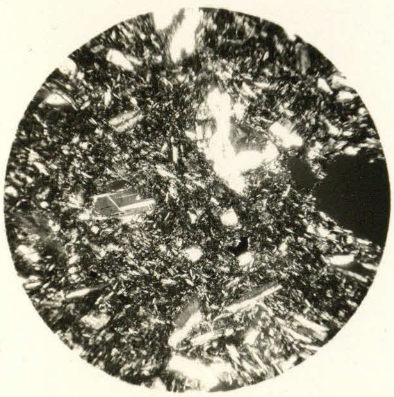
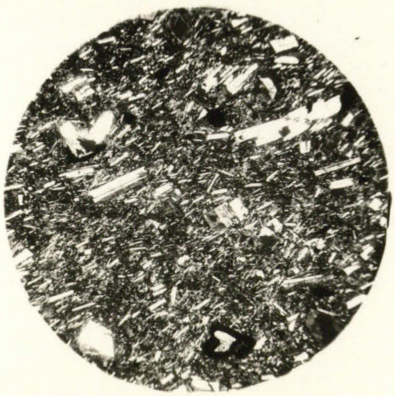

Plate LXXXVIII

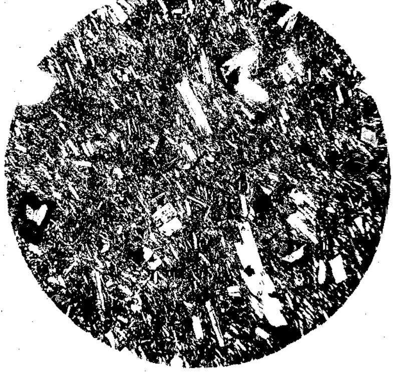

Fig. I

Fig. II

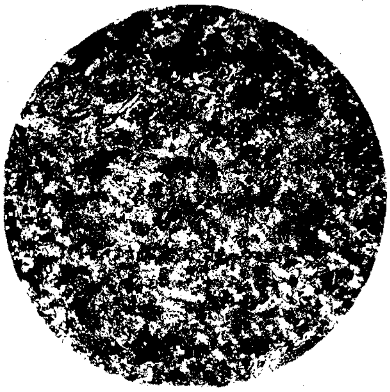

Fig. III

Fig. IV

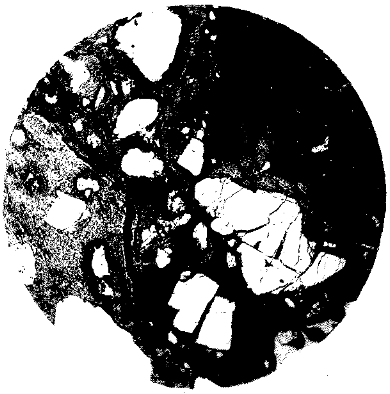

Fig. V.

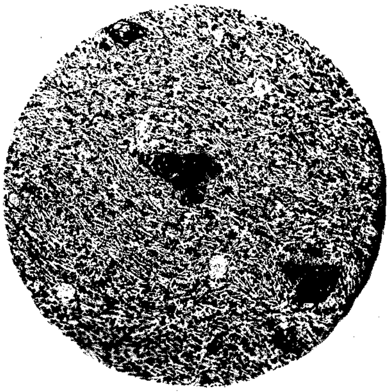

Fig. VI

THE VOLCANIC ROCKS

Petrographic study of the Tertiary and Quaternary volcanics in the White Mountain region has thus far failed to disclose any unusual or important features. Thus far some fifty sections prepared from samples collected in various parts of the area have been carefully examined under the petrographic microscope. This would seem to be a fair base on which to erect generalizations.

TERTIARY VOLCANICS

The rocks of the Tertiary volcanic series are predominantly of rhyolitic composition. They include some andesites and perhaps some trachytes but the intermediate rocks are greatly in the minority. Flows, breccias and tuffs are the chief modes of occurrence.

The Tertiary rocks are mostly light in color. The rhyolitic flows are mostly light or dark pink; the andesites are gray or greenish gray. The tuffs are mostly white but where they underlie Quaternary basalts they are usually yellow, brown or red. In zones of hydrothermal alteration the flows may be bleached and whitened or they and the tuffs may be stained pink or green or red producing a vivid array of colors which instantly attracts the attention and admiraation of the observer.

Virtually all of the Tertiary volcanics are hypocrystalline. The amount of glass present in the groundmass

PLATE LXXXIX

Figure I

"Felsite" from south branch Indian Creek. Natural size

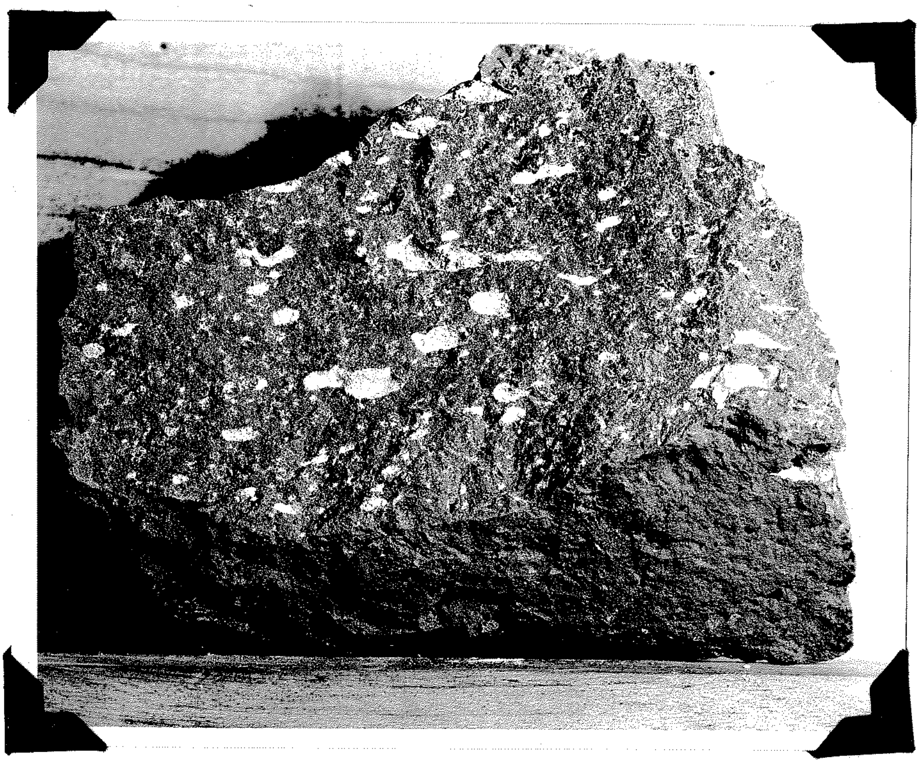

Figure II

Amygdaloidal basalt from north of Trail Canyon. Natural size.

is variable. In some specimens, especially those obtained from the top or bottom of flows, the proportion of glass is very high. Perlitic textures are common in these rocks. Most of the flows have a cryptocrystalline groundmass with fluidal and spherulitic textures well developed. In many of the tuffs also the component minerals are for the most part too finely divided to be identified.

The proportion of phenocrysts to groundmass is also variable. In several cases only one or two phenocrysts could be discovered in a large section; in the hand specimen they are almost entirely indiscernable. In other cases the phenocrysts are so numerous as to justify calling the rock, except for its occurrence, a rhyolite porphyry.

Quartz and sanidine are usually present as phenocrysts, occasionally accompanied by biotite and also by albite or oligoclase. Rarely green hornblende is observed. The quartz may diminish or disappear, thus leaving sanidine the only recognizable constituent of the rock. In other cases the phenocrysts are entirely of quartz. Where both quartz and sanidine occur among the phenocrysts, the sanidine is usually much in excess.

In the zones of hydrothermal alteration which parallel the Davis Fault zone north of Trail Canyon, the chief effect has been silicification of the tuffs and bleaching and silicification of the rhyolite flows. Propylitization of the andesites has occurred to some extent in those parts

PLATE XC

Descriptions of figures.

Fig. 1 - Spherulitic texture in rhyolite. The phenocryst in the lower right is sanidine. From porphyritic rhyolite, hill west of Red Rock Mine. Crossed nicols. X10

Fig. 11 - Spherulitic fluidal texture in rhyolite, Trail Canyon. Note the spherulite just under the light colored grain to the left. The flow lines bend around the phenocryst. Crossed nicols. X22

Fig. 111 - Reaction rim around augite in basalt. The dark grain to the left of the center and the large light colored one above, both with granular borders, are augite. The plagioclase phenocrysts are labradorite in a hyalopilitic groundmass. From basalt north of Queen fault zone. Crossed nicols. X10

Fig. IV - Biotite-hornblende-andesine from Black Mountain. The large grain in the upper left is a zoned plagioclase. Several flakes of biotite can be seen in the field. The feldspar phenocrysts are of oligoclase-andesine. Brown hornblende is also present. The groundmass is hyaloophitic. Crossed nicols. X10

Fig. V - Reaction rim around basaltic hornblende in basalt. The small grain with a black border near the center of the field is basaltic hornblende; the rim is magnetite. The occurrence is similar to that shown in Plate LXXXV111, Fig. 111, but hornblende takes the place of magnetite. Crossed nicols. X10

Fig. V1 - Beginning stage of pseudo-cataclastic texture in granite. Plate LXX111, Fig. 11, is an enlargement of part of this field. Note how the "veins" follow the grain boundaries, also how they coalesce in the lower right of the field. Crossed nicols. X10.


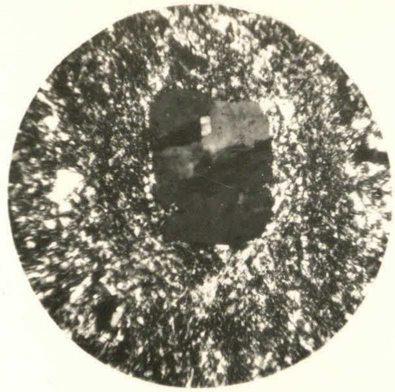
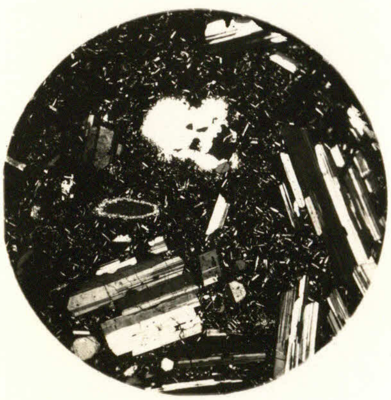
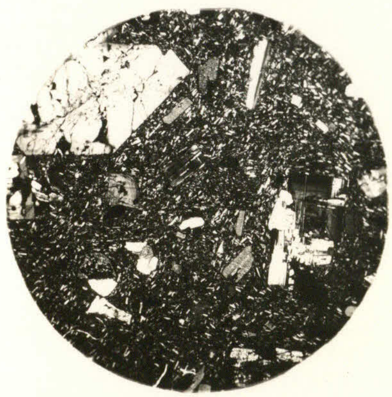
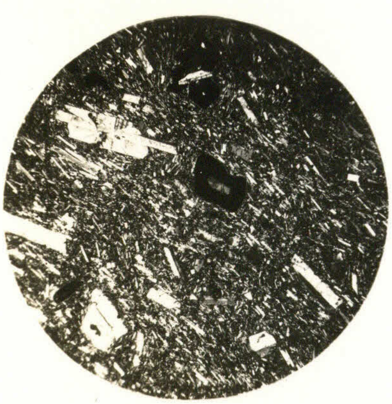


PLATE XC

Fig. I

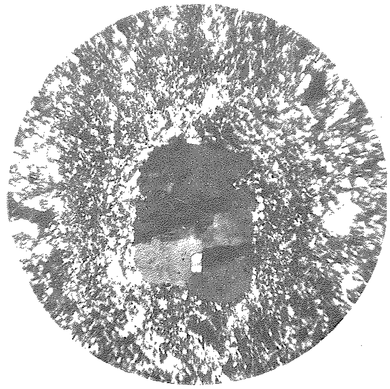

Fig. II

Fig. III

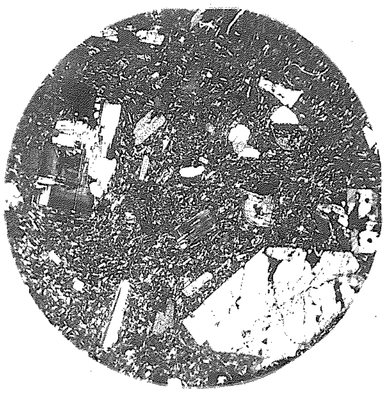

Fig. IV

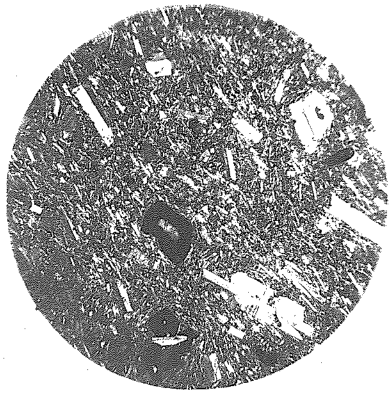

Fig. V

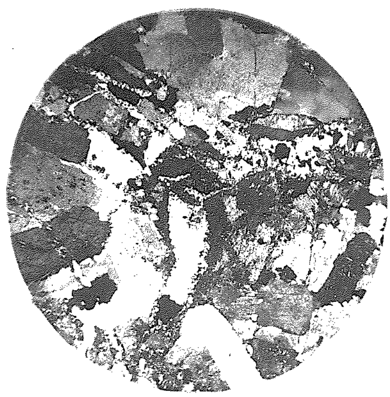

Fig. VI.

of the zone in which they occur. Locally the basalts have been reddened by oxidation. In some places, as near the abandoned village of Gold Hit, the basic rocks have been serpentinized. A mineral which is probably alunite has been observed in the Red Rose Mine on Sugarloaf Mountain[1]. In general it should be said, however, that silicification of the volcanic rocks is by far the most extensive effect of the period of hydrothermal activity[2].

Photomicrographs illustrating the chief microscopic features of the Tertiary volcanic rocks will be found in Plate LXXXVIII, Fig.2, Plate XC, Figures 1 and 2, and Plate XCIII, Figures 1, 2 and 4.

The following brief description of occurrences in various parts of the area mapped will give a general idea of the Tertiary volcanic rocks.

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1. Ransome, F.L. - Personal Communication.
2. Attention should be directed to the fact that by no means all of the secondary silica present in these rocks was deposited by hydrothermal solutions. Obviously it has in many cases been leached from various members of the series and redeposited by percolating surface waters. As indication of how extensively this has occurred, I may say that frequently in the talus cones accumulating at the base of outcrops of the rhyolitic flows he has observed spalled-off fragments cemented by chalcedony where there is no possibility that hydrothermal activity has occurred.

   On the other hand the effects of hydrothermal action in the zones of the eastern marginal faults are not only apparent in the alterations which the volcanic rocks have undergone but in the abundant occurrence in certain localities, as, for example, a quarter of a mile south of Sugarloaf Mountain, of materials characteristically deposited by hot springs.

108-109

PLATE XCI

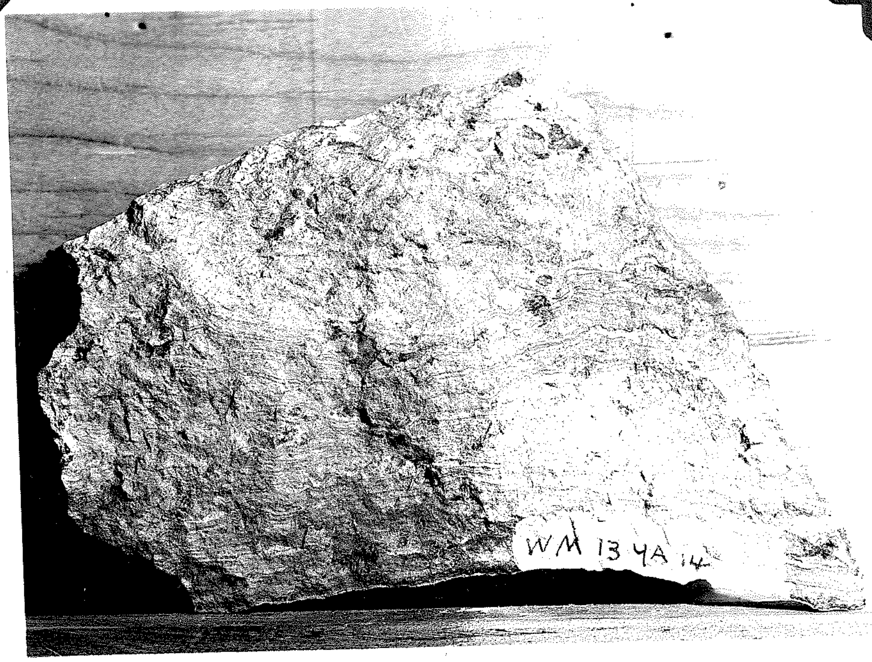

Figure I
Rhyolite from Trail Canyon, showing flow structure. Natural size.

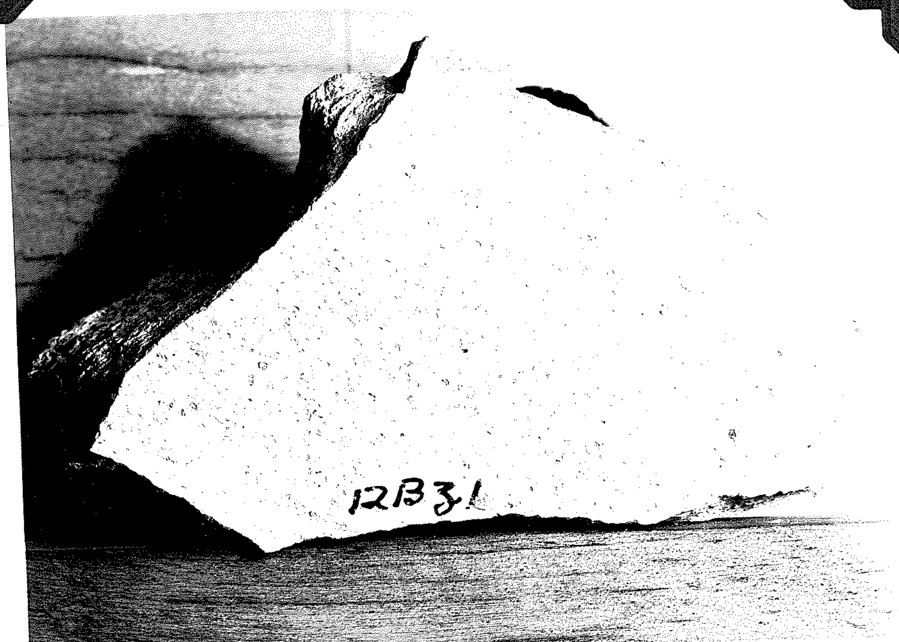

Figure II
Silicified rhyolite tuff from vicinity of B and B Mine. Natural size.

Overlying early or pre-Paleozoic limestones on the crest of the ridge just south of lower Dry Canyon are rhyolitic flows two or three hundred feet in thickness. The lowermost part is a black obsidian containing spherulites. Ten feet above the base is a vitrophyre twenty-five or thirty feet thick, which contains phenocrysts of quartz, sanidine and some biotite in a glassy groundmass with perlitic texture. In one of the sections many tiny rod-shaped feldspar microlites were observed which, exhibiting a maximum extinction angle of thirty-six degrees from the direction of their elongation, are probably labradorite.

Just above the vitrophyre is a layer containing phenocrysts of quartz and orthoclase in a hypocrystalline groundmass in part spherulitic, containing scopulites, trichites and other crystallites.

The middle portion of the flow is a pink rhyolite with prominent phenocrysts which, under the microscope, are seen to consist of quartz, sanidine, oligoclase, and a little biotite. The groundmass is cryptocrystalline with marked fluidal texture and containing many spherulites. The phenocrysts are often partially resorbed and appear to contain many inclusions of groundmass (although these apparent "inclusions" may be sections of corroding embayments of groundmass in the phenocrysts from above and below the plane of the section). The groundmass contains some chalcedonic silica, in cavities.

PLATE XCIII.

Description of figures.

Fig. I. - Perlitic structure, base of rhyolite flow near B and B Quicksilver Mine. Note the partially resorbed feldspar phenocryst, upper right. Nicols not crossed. X22.

Fig. II. - Pumice, uppermost part of same flow. Nicols not crossed. X22.

Fig. III. - Olivine basalt from northwest of Montgomery Pass. The phenocrysts are olivine, each with a border of iron oxide, in a pilotaxitic groundmass. Nicols not crossed. X10.

Fig. IV. - Vitrophyre. Lowest part of rhyolite flow west of Red Rock Mine. The phenocrysts are quartz and sanidine in a glassy groundmass containing some rod-shaped microlites of andesine. Crossed nicols. X10.

Fig. V. - This is the same field shown in more detail in Plate LXX, Fig. IV. Shows secondary matrix of pseudo-cataclastic texture with fringe of myrmekite where it borders microcline.

Fig. VI. - Pseudo-cataclastic texture in granite. The vein extending from right to left across the field is of quartz bordered below with biotite. In the upper right is an embayment into orthoclase, fringed with myrmekite (mostly just off the field). Crossed nicols. X22.

109-110

PLATE XCII

Figure I
Pyroclastic containing glass and pumice. Natural size.

Figure II
Rhyolite showing flow structure. From Mustang Mountain. Natural size.

The above sequence is repeated in detail in a rhyolite flow in the hills just north of Wildhorse Flat. The uppermost part of this rhyolite, in addition, is a pumice which, under the microscope, is seen to be almost completely glassy.

Just north of the point at which the 7800 foot contour crosses Trail Creek, a thick layer of pink rhyolite is exposed. A sample of this rhyolite contains phenocrysts of sanidine (80%) and quartz (20%) in a hypocrystalline fluidal groundmass. The latter contains many small grains of quartz arranged along the flow lines and concentrated in forms like "pressure shadows"[1] about the phenocrysts. This quartz may be due to devitrification but is more probably the result of deposition from impregnating solutions.

Just north of the point at which the 9000 foot contour crosses Trail Creek is the remnant of a flow consisting of a felsophyre which contains a few phenocrysts of an undetermined feldspar in a cryptocrystalline groundmass.

A porphyritic rhyolite from which a sample was collected three miles east of Nichols station consists of phenocrysts of quartz (80%) and an untwinned feldspar (20%) in a cryptocrystalline groundmass containing spherulites.

Two miles southeast of the abandoned village

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1. See Pabst, A. - Amer. Mineralogist, Vol.16, 1931, pp.55-70.

of Gold Hit are extensive flows from which several samples were taken. All of these contain scattered phenocrysts of sanidine in a hypocrystalline spherulitic groundmass. In some of the sections a few phenocrysts of quartz are present and occasionally some deep brown pleochroic biotite.

Underlying the basalts on Pinto Hill about a mile south of Sand Springs is a felsite which under the microscope is seen to contain in some slides a few scattered phenocrysts of oligoclase in a cryptocrystalline fluidal groundmass which in some slides includes tiny microlites which have 0° extinction and are therefore oligoclase. The phenocrysts are absent from some of the sections. No quartz occurs as phenocrysts in any of the slides.

The middle part of a rhyolite flow two miles northeast of the B. and B. Quicksilver mine contains abundant phenocrysts of sanidine (50%), quartz (40%) and oligoclase (10%), of composition $Ab_{75}An_{25}$ in a spherulitic groundmass.

The tuffs are frequently so fine-grained as to make their component minerals impossible of microscopic determination. For example, the tuff which underlies the rhyolite last described contains no grains or fragments large enough for determination. Small untwinned feldspars almost square as seen in section, are observed in the groundmass. Elsewhere the tuffs contain fragments of quartz, oligoclase, biotite and various other minerals in small numbers, besides fragments of glass.

PLATE XCIII.

Description of figures.

Fig. I.- Perlitic structure, base of rhyolite flow near B and B Quicksilver Mine. Note the partially resorbed feldspar phenocryst, upper right. Nicols not crossed. X22

Fig. II. - Pumice, uppermost part of same flow. Nicols not crossed. X22

Fig. III.- Olivine basalt from northwest of Montgomery Pass. The phenocrysts are olivine, each with a border of iron oxide, in a pilotaxitic groundmass. Nicols not crossed. XI0

Fig. IV.- Vitrophyre. Lowest part of rhyolite flow west of Red Rock Mine. The phenocrysts are quartz and sanidine in a glassy groundmass containing some rod-shaped microlites of andesine. Crossed nicols. XI0

Fig. V.- This is the same field shown in more detail in plate in Plate LXX, Fig. IV. Shows secondary matrix of pseudo-cataclastic texture with fringe of myrmekite where it borders microcline.

Fig. VI.- Pseudo-cataclastic texture in granite. The vein extending from right to left across the field is of quartz bordered below with biotite. In the upper right is an embayment into orthoclase, fringed with myrmekite (mostly just off the field). Crossed nicols. X22

Photomicrographs by the author.

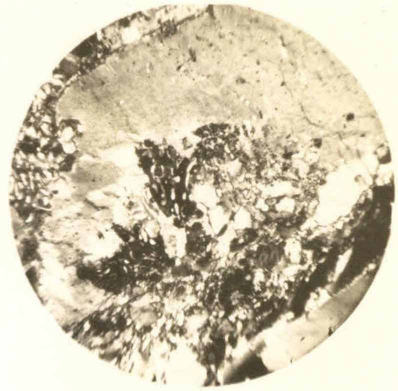
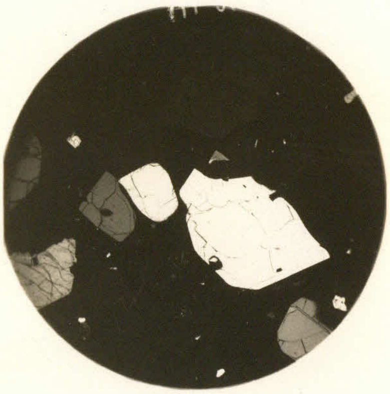
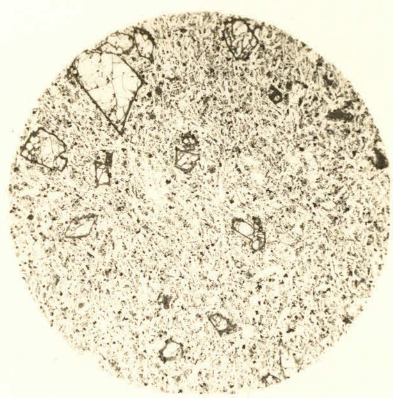





PLATE XCIII

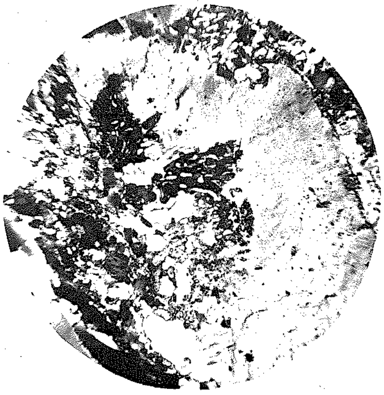


Fig. I

Fig. II

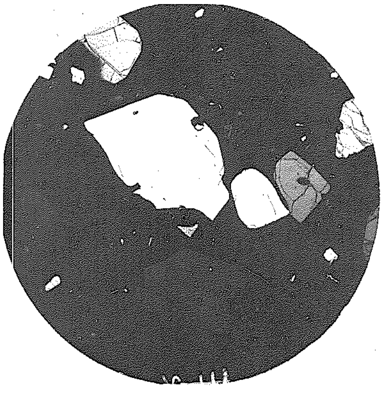


Fig. III

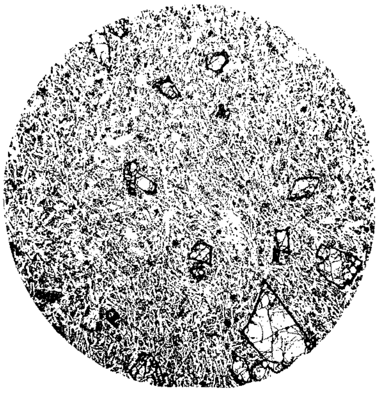


Fig. IV

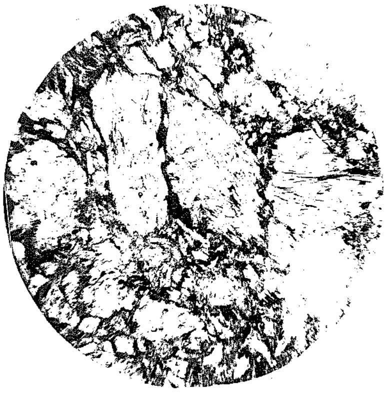


Fig V

Fig. VI

A silicified rhyolitic tuff which is found just west of the point at which the 6500 foot contour crosses the road from the Chiatovich Ranch to Trail Canyon contains phenocrysts of sanidine and quartz in a groundmass composed chiefly of tiny grains of quartz with a small amount of glass. Although these quartz grains are distributed throughout the groundmass there is a tendency for them to concentrate and to increase in size in halos around the phenocrysts. There is thus produced an appearance closely similar to the "pressure shadows" of Pabst, but it has probably been produced by percolating siliceous solutions.

Another section prepared from a white silicified tuff occurring in the zone of hydrothermal alteration near the B. and B. Quicksilver mine shows under the microscope a complete replacement of the original feldspar phenocrysts and of the feldspar microlites of the groundmass by silica. The replacing silica of the microlites and of the outer rims of the phenocrysts is an isotropic form with index below that of balsam. It is probably opaline silica. The inner parts of the phenocrysts are of fine-grained quartz. The present groundmass is a granular aggregate of very finely divided quartz. No other minerals, except a little magnetite, are to be observed in the section.

QUATERNARY BASALTS

The rocks which have been grouped under the general designation of Quaternary basalts are somewhat variable in composition and texture. The ultrabasic types are rare or absent. On the other hand, sodic types are abundant. In the latter, enrichment in soda has not taken place by albitization of the plagioclases, as in the spilites; on the contrary, the soda appears to have been a primary constituent of the lava, forming sodic plagioclases in the groundmass.

In color the basic lavas are either very dark gray or black. For the most part they are fine-grained and hypocrystalline; holocrystalline varieties have been seen only occasionally. Although few of them are prominently porphyritic, the porphyritic texture is observable in all but one of the sections examined.

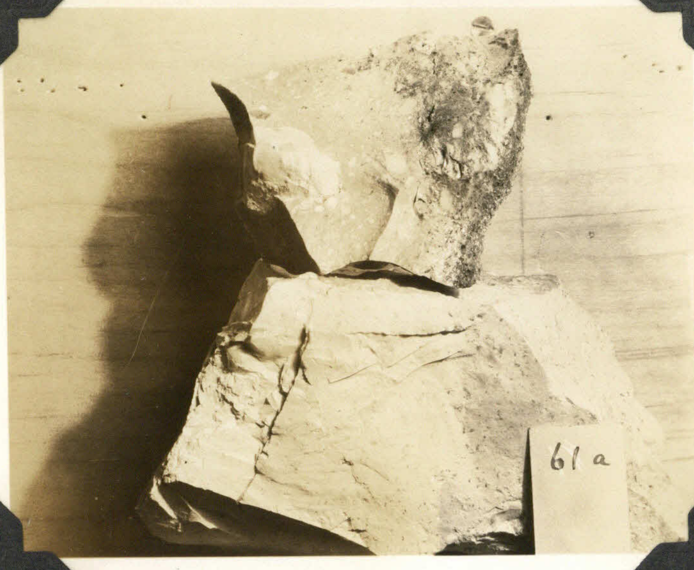
Vesicular and amygdaloidal varieties are frequently encountered in the upper portions of the flows. The minerals of the amygdules have not yet been determined.

The minerals of most common occurrence among the phenocrysts are, in order of increasing abundance, olivine, augite and plagioclase feldspar. Brown hornblende is rare and biotite more so. The olivine of the phenocrysts is mostly in euhedral or subhedral crystals and usually has a rim or border of iron oxide but is very little altered within. The augite is a non-pleochroic variety with good cleavage. It usually exhibits twinning. Both the augite and the olivine frequently show partial resorption effects; often these contain inclusions of the groundmass.

PLATE XCIV.

Figure I
Silicified tuff from B and B Mine. 3/4 natural size.

Figure II
Tuff from vacinity of Sand Spring. Natural size


61 a


104B
4
104B4

The plagioclase of the phenocrysts varies in composition from andesine of composition $Ab_{55}An_{45}$ in some cases to bytownite of $Ab_{30}An_{70}$ in others. It nearly always shows albite and sometimes a combination of carlsbad and albite twinning. It rarely shows any kind of secondary alteration.

The texture of the groundmass may be hyalopilitic, hyaloophitic, intersertal, intergranular or pilotaxitic. Diabasic (ophitic) texture has not been observed. The amount of glass is usually small but it is present in all but a few cases. The minerals of the groundmass are augite, olivine, magnetite and plagioclase feldspar. The first two occur usually in rounded granules distributed between the feldspars. The magnetite may be in grains with square or rectangular outlines of about the same size as the augite and olivine or it may be present as a fine dust in the interstitial glass.

The plagioclases of the groundmass may be in needle-like microlites or in skeleton or incomplete crystals, in some cases exhibiting albite or carlsbad twinning or both. They may be in sub-parallel or random orientation. In composition they vary from labradorite to oligoclase. Sometimes two distinct ranges of sizes of groundmass feldspars may be observed, in which case the larger are more calcic than the smaller.

From the above description it will be seen that the Quaternary lavas vary in composition from sodic andesites to olivine basalts. Although the majority of the occurrences are basic andesites many cases were observed in which the feldspars of the phenocrysts are labradorite or andesine and of the groundmass medium oligoclase and in which augite and sometimes olivine were also present in abundance.

Photomicrographs illustrating the Quaternary basalts may be found in Plate LXXXVIII, Figures 1, 3, 5, and 6 and Plate XC, Figures 3, 4, and 5.

The following brief descriptions will give an idea of the various types of lavas.

The lower part of the basaltic series which forms the top of Black Mountain north of Davis Creek is a porphyritic rock with a dense dark gray groundmass. Under the microscope this rock is seen to consist of phenocrysts of oligoclase-andesine ($Ab_{70}An_{30}$), biotite and brown hornblende in a hyalopilitic groundmass of oligoclase laths with a sprinkling of fine-grained opaque minerals. The phenocrysts, which are fairly large, show no resorption effects.

The large basalt area in the northwestern part of the quadrangle was sampled at various places. One of the samples obtained about three miles north-northwest of Queen Station showed phenocrysts of augite, labradorite and an unknown mineral in a hyalopilitic groundmass consisting of skeleton crystals of plagioclase of two orders of size, with

PLATE XCV

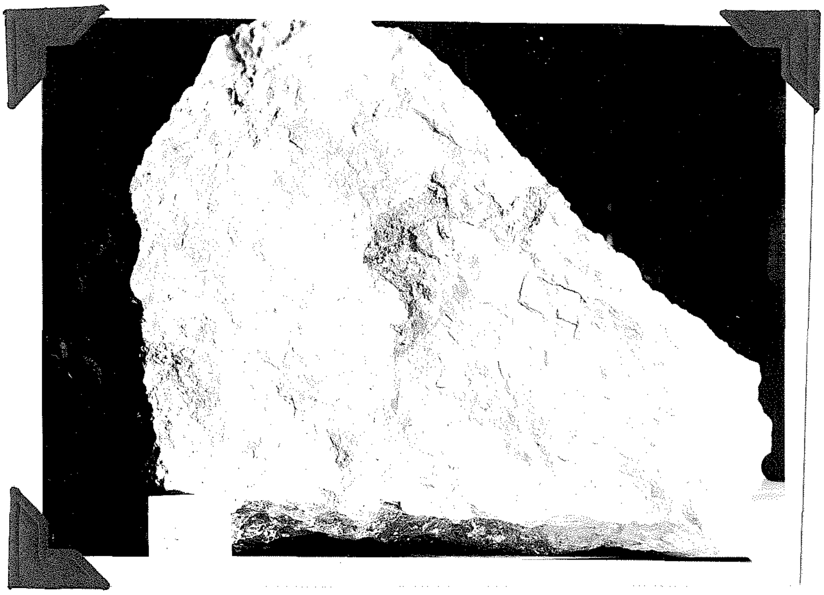


Figure I
Rhyolite flow-breccia from one mile north of B and B Mine. Slightly over 1/2 nautral size.

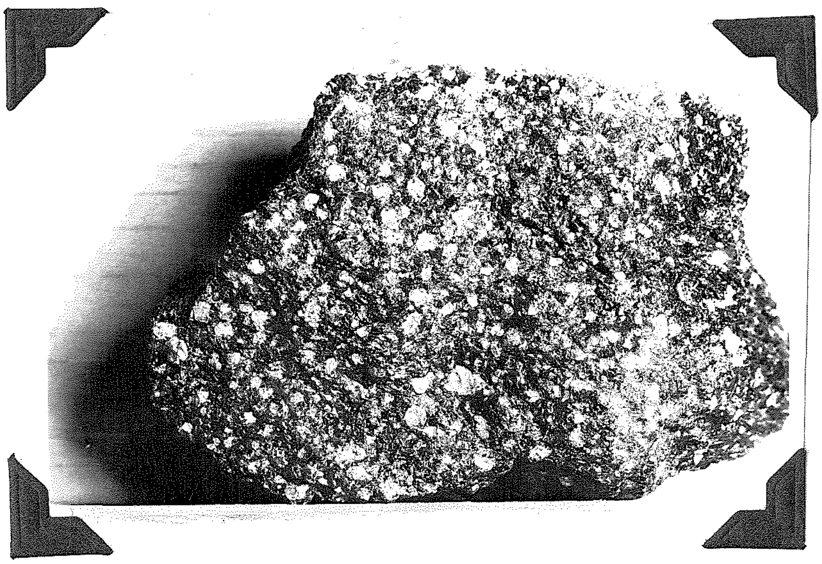


Figure II
Vitrophyre, bottom of rhyolite flow 1/2 mile west of Red Rock Mine. Natural size.


45a

intersertal glass and magnetite dust. The smaller plagioclases of the groundmass are oligoclase-andesine; the larger are ansedine-labradorite ($Ab_{50}An_{50}$). The labradorite phenocrysts have the composition $Ab_{40}An_{50}$, (as determined by measurements on a crystal showing combined carlsbad and albite twinning).

The augite shows typical pyroxene cleavage, better developed than in most cases, and a peculiar complex twinning on a plane oblique to the prismatic cleavage at about 35°. The optic sign is positive and the maximum extinction angle on the cleavage is 45°. It is non-pleocroic.

The unknown mineral is pale green, non-pleochroic and shows excellent cleavage parallel to the elongation. It has a rather low birefringence and is biaxial. The maximum observed extinction angle on the cleavages parallel to the elongation is 8°. From several excellent optic axis figures the optic sign was determined to be negative. The optic angle was estimated to be about 50°.

Both the augite and the unknown mineral are surrounded by reaction rims which are, however, better developed about the latter. In many cases the unknown mineral has been practically resorbed.

Serpentine occurs abundantly in irregularly-shaped masses throughout the rock.

A sample obtained from the basalt which occurs on Mustang Mountain east of Queen Canyon is that of a dense almost black variety with few phenocrysts which can be

PLATE XCVI

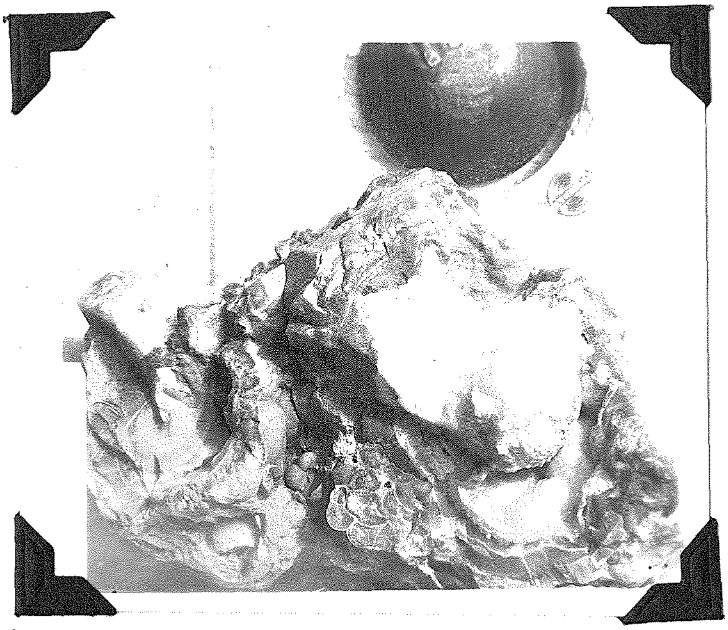
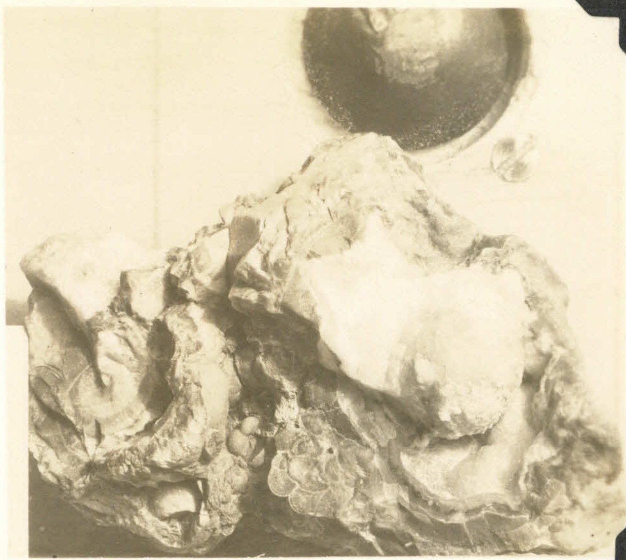


Fig.I
Opaline silica in rhyolite lithophysae from Mustang Mountain. About 4/3 natural size.

Fig. II
Lithophysae in rhyolite from east of Mustang Mountain. About 3/5 natural size.



observed megascopically. Under the microscope a section shows small phenocrysts of plagioclase in a hyalopilitic groundmass. Some secondary quartz occurs in small veins. The feldspars of the phenocrysts are labradorite-bytownite, $Ab_{30}An_{70}$, as determined by the measurement of extinction angles in a combined albite and carlsbad twin. The groundmass is composed of microlites and glass, liberally sprinkled with an opaque dust. The microlites all show extinction parallel to their long axes and may therefore be considered median oligoclase.

A slide prepared from a sample of basalt taken four miles directly north of Queen Station and a half mile south of the northern border of the quadrangle shows phenocrysts of olivine in a groundmass of plagioclase laths intersprinkled with granular augite and magnetite. All olivine phenocrysts are surrounded by a rim of iron oxide. The plagioclase laths of the groundmass have a composition approximately $Ab_{30}An_{70}$.

A section representing a small outcrop just north of the road nearly one mile north of the 6061 foot hill in the northeast sixteenth of the area mapped shows phenocrysts of hornblende set in a hyaloophitic groundmass containing laths of labradorite. All of the hornblende phenocrysts have a rim of magnetite and many of the smaller ones have been completely altered to magnetite. There is an abundance of magnetite dust in the groundmass. Megascopically the rock is greenish gray and rather dense with conspicuous hornblende phenocrysts.

From a small flow about three miles southeast of the abandoned village of Gold Hit a sample was taken which shows phenocrysts of andesine ($Ab_{55}An_{45}$) eighty percent, and augite, twenty percent, in a hypohyaline groundmass containing microlites and skeleton crystals of oligoclase-andesine ($Ab_{70}An_{30}$) with intergranular augite, magnetite and some hematite.

The basalts which occur just south of Sand Spring are for the most part somewhat more basic although the earlier flows are less so. A vesicular phase, representing the most recent part of a series, contained olivine phenocrysts in a pilotaxitic groundmass consisting of laths of labradorite ($Ab_{45}An_{55}$) with granules of augite, olivine and magnetite. A section from an earlier flow shows phenocrysts of andesine ($Ab_{55}An_{45}$) and some olivine in a hyalopilitic groundmass of feldspar microlites and glass. The phenocrysts are often partly resorbed. The microlites extinguish parallel to their long axes. There is much magnetite dust in the groundmass.

A sample collected about a mile northeast of the B. and B. Quicksilver mine is a dense nearly black rock with augite phenocrysts in a pilotaxitic groundmass of labradorite laths and granular augite and magnetite.

An amygdaloidal basalt occurring about one half mile northwest of Nichols station has a deep red groundmass containing, so far as could be observed, only a fine dust of opaque minerals, in which occur amygdules filled with material which, in most cases, is almost entirely converted to a mixture of sericite, chlorite and calcite. Unaltered portions are of a mineral which is either isotropic or of very low birefringence. It has not been identified.

A specimen taken about a mile northwest of Mount Montgomery station is classed megascopically as a medium gray hornblende andesite. Microscopically it is seen to consist of phenocrysts of labradorite, olivine and brown hornblende in a pilotaxitic groundmass consisting of subparallel laths of labradorite. The groundmass is sprinkled with magnetite and olivine but it contains glass.

The uppermost portion of the Black Mountain basalt is a dense almost black rock consisting of small augite phenocrysts in a hyalopilitic groundmass of lath-shaped feldspar microlites and skeleton crystals, probably andesine-labradorite ($Ab_{50}An_{50}$) with granular augite and glass. The augite of both generations is dull and stained greenish yellow to brown.

MINOR THESIS

Stratigraphy and Faunal Relationships of Pliocene Beds of San Diego Age in the Vicinity of Las Llajas Canyon, Simi Valley, California.

by George Harold Anderson

Overlying the Modelo Formation of Upper Miocene age north of Simi Valley is a series of arenaceous beds of marine origin whose stratigraphy and faunal relationships have heretofore been in doubt. At the suggestion of Dr. W. P. Woodring, then Professor of Invertebrate Paleontology at the California Institute of Technology, I undertook to study some of these beds as part of my preparation for the degree of Doctor of Philosophy. The following report covers in particular the section exposed from Las Llajas Canyon west to about two miles beyond Tapo Canyon.

Results of Previous Work.

On the geologic map which accompanies Bulletin 753 [1] of the United

[1] Kew, W. S. W., Geology and Oil Resources of a Part of the Los Angeles and Ventura Counties, California.— U. S. G. S. Bull. 753, (1924).

States Geological Survey, the beds here referred to are included with the Saugus Formation. This formation, as defined by Hershey, [2] who first des-

[2] Hershey, O. H., American Geologist, vol. 29, 1902, pp. 359-362.

cribed it was said to consist of " a great series of unlithified sand, gravel, and clay * * * * * whose physical characters are unmistakably those ofan alluvial deposit, a river delta, progressively sinking". It is well exposed, according to Hershey, in Soledad Canyon near Saugus, which is, presumably, the type section.

Kew [3] considers much of the formation as originally defined , in-

[3] Kew, W. S. W., Op. cit., p. 81.

cluding the "Lang Division", and the "Soledad Division", to be equivalent to the upper part of the Mint Canyon. The beds which he includes under the term Saugus formation are those which rest unconformably on the Pico and are unconformably overlain by Pleistocene terrace deposits. The term may therefore cover deposits of Middle or Upper Pliocene age or even of lower Pleistocene age. For the most part, according to his description, they are marine, but they grade northward and eastward into strata that are probably of fluviatile origin or are alluvial fan deposits. They contain a younger fauna than the Pico formation. The Saugus formation and the Pico together comprise the Fernando group.

It is evident from the above that the term Saugus is a very loose one, applicable to beds of both terrestrial and marine origin and of different positions in the stratigraphic sequence. As Woodring [1] has pointed out

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[1] Woodring, W. P., Pliocene Deposits North of Simi Valley, California. Calif. Acad. Sci. Proc. 4th Series, Vol. XIX, No. 6, 1930, p. 62.

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it "has been used as a catch-all for almost any Pliocene and Pleistocene beds in the Ventura and Los Angeles basins". Pressler's [2] work in the Las

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[2] Pressler, E. D., The Fernando Group in the Las Posas- South Mountain District, Ventura County, California. Univ. Calif. Pubs. Bull Dept. Geol. Sci., Vol. 18, No. 13, 1929, pp. 325-345.

Posas Hills, for example, has shown that in that region a lower part carrying a cool-water upper Pliocene fauna has been grouped with an upper part carrying a warm-water, probably interglacial, Pleistocene fauna under the designation " Saugus formation".

It seems highly advisable, in view of the inexactness of the name "Saugus" , that wherever possible the various dissimilar units which have been included under it should be separated out and their affiliations and proper position in the time scale determined. This would probably involve the renaming of much of what has been mapped as Saugus.

The stratigraphic and faunal studies made upon the so-called "Saugus" west of Las Llajas Canyon have thus far yielded the following results:

1) The beds exposed in this vicinity may be divided into two chief members separated from each other by an unconformity (probably local in character) and exhibiting a small but definite change in the fauna, and in lithologic character.

2) The fauna of the upper division is closely related to that of the San Diego formation of Middle Pliocene Age. That of the lower division is too small to be useful as a basis for a definite conclusion. It is thought probable that it represents a lower part of the San Diego, but the possibility also suggests itself that it may be a part ofthe Pico which has thus far escaped recognition.

3) West and northwest of Tapo Canyon the upper member appears to grade into or to be replaced by a heavy, loose conglomerate which may be of terrestrial origin. It appears to be non-fossiliferous in character. Its relations with the San Diego beds have not yet been fully investigated.

Lithologic Character

The lower member, to which reference has just been made, consists, where exposed on the west side of Las Llajas Canyon, of massive, buff, well-compacted, arenaceous strata which lie unconformably on the Modelo shales. Its thickness is here about 150 to 200 feet. It contains several layers, usually not over a foot or two in thickness, in which occur numerous boulders derived in some cases from the underlying Modelo, and in others from igneous or metamorphic rocks outside the immediate vicinity.

The upper member has at its base a hard reef-like bed of gray sandstone six or eight feet in thickness, containing numerous oysters. This is overlain by a thick series in which very loose buff-colored sands alternate with layers of hard sandstone. The highest bed exposed is a conglomerate ten or fifteen feet thick composed of numerous small pebbles of igneous rocks and cherts set rather loosely in a sandy matrix. This member is about a hundred feet thick just west of La Llajas Canyon; but it thickens rapidly to the west.

Relations Between the Members.

As has been indicated, the upper member rests unconformably upon the lower. Just west of Las Llajas Canyon gentle folds are to be observed in the lower member which are truncated by the upper; Moreover, at least two small faults occur in the lower member which do not affect the upper.

The lower member thins rapidly west of Las Llajas Canyon and is no longer exposed beyond the next canyon to the west. The relations indicate an overlap.

Fauna

From the beds under discussion I have collected the following fauna:

Lamellibranchs	Upper zone	Lower zone
Pecten (Pecten) hastatus Sowerby	C	
Pecten "purpuratus" var. "cerrosensis"	x	x
Pecten (Janira) bellus (Conrad) var. hemphilli Dall	C	
Pecten (Pecten) opuntia Dall	x	
Pecten(Patinopecten) healeyii Arnold	R	
Pecten (Pecten) islandicus Müller var. hindsii Carpenter	C	C
Pecten (Lyropecten) estrellanus (Conrad) var cerrosensis Gabb		x
Ostrea vespertina Conrad	C	
Acila cf. castrensis (Hinds)	R	
Brachiopod		
Dalinella occidentalis (Dall)	C	
Echinoids		
Dendraster diegoensis diegoensis Kew	C	
Astrodapsis ? sp.	x	

Gastropods	Upper zone	Lower zone
Epitonium (Opalia) varicostatum (Stearns) var. anomalum (Stearns)	x	
Neptunea (Sulcosipho) tabulata (Baird)	x	

C = common, R = rare, x = present.

(Note: The nomenclature adopted is that of Grant and Gale. Refer to Grant, U. S. IV, and Gale, H. R., Catalogue of the Marine Pliocene and Pleistocene Mollusca of California. Mem. San Diego Soc. Nat. Hist., vol. 1, 1931.)

Faunal Range

Species	Miocene	Pliocene Lower	Pliocene Middle	Pliocene Upper	Pleistocene	Recent
Pecten (Pecten) hastatus Sowerby	X	X	X	X	X	X
Pecten (Pecten) islandicus var. hindsii			X	X	X	
Pecten(Pecten) opuntia (Dall)			X	X	?	
Pecten(Janira) bellus (Conrad) var. hemphilli Dall.			X			
Pecten(Patinopecten) healeyi Arnold		X	X	?		
Pecten(Lyropecten) estrellanus (Conrad) var. cerrosensus Gabb		X	X	X	?	
Pecten "purpuratus" var. "cerrosensus" auct.		?	X	?		
Ostrea vespertina Conrad	?	X	X	X	X	X
Acila castrensis(Hinds)	X	X	X	X	X	X
Epitonium(Opalia) varicostatum (Stearns) var anomalum (Stearns)			X			
Neptunea (Sulcosipho) tabulata (Baird)	X	X	X	X	X	X
Dendraster diegoensis Kew var. diegoensis Kew			X	X	X	

It will be seen that of the thirteen species listed from the upper member of the series, all are found in the Middle Pliocene. Two of them, Pecten bellus hemphilli, and Opalia varicostata have been reported only from this horizon. Only five of the forms occur in the Lower Pliocene, and seven in the Upper. This would strongly indicate a Middle Pliocene age for these beds.

The fauna of the lower member is so small that its value for purposes of dating the beds is limited. It is significant however that Pecten islandicus var. hindsii one of the commonest forms occurring in these beds has not been reported from below the Middle Pliocene. The other species are not diagnostic. Thus, although it cannot be definitely declared that the lower member is also of Middle Pliocene age, what evidence there is points in that direction.

Affinities

The relationship with the San Diego formation is indicated by the fact that most of the short-range species which are present in the San Diego of Simi Valley also occur at Pacific Beach, the type locality for the San Diego Pliocene. The common forms include the following: (those starred are the forms which Grant and Gale mention as characteristic of the San Diego zone of the Pico formation.)

Opalia varicostata
Pecten hastatus
*Pecten bellus hemphilli
P. opuntia
*P. healeyi
*P. estrellanus var. cerrosensis (doubtful)
*Ostrea vespertina (doubtful)
Dendraster diegoensis diegoensis

A Pliocene locality from the west side of Temescal Canyon, 200 yards above the mouth has been reported by Woodring/1 to contain the following

/1 Woodring, W. P., Op. cit., p. 62.

characteristic San Diego fauna:

Brachiopods

Dalinella occidentalis (Dall)

Gastropod

Opalia varicostata Stearns

Lamellibranchs

Ostrea vespertina Conrad
Pecten bellus hemphilli Dall ?
P. stearnsii Dall
"Pecten" healeyii Arnold
"P." cerrosensis Gabb
"P." purpuratus Lamarck var.
Chlamys hastatus (Sowerby)
Chlamys opuntia (Dall)
Chlamys swiftii parmeleei (Dall)
Phacoides annulatus(Reeve) ?
Miltha cf. xantusi (Dall)

The similarity between this fauna and the one in Simi Valley is great enough to establish their virtual identity.

Faunal Zones

The San Diego beds north of Simi Valley may provisionally be divided into several zones on the basis of the characteristic fauna as follows:

	Upper oyster beds
Upper Member	Dendraster beds
	Pecten bellus hemphilli beds
	Lower oyster beds
Lower Member	Pecten cerrosensis beds

Future work will determine the applicability of this division to the exposures east and west of the area studied.