

A STRUCTURAL AND PETROGRAPHIC STUDY OF THE GLASS BUTTES
LAKE COUNTY OREGON

by

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A STRUCTURAL AND PETROGRAPHIC STUDY OF THE GLASS BUTTES,
LAKE COUNTY, OREGON

INTRODUCTION

The northern portion of Lake County and the adjoining sections of Crooks, Deschutes and Harney Counties in Oregon is a region characterized by a great expanse of desolate sagebrush covered plateau above which project numerous small isolated mountain ranges, peaks and buttes, and upon whose surface may be seen innumerable small ephemeral lakes. The desolateness and desert character of the vegetation of the region have resulted in the application of the name, Great Sandy Desert, to this district on all of the United States and many other maps. The name is somewhat of a misnomer, however, because it brings to mind a region of shifting sand dunes instead of the wide expanse of vegetation covered plateau that is characteristic of this region.

The elevations that rise above this plateau fall into many diverse types when an attempt is made to classify them as to origin, structure or petrologic type. Some of them are undoubtedly volcanic craters of very recent origin. Partially dissected craters are also common, perhaps the best example from this district being Newberry Crater which rises high above the surface of the plateau in southern Deschutes County. Iron Mountain (1) in western Harney County

(1) Waring, G.A. Geology and Water Resources of the Harney Basin Region, Oregon. U.S.Geol.Survey, W.Sp.Paper 231, p. 19 (1909).

has been described as an early volcanic cone which remained as a steppe above the later lava floods. Other eminences undoubtedly owe their origin to structural forces that have affected the surface of the plateau and buckled or faulted it up into small isolated mountain ranges.

Of this latter type are the Glass Buttes, a small mountain range in the northeastern corner of Lake County.

The attempts of the white man to inhabit or utilize the arid region surrounding the Glass Buttes have, in general, met with scant success. The Buttes were of great importance to the Indians, however, because at this locality occurs a plentiful supply of easily worked obsidian which was much used by the Indian tribes in making various implements. Innumerable localities in this region are covered with broken and chipped obsidian, showing the localities where the Indian people congregated to fashion their tools. Broken and defective implements are very common in these localities, while implements of perfect workmanship are not rare.

The white men first turned to stock raising. Piles of bleached bones surrounding the only flowing spring in the district give mute testimony as to the success of the venture. During the period of the World War the greatly inflated price

of wheat caused practically all of the region immediately surrounding the Glass Buttes to be homesteaded. Wells sunk to a depth of about 300 feet were found to yield a plentiful supply of water and as a result much of the land was fenced into desert claims occupying one section each. The scanty rainfall of the district proved insufficient to support a paying crop of cereal except in times of excessively high prices, however, so that the homesteaders were forced to abandon their claims one by one until now, of perhaps fifty or sixty that originally settled in this district, there are only three left.

Geological Literature Relating to the Glass Buttes Region.

The Glass Buttes, in common with much of the volcanic area of southern Oregon, have remained almost unknown, geologically, to the present day. The Glass Buttes were visited by I. C. Russell in his reconnaissance in southern Oregon (2).

(2) Russell, I.C. A Geological Reconnaissance in Southern Oregon. U.S. Geological Survey. Ann. Rept. 4, p. 440 (1882)

Concerning this locality Russell writes:

"The Glass Buttes were found to be composed of rhyolite, together with large quantities of obsidian, or volcanic glass. No evidence that they were once volcanic craters was observed; and no basaltic overflows, or other phenomena, were seen to indicate that they had recently been centers of volcanic action."

Curiously enough, in a later publication (3), Russell says:

(3) Russell, I.C. Preliminary Report on the Geology and Water Resources of Central Oregon. U.S.Geol. Survey, Bull. 252, p. 49 (1905).

"To the west rise the Glass Buttes, consisting of two rounded domes and several lesser hills, which, as known from a previous visit, are remnants of ancient rhyolitic or andesitic volcanoes, now deeply dissected by erosion. They form not only a most prominent object in the vast desert landscape, but add a touch of color to the prevailing gray of the surrounding sagebrush-covered plain by the tawny yellow of the ripened bunch grass and the dark shades of the trees that grow on the northern sides of their prominent ridges."

It seems likely that in this later paper Russell confused the Glass Buttes with one of the numerous volcanic cones which he had studied in this district. There is little in the topography or structure of the Glass Buttes to suggest that they are the remains of a dissected volcano; a fact which he had recognized in his earlier paper. The reference to trees also seems out of place in a description of the Glass Buttes. In this locality trees are numerous only at the northwestern end of the range and in a small area on its southern slope, but they are well developed on the slopes of some of the craters in south-central Oregon.

Pirsson (4) noted the occurrence of obsidian at this

(4) Pirsson, L.V. Rocks and Minerals.

locality in his text (published in 1915). The writer has failed to find any other citations to this district in the literature.

THE STRUCTURE OF THE GLASS BUTTES RANGE

Relation to Broader Structural Features in South-central Oregon

Northern Lake County occupies a strategic position for an investigation of the mountain making movements that have affected Eastern Oregon, parts of it having been affected by each of the movements that give the state its present structural and physiographic form.

Eastern Oregon is divided into four main structural and physiographic provinces. On the west the Cascade Mountains rise to a general elevation of from 5,000 to 6,000 feet above the sea with many volcanic cones reaching elevations of over 10,000 feet. Although towering high above the low-lying Willamette Valley to the west the Cascades are not impressive when viewed from the eastern side, due to the fact that the greater part of eastern Oregon has a general elevation of from 4,000 to 5,000 feet above the sea. They thus form an asymmetrical mountain mass bordered on the west by the low Willamette Valley and on the east by a high plateau.

The folded structure of the Oregon Cascades is easily apparent in the great cross section cut in them by the Columbia, in whose gorge the middle Miocene lavas may be seen thrown into steeply dipping folds. Elsewhere the structure

is not so obvious for the folds in the interior of the state have been covered with a great deluge of recent lavas largely emitted from the numerous volcanic cones which dominate the crest line of the range. Transverse folds similar to those of the Cascades in Washington, are well developed in the northern portion of the Cascade province of Eastern Oregon, where they have the same northwest-southeast trend characteristic of the transverse ranges in Washington. Farther south these transverse systems have not been observed, but they may lie buried beneath the very recent volcanics south of Bend. The widespread warping of south-central Oregon, as exemplified in the broad structural depression in which Malheur and Harney Lakes lie, has been attributed by Waring (5)

(5) Waring, G.A. Geology and Water Resources of the Harney Basin Region, Oregon. U.S. Geol. Survey, W. Sp. Paper 231, pp. 26-27 (1909).

to earth movements operating at the time of the uplift of the Cascades. If this warping does owe its origin to structural forces operating during the folding of the Oregon Cascades these forces were certainly of different nature than those forming the northern Cascades. In Washington the transverse offshoots of the Cascade mass extend only for short distances across the Columbia River and are characteristically sharp anticlinal folds trending northwest-southeast. In south-central Oregon the deformation is exemplified by widespread shallow warping which extends eastward into Idaho and southward into Nevada. The warped areas are so shallow and irregu-

lar that their axial trend is seldom well defined or constant in direction for any great distance, the downwarped areas appearing as shallow spoonlike depressions which are separated by irregular dome-like anticlines. The writer sees no more obvious reason for connecting this warping with the uplift of the Cascades than for connecting it with the late Tertiary orogeny in the Blue Mountains to the north, in the Rockies to the east, or in the Great Basin area of Nevada and Utah to the south. Each of these districts was the center of pronounced late Tertiary mountain-making movements, and it seems more probable that the warping of southern Oregon is the result of all of the forces operating in the nearby areas, and is not to be traced to a single cause. The irregular axial trend of the warped structures lends added weight to this hypothesis.

The Blue Mountains of Oregon are a complex mountain system, the structural and historical relations of which are at present not fully understood. Appearing first as the high Wallowas and Strawberry Mountains in the northeastern part of the state, they trend across the interior plateau to their junction with the Cascades in the vicinity of the town of Prineville. The Wallowa Mountains of eastern Oregon are continuous across the Snake River Canyon with the Seven Devils which, in turn, merge into the Rocky Mountain system of Idaho. They are similar to this eastern extension as well in that they bring to light early Mesozoic sediments and volcanics which are cut by late Jurassic batholiths. That

they were uplifted to their present position since middle Miocene time is testified by the fact that the basal flows of the Columbia River Lava cap the highest peaks of the system(6).

(6) Personal Citation. Prof. G. E. Goodspeed.

In the light of this evidence it seems doubtful that the larger part of the Blue Mountain mass of northeastern Oregon remained as steptoes or peninsula above the basaltic floods. To the west of the Wallowas the Blue Mountain uplift lies at a slightly lower elevation and exposes in its core rocks of late Mesozoic and early Tertiary age instead of the older metamorphics which crop out to the east. The absence of the Cretaceous and Eocene deposits in the eastern part of the range testifies to the fact that this portion existed as a land mass at the time these sediments were being deposited and has had a much different pre-Tertiary history than the western portion of the mountain mass that it now forms a part of. The structural relations of the eastern and western part of the Blue Mountain mass also appear to be different. The steepness and abrupt character of the mountain scarps, together with the wide intermontane valleys of the eastern part of the district suggest that the mountains owe their present form to the erosion of great fault blocks. To the west the upturned Columbia Lavas and associated Mascall and John Day beds suggest that the folding has been the dominant agent in the uprising of the mass. Much more evidence must be collected before the various geological relations of these mountains will be completely known. The junction of this uplift with the Cascades is obscured by a

covering of recent lavas.

The Columbia River Plateau occupies that portion of eastern Oregon which lies north of the Blue Mountains uplift. Its flows of basaltic lava slope northward from the summits of this mass until they meet and join the much greater expanse of the plateau in eastern Washington.

The fourth, and from the standpoint of the Glass Buttes, the most important physiographic province in Eastern Oregon is the northern continuation of the Great Basin Region. This province, which includes the greater parts of the states of Nevada and Utah with various portions of the adjoining states, extends northward into Oregon, its northern margin being determined by the southern limb of the Blue Mountains uplift. This province, therefore, embraces the whole of Malheur, Harney and Lake as well as part of the adjoining counties in Oregon and thus occupies considerably more area than any other physiographic province in the eastern part of the state. The structure of this part of Oregon is identical with that of the Great Basin to the south. Great orographic blocks have been broken and tilted at various angles into well defined, asymmetrical mountain ranges. Southern Oregon has perhaps the finest examples of fault-block mountains of any region in the world. These mountains, composed entirely of the great thickness of lavas that cover all of this portion of Oregon, have remained practically unmodified since their uplift, so that their present topographic aspect is due almost entirely to structural movements. The graben structure is characteris-

tic of southern Oregon. Alvord, Guano and Warner valleys are all well defined grabens, which face steep fault scarps on either side. Guano and Warner valleys are fairly symmetrical, the faulted valley walls on either side rising to about equal heights, but in the Alvord graben the eastern wall of the valley rises only a few hundred feet while its western limit is defined by the tremendous fault scarp of Steens Mountain, which rises over 5,500 feet above the valley floor, reaching an elevation of over 11,000 feet above the sea. These graben valleys, during the later part of the Pleistocene and throughout the Quaternary were occupied by great lakes which, at least in some cases, were connected with the vast Quaternary Lake Lahontan in Nevada. Silts and sands deposited in the lakes have reached thicknesses of over 5,000 feet in places and deposition has proceeded to such an extent that it practically everywhere masks the bedrock structure of the graben floors and leaves each valley as a flat expanse of lake sediments from one major fault scarp to the next.

During the late Quaternary and in recent times most of these lakes have gone out of existence, so that at the present time the graben valleys are a desolate expanse of perfectly level undissected, vegetationless, silty clay, above which, along the sides of the valley, various beach lines testify to the former depth and fluctuations of the lakes. Many of the lakes have dried up within historic times. The Warner Valley was occupied by an extensive system of shallow lakes as late as twenty-five years ago. These have undergone

gradual desiccation until at the present time the only permanent body of water is a small lake at the southern end while the very large depressions in the upper part of the valley have not held standing water for over ten years. Another good example of the desiccation of the lakes of this arid region is seen in Lake Abert. This lake lies in the depression facing Abert Rim, a scarp that has been described as the best example of a fault block in the United States. It once covered a very wide area but has been rapidly drying up in the past few years so that it is greatly reduced in size at the present time and is bordered everywhere by a broad expanse of white alkaline deposits. It is predicted that it will be entirely dry in a few years.

The fault blocks of Oregon are most pronounced toward the southern boundary of the state and gradually die out to the northward as the base of the Blue Mountains uplift is approached. Along the northern border of the province faulting is much in evidence still, but the scarps rarely have a throw of over a few hundred feet and there are none of the vast fault escarpments characteristic of the southern part of the state.

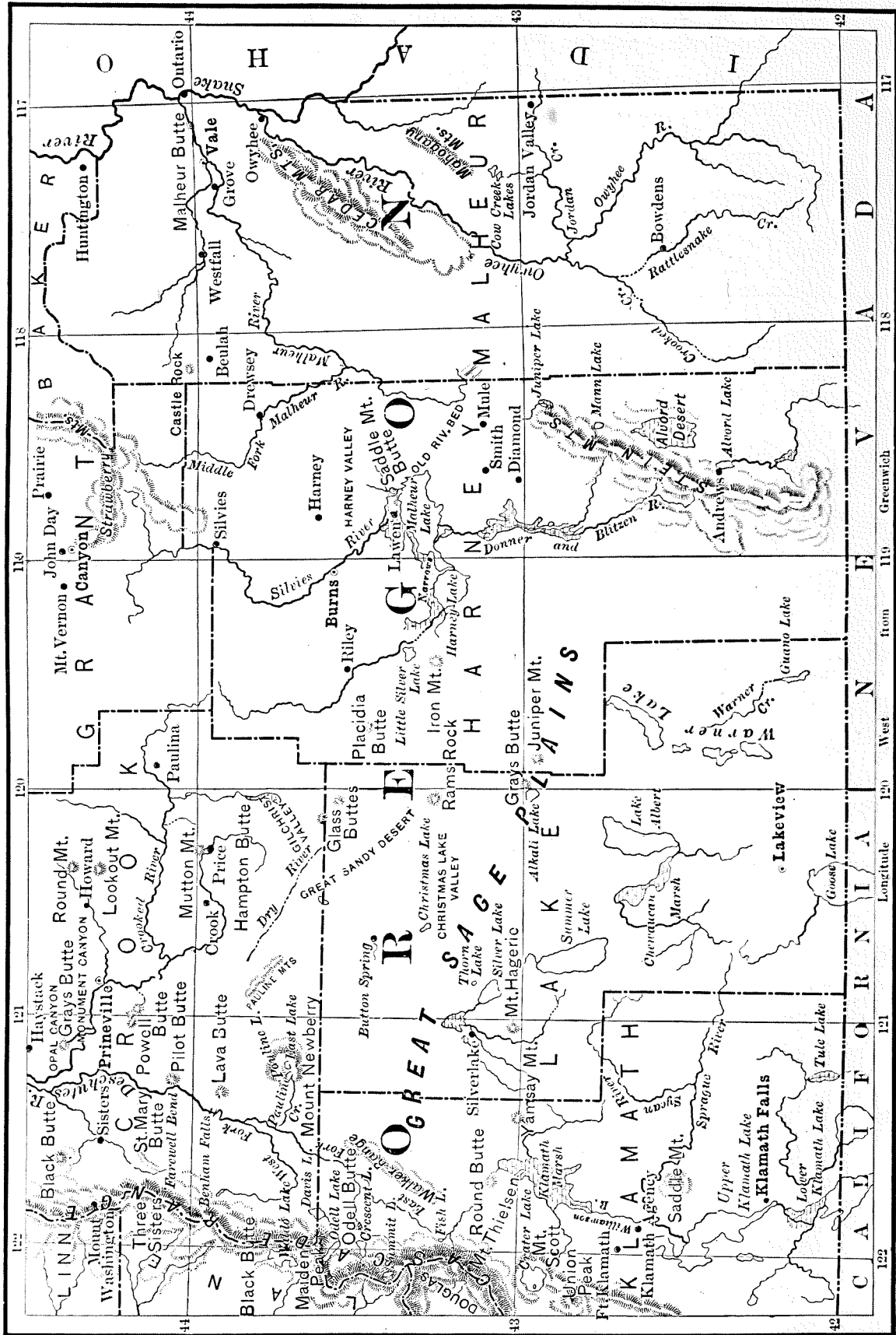
The widespread warping of this portion of the state has already been referred to in a discussion of the Cascades. In general the grabens occupy what appear to have been former anticlines, but it is possible that this structure is the result of movement of the blocks at the time of faulting and that true anticlines without dropped axes never did exist in

the area now occupied by the graben valleys. Anticlines of even moderate size which did not have faulted and downdropped arches have never been observed by the writer anywhere in this district.

Structure of the Glass Buttes

The Glass Buttes range occupies a part of the extreme northerly border of the fault-block district of Oregon. Its exact position may be obtained by reference to the enclosed map of southeastern Oregon (Plate I). Rising abruptly out of the desert plateau in the vicinity of the postoffice of Roly- at it trends away to the southeast in a shallow arc, dying out in a low range of hills about 22 miles from its western beginning. The greatest width of the range is about 22 miles from the western end where a small transverse ridge causes a maximum extension of about 8 miles. In general it is about 6 miles from one side to another. The range rises about 1900 feet above the surrounding plateau which, at this locality, has a general elevation of between 4,000 and 5,000 feet.

From the summit of the Glass Buttes topographic forms of constructional origin are present on every side. In the arid climate of this district drainage has not as yet been definitely established and the average elevation that rises above the plateau has remained practically unmodified by erosion. Hundreds of small lakes and alkaline flats that lie in purely structural depressions may be seen from the summit of the range, testifying to the immaturity of the drainage in this



SKETCH MAP OF SOUTHEASTERN ORE.
(After Russell, Bowman)

district. Small fault scarps are everywhere in evidence upon the surface of the plateau. These wander across its surface in an exceedingly irregular manner, branching and coalescing to form a most intricate pattern. These scarps are capable of no other interpretation than through faulting. No erosional agency could approach the forms that they assume and they cannot be interpreted as the edges of lava flows on account of the fact that they commonly truncate and expose more than one flow and also show by their irregular branching pattern that they cannot represent the ends of flows. The fault scarps on the plateau are commonly of low elevation, seldom exhibiting a throw of over 200 feet with the majority of them less than 100 feet in height. The branching, irregular trend of the scarps makes the fitting of the fault lines into any regional structural trend somewhat of a problem, but it seems probable that they fit into two rather definite intersecting structural lines, one trending northwest-southeast, the other almost north and south. The northwest-southeast trend is the dominant one as is also the case in the Glass Buttes range.

Off to the northwest at a distance estimated between 15 and 20 miles a complex mountain mass apparently of much the same size and type as the Glass Buttes, rises in a course roughly paralleling them. Far off to the northeast the view is broken by another similar mass. Many small eminences, having the appearance of small basaltic cinder cones, can be seen from the summit of the Buttes.

The Glass Buttes Range consists entirely of volcanic

rocks representing three periods of extrusion. The first flows were of olivine and augite basalts. These early flows were covered by a conformable lava series in which such petrographic types as augite andesite, quartz andesite, hypersthene dacite, augite dacite, hypersthene-augite dacite, perlite, obsidian and vitrophyre have been found. This series is in turn covered, on the plateau adjoining the range, by very recent flows of olivine and augite basalt.

When viewed from the crestline of the Glass Buttes Range, the lava flows can be seen to tilt away at rather steep angles on either side until they flatten out and join the horizontal plateau below. The dominant structure of the range is known from these relations to be an anticline, and the range is similar in this respect to the anticlinal mountains that form the eastern spurs of the Cascades in Washington (7) and Oregon.

(7) Especially excellent examples of these anticlinal mountains may be seen in the Ellensburg Folio, Washington, of the Geologic Atlas of the United States.

Minor topographic irregularities of the Range are due mainly, not to the erosion of this anticline, but to a complicated system of normal faults which traverse the structure. The top of the anticlinal arch has been downdropped into a graben which forms a great longitudinal valley in the very heart of the range. This central valley extends throughout the entire eastern three-fourths of the uplift. Small transverse grabens intersect this larger one and there is a profusion of small normal faults and fractures on the sides of the anticline.

Numerous small faults also occur on the floor of the plateau adjacent to the range and their uneroded scarps can be seen winding cross its otherwise featureless surface. Field evidence indicates that the faults are purely tensional and not compressional. The anticlinal sides of the main graben valley are cut by normal faults which define these sides as horsts; a condition that is considered highly improbable in a compressional graben.

The multiplicity of very small normal faults and fractures is perhaps the most interesting phenomena in the structure of the Glass Buttes. These small faults are extremely numerous. Their throw rarely exceeds fifty feet and there are many examples of slips of ten feet or less. Small minor faults seem to be characteristic of the very recently faulted blocks of southern Oregon. D. W. Johnson (8) quotes Dr.

(8) Johnson, D.W. Block Faulting in the Klamath Lakes Region, Oregon. Jour.Geol., Vol.26, p. 256, 1918.

G. K. Gilbert as stating that, in the Klamath Mountains, reconstruction of the pre-faulting surface would be a difficult task, because the great fault blocks have been "intricately sliced and dislocated on a small scale; and one of the marvellous features of the region is the association of major faulting with elaborate contemporaneous minor faulting."

Major faults also occur at the Glass Buttes. The largest throw measured on any one fault exceeds 1,000 feet. There are, however, in this portion of central Oregon none

of the vast fault escarpments such as those defining the eastern slope of Steens Mountain or the westward facing wall of Abert Rim.

A conception of the intricate fault pattern at the Glass Buttes may best be obtained from a study of the enclosed sketch map and structure sections (Plates II and III). The writer wishes it distinctly understood that this map is not presented to depict the accurate location of the fault lines in the Glass Buttes district but only to show the character of the fault pattern. There is no map which could be used as a base map in the study of the Glass Buttes. In various maps of Oregon the Glass Buttes are placed in different positions and are given different axial trends. The appended map was made by traversing the region in detail with a Brunton and Aneroid. Distances were plotted only by pacing and may be in error as much as one mile in ten. The map does give an accurate representation of the character of the fault pattern of the district, however, and is of value on this account.

As was noted earlier in this paper mountain ranges with a faulted anticlinal structure similar to that of the Glass Buttes are common throughout southern Oregon. Steens Mountain, the Warner Ranges, and Winter Rim furnish examples. They are seen to be the northern extension of the fault-block ranges of Nevada. The exceedingly uneroded character of the fault scarps in Oregon in contrast to the somewhat dissected ones of Nevada suggests that the faulting in southern Oregon, while following the same structural lines as that to the south,

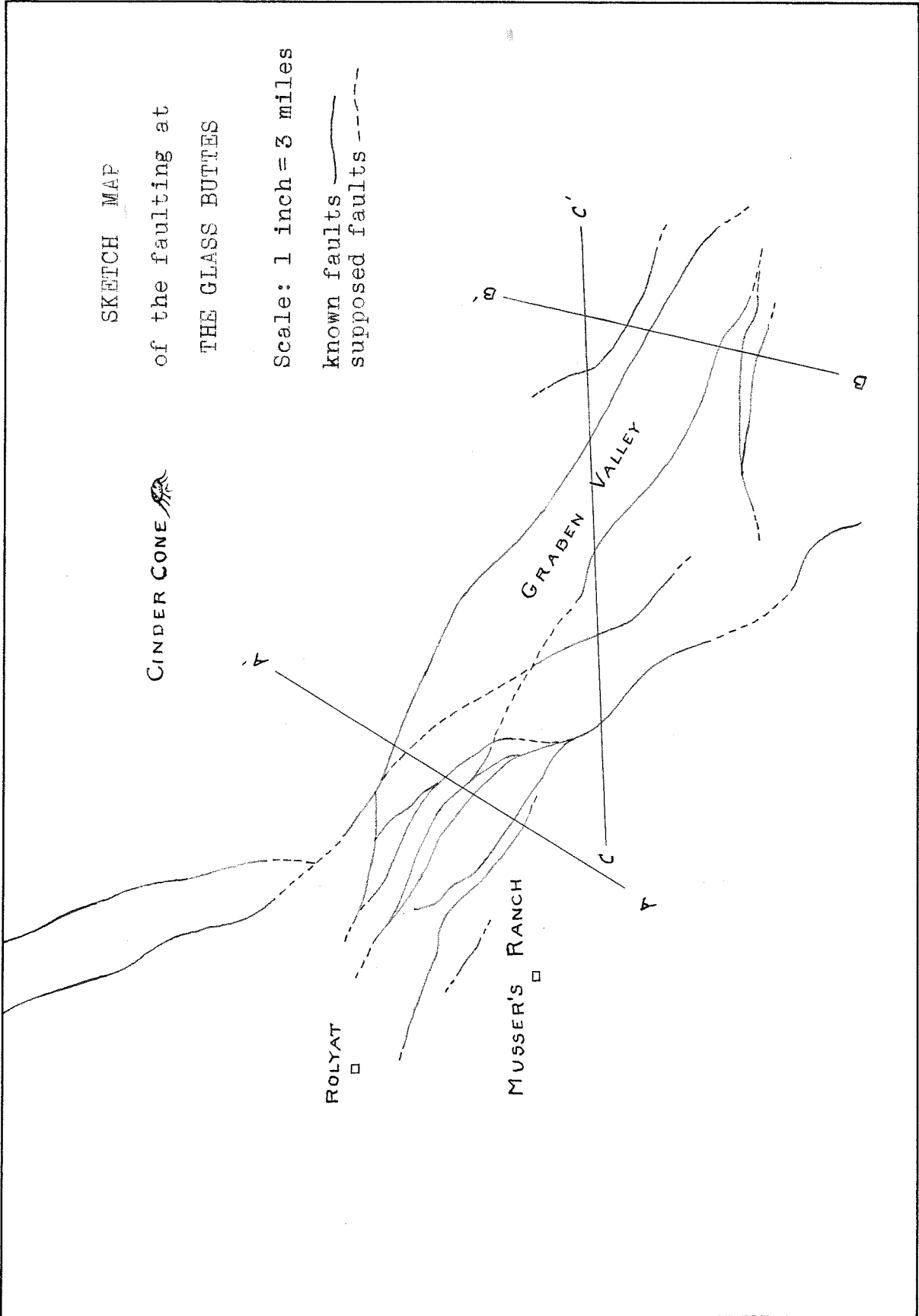
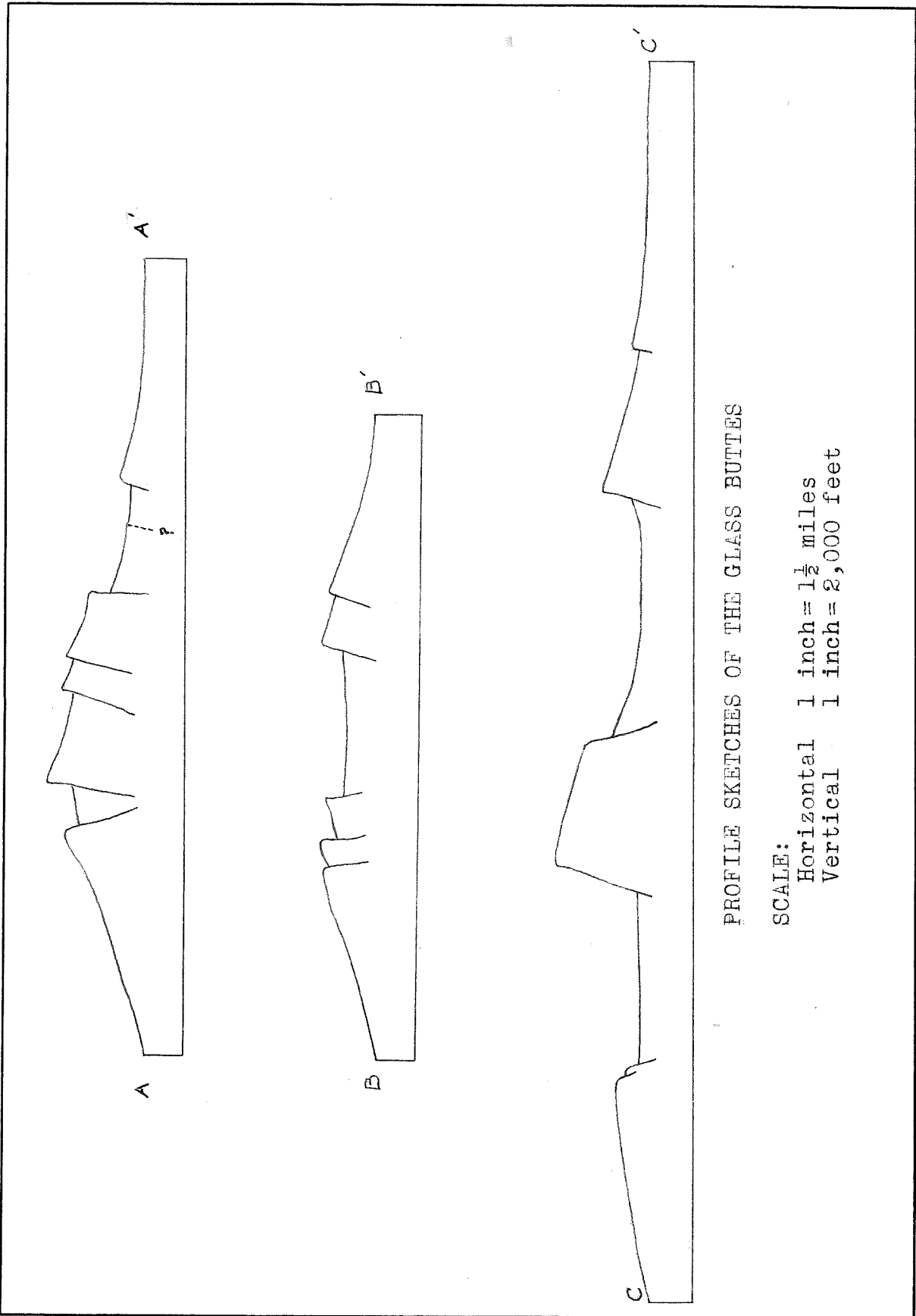


PLATE III (to follow Plate II)



PROFILE SKETCHES OF THE GLASS BUTTES

SCALE:

Horizontal 1 inch = $1\frac{1}{2}$ miles
Vertical 1 inch = 2,000 feet

was of later date. In the Glass Buttes region minor faulting affects a series of lava flows so recent that vegetation appears to have only lately gained a foothold upon them. The soil cover of these flows is nowhere over a few inches thick and is largely of a transported variety. Faulting of post Lahontan date is described by Russell (9) as occurring in the

(9) Russell, I.C. The Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada. U.S. Geol. Survey, Monograph 11, pp. 163-166 (1885).

Black Rock Desert of northwestern Nevada. From these considerations it would seem probable that a considerable portion of the faulting of southern Oregon does not date back of the Pleistocene.

PETROLOGY OF THE GLASS BUTTES

The Younger Basalts

Three series of lava flows of different periods of extrusion occur at the Glass Buttes. The younger of these is a series of basaltic lavas so recent in age that the flows still preserve their original surface features although they have been covered with a few inches of transported soil. This series of lava flows appears to have been erupted contemporaneously with the faulting in the Glass Buttes district, for not only do these lava flows lap up against the main fault blocks of the Glass Buttes Range, but they are in turn cut by other faults of slight displacement. This series

of flows has remained unmodified by erosion since its extrusion.

Evidences of recent vulcanism are widespread throughout southern Oregon and central Idaho (10). Many of the recent

(10) Russell, I.C. Notes on the Geology of Southwestern Idaho and Southeastern Oregon. U.S.Geol.Survey, Bull.217, pp.36-58 (1903), and Waring, G.A. Geology and Water Resources of the Harney Basin Region, Oregon. U.S.Geol.Survey, W.Sp.Paper, 231, pp.22-23.

basaltic eruptions have been described by I. C. Russell and by other authors, and in fact, these recent volcanic products have received more attention than the much thicker and more widespread lavas of earlier age that occur in central Oregon. Famous localities of very recent basaltic lavas are the Craters of the Moon District in Idaho and the Jordan Craters in southeastern Oregon. These eruptions were apparently of a very viscous type, characterized by ropy surfaces (11). Unfortunately little has been published of strictly

(11) Washington, H.S. Petrology of the Hawaiian Islands; IV, The Formation of AA and Pahoehol. Am.Jour.Sci., Vol.6, pp. 409-423 (1923).

petrographic nature concerning these basalts, the principal aim of previous workers having been to place on record descriptions of the surface features of the lava flows and of the bombs and ejectamenta from the craters irrespective of the composition of the magma involved.

Cinder Cones: In the area of the Glass Buttes recent lavas occupy a portion of the plateau directly to the north

of the central portion of the range. They are probably represented at other nearby localities on this plateau as well. From the summit of the Glass Buttes several small cinder cones can be seen, all but one of which appear to be at least twenty miles from the range. This nearer cone, situated a few miles north of the central portion of the range, rises from 200 to 250 feet above the level of the plateau and has a circumference of a little less than a quarter of a mile at the crater lip. It is composed of small lapilli, bombs of various size and shape, and large blocks of solidified lava that have apparently been broken loose from below and ejected from the crater. The southwestern side of the cinder cone is lacking. However, if this portion was breached and carried away by an excessive flow of lava, showers of ejectamenta have since covered the lava filling which originally occupied the breach.

On the western side of the cone a small wall-like mass extends with a gentle slope from the lip of the crater to the plateau below. It has the appearance of a thin, uneroded dike but examination reveals it to be composed entirely of lapilli and "drilet lava" from which it seems probable that this ridge represents a fissure extending out from the cone along which numerous "drilet cones" or (12) "ovens" (13)

(12) Dana, J.P. Characteristics of Volcanoes.

(13) Russell, I.C. Notes on the Geology of Southwestern Idaho and Southeastern Oregon. U.S. Geol. Survey, Bull. 217, p. 52 (1903).

were developed which have since been broken and fragmented.

Recent Lava Flows: It is probable that the majority of

the basaltic flows that cover wide areas of the plateau in the vicinity of the Glass Buttes belong to the same period of eruption as the cinder cone, but they cannot be separated petrographically from an older series of basalts, and can only be determined stratigraphically when an intervening series of acidic lavas are present.

Two flows can be definitely correlated with this period of vulcanism. They were erupted upon a soil layer containing particles of obsidian, pumice and dacite thus furnishing definite evidence that they are younger than the acidic flows which lie upon the older series of basalts. The Cinder Cone rests upon these two flows which shows that they reached the surface slightly before its formation. The flows apparently originate somewhere near the base of the Cinder Cone or immediately to the west of it. The older one occupies a considerable area between the Cinder Cone and the main Glass Buttes range. It averages about ten feet thick, and is characterized by ropy surfaces and very little scoriaceous or vesicular material. Microscopical examinations show the rock to be entirely holocrystalline. It is composed of labradorite, augite, and olivine with minor amounts of magnetite. The feldspars are wholly or partly included within large individuals of augite forming a typical ophitic texture. Olivine is abundant in large rounded crystals. The rock is very fresh. The only alteration product consists of a thin rim of brownish-red substance occurring on the border of olivine which has the color but lacks the cleavage of

iddingsite. Very small olivine crystals are entirely replaced by it. The other minerals are perfectly fresh. The crystallinity of this flow is remarkable. Although only ten feet thick the flow is holocrystalline almost to its borders.

A flow of porphyritic augite basalt occurs directly above the earlier flow. The two are separated in a few places by a slightly baked soil layer of pumaceous sand of transported origin. The surface of the flow is of the pahoe-hoe type. Pressure cracks from ten to fifty feet long are much in evidence upon its surface. The flow differs considerably from the earlier one in mineral composition and crystallinity. It is a porphyritic rock containing small phenocrysts of less calcic labradorite than the older flow. These phenocrysts are thickly studded with inclusions of black glass and of acicular to hair-like crystals of a brownish-yellow mineral with very high refractive index. The groundmass has an intersertal texture and consists mainly of small microlites of sodic labradorite, grains of augite, patches of magnetite and an interstitial mesostasis of brownish-black glass. Flow structure is pronounced, especially in that portion of the groundmass immediately surrounding the phenocrysts. No alteration products were observed.

Change in Composition of the Flows: The difference in composition shown by the analysis of these two flows points to rapid changes in composition of the original magma from which the flows were fed in a very short space of time. Although they are in part separated by a soil layer, this soil

is of a transported variety and the original surfaces of the flows show scarcely any alteration from weathering. In the older flow counts made of the proportions of different minerals by comparing areas occupied in the thin section show the rock to contain about 65% olivine and augite. In the younger rock the amount of augite present is only about 30% and olivine is entirely absent. Although considerable amounts of glass are present it is improbable that the difference in the quantity of the mafics shown in the crystalline portions of the rock is compensated for in the composition of the glass.

In a recent article (14) William O. George has attempted

(14) George, William O. The Relation of the Physical Properties of Natural Glasses to their Chemical Composition. Jour. Geol., Vol.32, pp.353-373 (1924).

a correlation of the chemical composition of natural glasses with their physical properties. Several methods of attack were followed and a very interesting series of results was obtained. It was found that a number of physical properties of natural glass vary in a regular order with the percentage of silica which the glass contains. One of the most reliable of these properties is the variation in index of refraction with silica content. The more basic glasses have the higher index, the index decreasing in a fairly regular manner from 1.58 to 1.60 for a glass with about 50% silica to about 1.49 in glasses of acidic composition. A careful determination of the glass in the base of the younger flow was made and gave the surprising result of 1.489 .005. This would

correspond to a very acidic glass. It seems hardly possible that the glass in the base of this rock can contain over 70% silica as its index would indicate. It is probable that the excessively low index is due to some other factor. On the other hand this low index is of interest in that it helps to prove the far greater acidity of the younger flow over its predecessor.

The labradorite in the younger flow is also of a less calcic variety than that in the older. Changes in viscosity attend the change in composition,--although the older flow is of the same thickness as the younger it must have been markedly more fluid. It is holocrystalline and of ophitic texture while the younger flow has an intersertal groundmass characterized by large amounts of glass and marked fluxional structure. The marked crystallinity of the lower flow cannot be explained by assuming that these flows were nearly contemporaneous, and that the upper flow acted as a thermal blanket for the lower, because a thin soil layer is seen to separate them.

The Glass Buttes Series

The name Glass Buttes Series is used in this paper to designate a closely related series of volcanic rocks of acidic composition that form the main portion of the Glass Buttes Range. This series is repeated by faulting at several places within the range which gives a false idea of its thickness. Seven lava flows belonging to this series, each

of which are at least 50 feet thick, occur on one fault scarp, while two other flows are exposed on the downthrown block of the same scarp. This brings the total known thickness of this series up to over 400 feet. It is improbable that the series is much thicker, for the older basaltic flows upon which the acidic types were poured out are exposed on several of the fault scarps beneath the younger acidic lavas.

In the field the most striking feature of the lavas of the Glass Buttes Series is the pronounced lamination which practically all of the larger flows exhibit. So pronounced is this feature that when viewed from a slight distance these rocks look like a vast series of sediments with very well developed bedding. The banding is remarkably parallel in the lower and middle portions of the flow but toward the top it generally becomes very much contorted and is finally lost in the thick pumiceous and broken obsidian caps which cover most of the flows. The surfaces of the lava flows of the Glass Buttes Series must have been entirely covered with loose blocks of obsidian and pumice at the time of the eruption. A similar type of eruption has been described by Washington from Fougue Kameni on the island of Santorini (15).

(15) Washington, H.S. Santorini Eruption of 1925. Geol. Soc. Am., Bull. 37, pp. 349-384 (1926). The section from page 359 to 363 is of especial value.

Petrography: The well banded portions of the lavas of the glass Buttes are generally light brownish-red in color and show perfectly aligned phenocrysts of feldspar and bands

of flattened vesicles partially filled with rounded aggregates of colorless hyalite. In thin section the feldspars prove to be andesine which often shows a ragged oscillatory zoning. The addition of more calcic zones to a sodic nucleus must have been preceded by some resorption because in each case the calcic zones were deposited on an irregular nucleus, while where more sodic material was added to a more calcic nucleus the border between the two is well defined. Augite and hypersthene occur in all of the banded lavas studied and are characterized in all cases by marked reaction rims consisting of finely divided reddish-brown material with much included magnetite. In several of the rocks hypersthene is represented only by pseudomorphs of magnetite and of the reddish material. Quartz phenocrysts occur in several of the rocks. They appear to have been very unstable and where present are very badly resorbed and corroded. The resorption has taken place irregularly so that the phenocrystic remnants are often of peculiar shapes with finger-like extensions and narrow embayments along their sides. No synantetic minerals are present surrounding these resorbed phenocrysts, the glassy base of the rock penetrating into the innermost recesses of the resorption cavities.

In three of the rocks that were studied andesine appeared to be unstable, as well as quartz, hypersthene and augite, and showed corroded outlines and marked reaction rims consisting of a fine mat of colorless cryptocrystalline grains and scaly material showing low polarization colors. The

usual explanation for the resorption of an already formed mineral by the magma from which it crystallized is that progressive change in the composition of the magma has proceeded to such an extent that the earlier crystallized mineral is no longer stable in the liquid which surrounds it. Such an explanation leaves something to be desired, however, in the case of a rock in which such diverse minerals as hypersthene, augite, andesine and quartz are all unstable at the same time. That the equilibria conditions under which intratelluric phenocrysts form would be greatly altered by extrusion and consequent loss of the volatile constituents of the magma and relief of pressure is well known, and it has been pointed out that a logical result of these equilibria changes is the resorption of phenocrysts formed at depth (16). It has been

(16) Holmes, Arthur. Petrographic Methods and Calculations, p. 340. London (1921).

especially noted that in certain lavas olivine phenocrysts brought from below tend to be quickly resorbed (17). "A con-

(17) Fenner, C.H. The Katmai Magmatic Province, Jour. Geol., Vol. 34, p. 699 (1926).

dition necessary for its existence seems to have been lost upon extrusion."

The resorption of minerals by the magma from which they crystallized has long been a problem of great interest to petrologists. From the earliest days of the use of the microscope in the study of rocks the reaction rims or coronas

of enstatite and hypersthene around olivine were noticed and were correctly attributed to the reaction of the mineral with the magma to form these new products. Within the last few years, however, our knowledge of these reactions and the changes producing them has grown by leaps and bounds. It is also being clearly realized that the resorption of phenocrysts by the parent magma is a process identical with the assimilation of wall rock by the magma (18).

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- (18) Of the voluminous literature on this subject the following publications are worthy of especial note:
- (a) Fenner, C.N. The Katmai Magmatic Province, Jour. Geol. Supplement, Vol.34, pp.675-772 (1926).
 - (b) Harker, A. The Tertiary Igneous Rocks of Skye. Memoirs of the Geol. Survey of the United Kingdom (1904).
 - (c) Adams, F.D., and Barlow, A.E. Geology of the Haliburton and Bancroft Areas. Dept. of Mines Memoir, No.6, p.87 on (1910).
 - (d) Berkey, C.P., and Rice, Marion. Geology of the West Point Quadrangle, New York. N.Y.State Museum Bull.225 and 226 (1921).
 - (e) Read, H.H. Geological Magazine, Vol.61, pp.443-444 (1924).
 - (f) Foye, W.G. Nephelite Syenites of Haliburton County, Ontario. Am. Jour. Sci., Vol.40 (1915)
 - (g) Knight, C.W. Geology of the Sudbury Area, Report of the Royal Ontario Nickel Commission (1917).
 - (h) Harker, A. Differentiation in Intercrustal Magma Basins. Jour. Geol., Vol.24 (1916).
 - (k) Daly, R.A. The Secondary Origin of Certain Granites. Am. Jour. Sci., Vol.20 (1905).
 - (l) Sederholm. On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Commission Geol. de Finlande, Bull.58 (1923).
 - (m) Fenner, C.N. Application of the Law of Mass Action to Phenomena of Resorption in Igneous Rocks. (abst.) N.Y. Acad. Sci., An 19, pp.325-326 (1910).
 - (n) Bowen, N.L. Jour. Geol. Supplement, Vol.23, pp.1-89 (1915).
 Am. Jour. Sci., Vol.39, pp.175-191 (1915).
 Am. Jour. Sci., Vol.40, pp.161-185 (1915).
 Jour. Geol., Vol. 27, pp.393-430 (1919).
 Proc. Nat. Acad. Sci., Vol.6, pp.159-162 (1920).
 Jour. Geol., Vol.30, pp.177-198, 513-570 (1922).
-

The widespread assimilation of wall rock by an intruding

batholith has been accepted by the French geologists (19)

(19) See especially the work of Lacroix on the Pyrenees.

from very early times but has been much slower of adoption in America. The heat supply for assimilation has always been the stumbling block for the acceptance of the theory by American geologists. On the other hand Adams and Barlow (20) in Canada and Fenner (21) in America have advanced

(20) Adams, F.D., and Barlow, A.E. Geology of the Haliburton and Bancroft Areas. Department of Mines Memoir No.6 (1910).

(21) Fenner, C.N. The Mode of Formation of Certain Gneisses in the Highlands of New Jersey. Jour. Geol., Vol.22, pp.594-612 (1914).

exceptionally conclusive evidence of the wholesale assimilation of limestone and the production of a synt~~x~~etic magma by this process. In both of these cases the limestone was not actually the material engulfed and incorporated into the magma but the actual assimilation was preceded by widespread transfer of volatiles carrying lime and magnesia from the magma which completely altered the limestone over great areas into an amphibolite. This amphibolite, and not the limestone, was the material with which the magma actually came in contact and which it engulfed. In a very interesting article Professor George E. Goodspeed (22) has advanced undoubted

(22) Goodspeed, G.E. Effects of the Assimilation of Xenoliths in a small Porphyry Dike. To be published in Jour.Geol. during 1927.

proof of the extensive assimilation of xenoliths of a basic schist by a two foot porphyry dike. If assimilation can go on in a magmatic system of this size it undoubtedly would be of considerable importance in a magma of batholithic dimensions.

Reaction phenomena are very marked in the acidic lavas at the Glass Buttes. The main effects are confined to the resorption of phenocrysts of various minerals and the production of coronas about the same. In addition to these it was noticed that various types of enclaves are present in many of the rocks, the relation and origin of which are not fully understood. The majority of the enclaves are probably enclaves homoeogenes and represent simply an earlier stage in the cooling and in the textural development of the rock. Many of these enclaves appear to have undergone the effects of magmatic corrosion and have been converted over into the type more correctly described as enclaves polygenes. In some cases the inclusions mentioned as enclaves polygenes may have had a foreign origin but if this is the case the nature of the rock from which they were derived is not apparent.

Zoning of minerals is another common feature of the acidic rocks from the Glass Buttes. The zoning exhibited by andesine phenocrysts has already received comment in the earlier part of this section. In addition to the andesine, however, it was noticed that augite in some of the specimens studied had a marked zonal structure, individuals varying as much as 20° in extinction from the center to the periphery. The higher index of refraction of the more central portions

of the crystal indicates that this zoning consists in a decrease of the lime content from the center to the margin of the crystal. The zoning in augite is distinctly of progressive type but, as was the case in the feldspars, addition of less calcic material to a more calcic nucleus seems to have been preceded by a considerable amount of resorption because numerous zonal breaks may be noted where the inner material shows the ragged effects of corrosion. A distinct sympathy is seen between the zoning in the feldspar and in the augite. In both cases the arrangement of the zonal layers indicates that the magma was becoming leaner in calcium as crystallization went on.

Zonally arranged inclusions of glass are very common in the andesine phenocrysts. They vary from the glassy base of the rock in that they are perfectly colorless and do not contain inclusions within themselves.

The groundmass of the well banded portion of the flows from the Glass Buttes generally consists of a yellowish-brown glass containing innumerable crystallites of various types. Microlites of oligoclase-andesine are also numerous and in some of the lavas become so abundant that they give the groundmass a felted aspect of trachytic nature. Fluxion banding is pronounced. Microlites and crystallites are all aligned parallel to the direction of flowage and the streams of microlites can be seen to bend around the larger phenocrysts. An exception is seen in one series of trichites which show no relation to the flow structure and were

apparently formed after flowage had ceased. Small, drawn out vesicles, partially filled with aggregates of hyalite are numerous. Quartz is also present in some of these vesicles.

In the upper portions of the flows, in which the banding is much contorted, the groundmass of the rocks takes on a slightly different appearance. The glassy base appears brecciated and shows decided changes in color. Some portions of the glass are nearly opaque, while adjoining areas may be nearly colorless. Aggregates of minute spherulites are very common in these portions of the flows.

Nomenclature: The nomenclature of these rocks presents several problems. Most of the specimens studied contained phenocrysts of hypersthene, augite, andesine and quartz set in a glassy base containing many microlites of oligoclase-andesine. Rocks of this nature would obviously be referred to the dacites and would be called hypersthene-augite dacites. In some of the flows, however, quartz is very rare, occurring in small, badly resorbed crystals, while in a few of the rocks it could not be detected at all. In addition quartz was not detected in the groundmass of any of the rocks. There is no reason to believe that there is any appreciable change in the composition of the different flows belonging to this series, either from their relations in the field or from their study in thin section. In those rocks in which the quartz phenocrysts did occur they were unstable as is shown by their corroded and embayed outlines. It is significant in this respect that in

those rocks whose groundmass is of trachytic nature the quartz is either totally absent or very rare. The name "dacitoid" (23) was used by Lacroix in describing lavas

(23) Lacroix. C.R. Acad. Sci., Vol.168, p. 298 (1919).

which correspond in composition to dacite but which do not contain modal quartz. More recently Washington has proposed the name "hyalodacite" (24) for lavas of this type. Both of

(24) Washington, H.S. Santorini Eruption of 1925. Bull.Geol. Soc.Am., Vol.37, p.382 (1926).

these names are based on definite evidence as to the composition of the rock obtained from chemical analysis, however, and cannot be applied to the lavas of the Glass Buttes on the basis of the evidence now at hand. Owing to the inability of obtaining analyses it is necessary to retain the name andesite for those rocks in which modal quartz is not present, although it is highly probable that chemical analyses would show them to correspond more closely to dacites. It might be pointed out as evidence against this viewpoint that the mafic minerals, hypersthene and augite, are characteristic of andesites, while hornblende and biotite are more commonly found in dacites. Pyroxene dacites are not rare, however, and have been described from several localities in the West (25).

(25) Iddings, J.P. Igneous Rocks, Vol.II.

Obsidian: Obsidian, although very common as boulders in

the dry washes and as loose blocks in the pumiceous sand of the Glass Buttes region, is rarely found in place. One flow of perlite is exposed at the southwestern corner of the Glass Buttes range that contains blocks of black obsidian that are not affected by the perlitic cracks. In the central portion of the range a thick flow of dacite contains blocks of obsidian in its upper, pumiceous part.

The obsidian is of two types. One of these is a jet black color in thick pieces but is almost perfectly transparent in slices one-fourth inch or less in thickness. The other is a variegated type which contains angular black fragments in a brilliant brownish-red opaque base. Some of the variegated types show alternating bands of red and black.

The obsidians from this locality were studied in detail by Mr. R. E. Fuller. The results of his investigation are to be published in the Journal of Geology during the present year. Mr. Fuller very kindly consented to the reproduction of his article in this thesis.

THE MODE OF ORIGIN OF THE COLOR OF CERTAIN

VARICOLORED OBSIDIANS

By Richard E. Fuller

Abstract

Irregular pigmentation is due to the oxidation and the subsequent re-fusion of flow breccias. In banded varieties the oxidation occurs in minute tensional cracks developed by

the differential rate of flow between the successive layers of lava. This same factor may be the cause of the laminations in acidic lavas.

The red and brownish opaque colors frequently observed in black obsidians have been proven to be due to the oxidation of the small iron content.* A microscopic examination

*Iddings, J.P. Obsidian Cliff, Yellowstone National Park, U.S.Geol.Surv., Seventh Annual Report (1886), p.274.

of specimens of obsidian from the Glass Buttes and Beatty's Butte in south-central Oregon furnished evidence of two types of mechanism by which this oxidation occurred. The interpretation was strengthened by field observation of the very recent acidic flow on Newberry Mountain, about twenty-five miles south of Bend, Oregon.

The most common type is due to the oxidation of local zones of flow brecciation. The finer particles in these zones would be easily oxidized by the gases escaping from the more fluid lava below. The heat of these gases, reinforced by their own exothermic reactions would again fuse the amorphous mass, leaving the larger more resistant black fragments in a matrix of the red. Then with continued pressure the viscous mass could suffer contortions or additional fracturing with a repetition of the process.

Thin sections testify to the progress of oxidation along the cracks in a breccia. A hand specimen frequently exhibits a transition from an angular breccia to a contorted mass. At Newberry Mountain oxidized fracture zones were

examined where the heat had been sufficient to cause refusion only where the breccia had been subjected to continued gas action along the major contractional joints.

At times, however, the pigmentation is present in fine parallel bands, which may exhibit such extreme regularity as to give the rock a satin-like luster. Although varying both in fineness and in regularity, they always appear in thin section to show one common characteristic. The bands consist largely of an aggregate of fine reddish flecks, the individuals of which have a common orientation diagonal to the main direction of the banding.

An observation of small feldspar crystals in this banded obsidian shows a uniform rotational movement that must be developed by a differential rate of flow between the adjacent layers of the lava in which they are imbedded. This differential rate of flow would develop a series of rotational stresses between these adjacent layers. To consider an incipient stage of this rotational stress in terms of rock dynamics, the maximum elongation of the resulting strain ellipsoid would form an acute angle with the direction of flow (Fig.). Tensional cracks would then tend to develop at right angles to the direction of the maximum elongation. These cracks have been shown* to be especially well developed in a rather plastic

(*) Mead, W.J. Mechanics of Geologic Structures, Journal of Geology Vol.28 (1920), p. 512.

substance and to result from rotational stress prior to the actual shearing. The local relief of gas pressure resulting

from these cracks would cause the concentration of the volatiles from the immediately adjacent lavas. The oxidation caused by these liberated gases would be responsible for the minute diagonal flecks of red.

In this mechanism the fluidity of the lava would probably be sufficient to prevent the lines of shear from developing actual fractures along the planes of least distortion. This contemporaneous association in obsidian of fluidity and brittleness has been previously noted by Fenner at Katmai.* It is

*Fenner, C.N. Katmai Region, Alaska, Journal of Geology, Vol. 28 (1920), p. 590.

also illustrated by several specimens collected by the author at Newberry Mountain. These show the irregular occurrence of gaping tensional cracks combined with a contorted flow surface.

The above mechanism appears also to have bearing on the origin of the laminations frequently observed in acidic lavas. This structure is considered by Iddings "to be directly due to the amounts of vapors absorbed in the various layers of the lava and to their mineralizing influence."* In the cases il-

*Iddings, J.P. Nature and Origin of Lithophysae and the Lamination in the Acidic Lava. Am. Journ. Sci., Vol. 183 (1887), pp. 36-45.

lustrated in this article the tensional cracks would have been developed just prior to the final solidification. If a similar mechanism, however, permitted a local concentration of volatiles in parallel lines before the magma reached its

extreme viscosity, the fluidity of the enriched layer would increase while the adjacent layer would become more viscous. This local concentration of mineralizers might act as a lubricant in flow. At the same time it would locally increase the tendency toward crystallization. This hypothesis is substantiated by the frequent alignment of spherulites in parallel bands in the obsidian, and also by the presence of vesicular bands, both of which are observed at Newberry Mountain. Likewise the highly laminated hypersthene dacite* at Glass Buttes shows alternate bands of black and red. This rock is associ-

*Waters, Aaron. A Structural and Petrographic Study of the Glass Buttes. Unpublished thesis, University of Washington, 1927.

ated with the obsidian, and is undoubtedly due to the crystallization of a banded red and black glass. In this case, however, in spite of the color no textural change was observed.

By this interpretation the author endeavors to show the likelihood that the alternate concentration of volatiles, which is probably responsible for acidic lamination, may logically be caused by the mechanics operative in the movement of a very viscous lava, and not only by the mere fluxion of a lava extruded with a variable concentration of volatiles.

The author gratefully acknowledges the use of material collected by Mr. Waters in his recent study of the Glass Buttes.

The Older Basalts

The oldest rocks exposed in the Glass Buttes region are a series of augite and olivine basalts. This series is exposed beneath the dacites and andesites on several of the fault scarps in the Glass Buttes and also forms a considerable area in the northwestern portion of the range. No estimate of the thickness of this series can be obtained in the Glass Buttes region.

Petrography: The flows belonging to this series are remarkably alike in thin section. They consist of the usual ophitic and intergranular aggregates of labradorite, augite, olivine and magnetite and do not differ from the usual types of basalt that occur in other localities. They are slightly more altered than the younger basalts but are very fresh. Some types are very porphyritic, showing thickly studded phenocrysts of labradorite up to an inch long.

Relation of the Volcanic Rocks at the Glass Buttes to the Southern Oregon Volcanic Field

Lavas of basic and acidic composition are widespread throughout southern Oregon. The acidic and basaltic flows are everywhere conformable and at several localities are interbedded (26). Basaltic flows of very recent origin are

(26) Fuller, R. E. Per. Cit.

also widespread. The older basalts and acidic lavas have been referred to the Miocene (27), while the younger basalts

(27) Waring, G.A. The Geology and Water Resources of the Harney Basin Region, Oregon. U.S.Geol.Survey, W.Sp.Paper 231 (1909).

are known to be very recent. In the Glass Buttes region the older basalts and the dacites probably correspond to the Miocene series exposed on Steens Mountain and at other localities in south-central Oregon.

PLATE IV

Fig. 1. Enclave homoeogene in hypersthene dacite. Magnification, 110 times.

Fig. 2. Enclave in hypersthene dacite. Magnification, 62 times.

Fig. 3. Resorbed quartz phenocryst in spherulitic augite dacite. Magnification, 375 times.

Fig. 4. Resorbed andesine phenocryst with dark colored corona in andesite vitrophyre. Magnification, 35 times.

PLATE IV (to follow page 40)

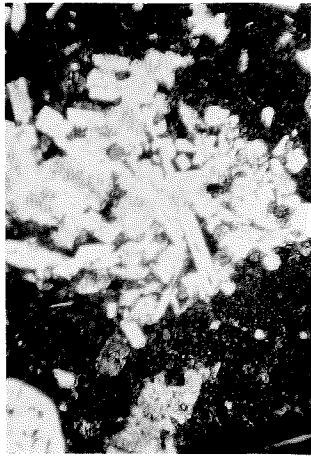


Fig. 1



Fig. 2



Fig 3

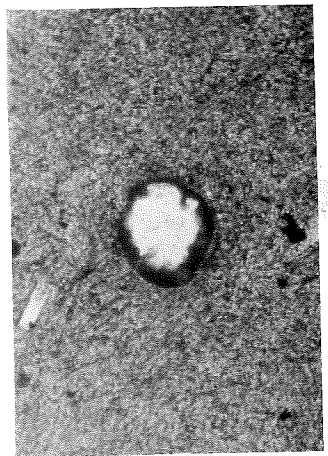


Fig 4

PLATE V

Fig. 1. Resorbed phenocryst of andesine with marked corona of colorless cryptocrystalline grains in quartz andesite. Magnification, 35 times.

Fig. 2. Corona of magnetite and scaly reddish material surrounding a phenocryst of hypersthene in hypersthene-augite dacite. Magnification, 110 times.

Fig. 3. Cryptospherulites in brecciated pumiceous obsidian. Magnification, 630 times.

Fig. 4. Microphotograph of hypersthene dacite showing phenocrysts of hypersthene, andesine and quartz surrounded by the glassy base of the rock. Magnification, 35 times.

PLATE V (to follow page 41)

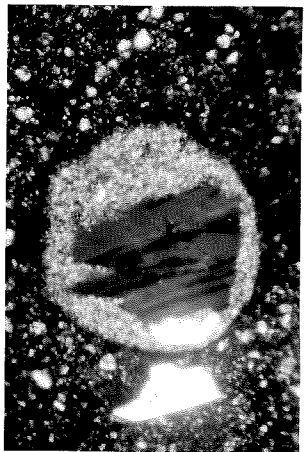


Fig. 1



Fig. 2

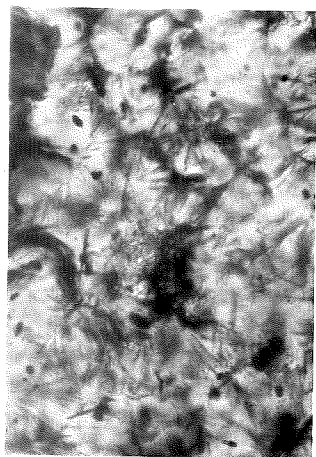


Fig. 3



Fig. 4

PLATE VI

- Fig. 1. Microphotograph of an ophitic textured olivine basalt which occurs as a ten foot flow adjacent to the Conder Cone. Magnification, 46 times.
- Fig. 2. Microphotograph of augite basalt overlying the flow represented in Fig. 1. Magnification, 46 times.
- Fig. 3. Microphotograph showing the common textural relations in the older basalts.
- Fig. 4. Microphotograph of brecciated obsidian. Magnification, 20 times.

PLATE VI (to follow page 42)



Fig. 1

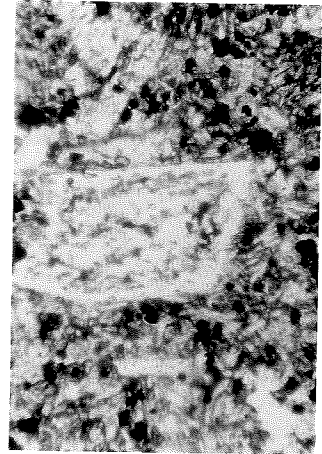


Fig. 2



Fig. 3



Fig. 4

PLATE VII

Fig. 1. Very finely laminated obsidian showing the development of oxidized minute tensional cracks at an angle to the lamination. For explanation see the included article by Mr. R. E. Fuller. Magnification, 62 times.

Fig. 2. Laminated obsidian. Magnification, 20 times.

Fig. 3. Finely laminated obsidian showing the rotational movement of phenocrysts. Magnification, 62 times.

Fig. 4. Laminated obsidian. Magnification, 20 times.

PLATE VII (to follow page 43)

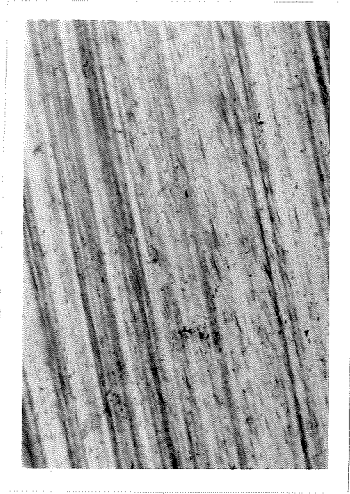


Fig. 1

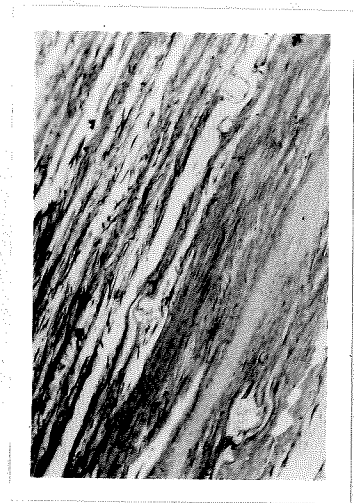


Fig. 2

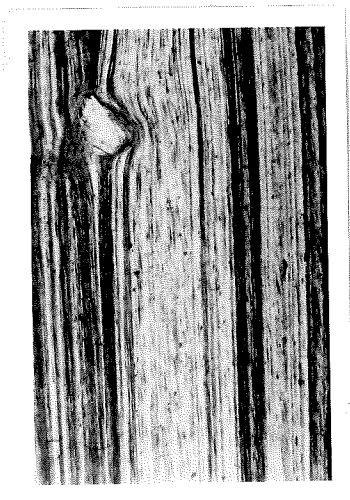


Fig. 3

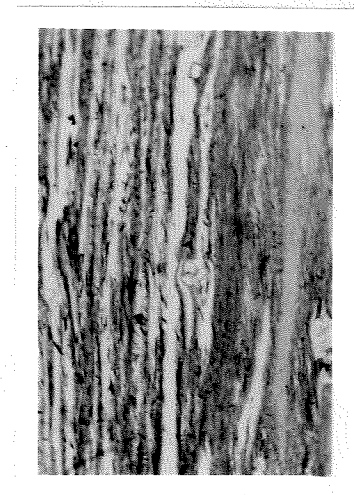


Fig. 4