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GEOLOGY AND ZONAL MINERALIZATION
OF THE HORSESHOE-SACRAMENTO REGION,
MOSQUITO RANGE, COLORADO

by
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GEOLOGY AND ZONAL MINERALIZATION
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MOSQUITO RANGE, COLORADO

by

Robert Dexter Butler
Frontispiece

The Horseshoe
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ABSTRACT

The Horseshoe-Sacramento region lies near the geographical center of the state of Colorado on the east side of the Mosquito or Park Range. The Leadville mining district is situated to the west and the Alma district to the north. To the south of the area, the Mosquito Range continues for many miles as the divide between the Platte and Arkansas drainage basins. Eastward lies the high basin of South Park whose average elevation is nearly 10,000 feet, and beyond the park are the western ridges of the Colorado Front Range.

The Mosquito Range contains numerous peaks whose heights exceed 14,000 feet. The range has been incised by gulches with steep talus-covered walls and in places, vertical cliffs. Streams, fed by the ever present snow-banks flow eastward to join the middle fork of the South Platte River. The heads of the gulches are broad cirques with steep walls. Pleistocene glaciation modified the rolling late Tertiary upland and has been responsible for many of the topographic features of the area. There were two periods of glaciation, the earlier of great lateral extent and outward flow, while the later period was confined within narrower limits but overdeepened the interglacial stream valleys. Much of the upland country east of the crest of the range escaped glaciation. Two moraines have been
distinguished neither of which contains appreciable amounts of placer gold.

The rocks in the area are divided into the pre-Cambrian crystallines, lower Paleozoic sediments, Pennsylvanian sediments, and early Tertiary porphyritic intrusives. The pre-Cambrian rocks are principally schists and allied injected facies although there is some granite and gneiss present. These have been correlated by others as Algonkian.

Following the great erosion interval which terminated in the later Cambrian time in this area, the Sawatch quartzite of upper Cambrian age was deposited as a fine, even-grained quartz sand with but slight conglomerate development at the base. Overlying this formation is the Peerless shale member of Cambrian age, which is the equivalent of the Transition shale of Emmons in the Leadville area. The Manitou limestone, characterized by weathered surfaces showing siliceous ribs and nodules, is the stratigraphic term for the next overlying formation. The miners' term for this is the White limestone. It is of Ordovician age and the upper contact with the Parting quartzite of Devonian age is everywhere in stratigraphic conformity. Overlying the Parting quartzite is the Blue limestone which has been separated into the Devonian lower
member, the Dyer dolomite, and the Mississippian upper member, the Leadville limestone. At the base of the Leadville portion a thin lenticular quartzite member is found throughout the area although in the Alma district to the north it is missing in most places. Although the terminology requires that the calcareous formations be known as limestones, they are actually dolomitic for the most part.

The total thickness of the pre-Pennsylvanian beds in the area is about 500 feet. Following the Mississippian epoch, broad uplifts occurred which resulted in erosion of the Leadville formation in places. The Pennsylvanian series, the Weber(?) formation, is found for the most part, in stratigraphic conformity with the upper Leadville strata. The Weber(?) has a total estimated thickness of about 2000 feet of which the lower 500 feet are dominantly shales, whereas the remainder comprise coarse sandstones, conglomerates, and arkosic grits. The series is extremely variable from place to place and it is impossible to correlate the members over short distances.

Early Tertiary times saw the inception of the intrusive period as part of the Laramide activity. Both intrusions and the later ore deposits are magmatic manifestations within the Colorado mineral belt, although the center of the belt lies several miles to the north. Two principal rock types are present, the White porphyry and
the Gray porphyry. Both are of a general quartz monzonitic composition. Hydrothermal solutions whose activity was confined to the later stages of the intrusive epoch effected an end-phase alteration of all the bodies. The principal visible effect is seen in the bleached aspect of the rocks. The porphyries are present in the form of dikes, sills, and laccolithic sills. Dikes are present here and there in the sedimentary horizons but are principally represented by small bodies within the pre-Cambrian rocks. Sills average 40 feet in thickness and have been intruded in two principal zones, the Sawatch and near the base of the Weber(?) formation. Laccolithic sills of both White and Gray porphyry are found in the lower members of the Weber(?) formation. Their thickness exceeds 2000 feet in places. The Gray porphyry is more abundant than the White.

The area lies on the eastern flank of the Sawatch uplift and displays a regional monoclinal dip to the east of about 15°. Crossing it in a northwesterly direction is the London fold and associated fault which is the principal structural feature of the region. They originated during the Laramide orogeny although there have been later movements on the fault. Folding and faulting occurred in the early Tertiary after the intrusive period had ceased as the porphyritic rocks were involved in the deformation.
Early stresses were expressed by the flexure of the London anticline. It is asymmetric with steep limb on the west. The attendant syncline to the west is not well-displayed in the region because the key horizons lie at considerable depths. In places, the syncline appears to have been over-deepened by the folding and the anticline overturned towards the west. Identical stresses with those responsible for the London fold produced the smaller Cooper Gulch fold which was broken by a thrust fault located nearly parallel to its axial plane and with low east dip. This fault dies out in the northern part of the area. The London fold was ruptured by the London reverse fault which has steep east dip and because of many auxiliary tensional features is thought to represent a later period when the stresses had a different value. The London structure trends irregularly across the area from northwest to southeast and is lost in the flats of South Park. Its northern terminus is at the Mosquito fault on the west side of the range; the total length displayed is about 20 miles. The distance between the anticlinal and synclinal axes is variable, and although the fault is confined to the limb of the fold between the axes, its trend is variable within its confines. The total displacement of the combined folding and faulting is in the neighborhood of 3000 feet. About half of this is due to the
fault displacement. Exact measurements are impossible because of the effects of folding and the drag which accompanied the faulting.

A tremendous number of auxiliary faults and fissures are found in both walls of the fault. Those in the west are in part inferred because in this district footwall relations cannot be determined with satisfaction but underground studies north of the area indicate the complex structures. The hanging wall fractures are principally the divergent type which make cut into the country rock north and northeast at a small angle with the London fault. The ground adjacent to the fault is highly broken and shattered.

The ore deposits in the area are principally narrow bedded replacements of either the Leadville or Dyer formations. The Leadville was more receptive to replacement as it is characteristically capped by impervious Weber (?) shales and porphyry and was more shattered than the Dyer. The principal mines of the area, which have long since been abandoned are the Sherwood, Sacramento, and Mudsill. Their total metal production is estimated as around $300,000. There are other small operations which may have had some slight production. The principal values were in silver and lead.

The ores were localized by north or northeast fissures for the most part, from which the solutions penetrated
the easily replaceable dolomite horizons. Areally the deposits are grouped in a narrow zone in the rocks of the hanging wall of the London fault. The most productive mine, the Sacramento, is located three-quarters of a mile east of the fault whereas the other two important ones are less than one-quarter of a mile from it.

Two groups of deposits are recognized within the area. The productive mines all lie within a mile of each other at the north end of the mineralized zone while an impoverished area is found on Sheep Mountain immediately south of the productive area. A barren zone of several miles extent persists between the northernmost mine, the Sherwood, and the footwall fissure veins of the London type in the Alma district.

The principal interest in the area lies in the question as to whether the London veins are likely to be encountered down to their south pitch in the ground underlying this region. The London mines are operating in a narrow zone in the immediate footwall of the fault where the synclinal rocks have been upturned, dragged along the fault, and in places overturned. The attitude of the veins nearly conforms with the strata. The mineralization consists essentially of quartz, pyrite, sphalerite, galena, chalcopyrite, and gold. Over the two mile stretch in which the London ores are found there is no appreciable change in
their grade or mineralogic character although one-quarter mile north of the North London mine, silver-lead replacement deposits are found in the Leadville formation and the London veins are apparently lacking.

The ores in the Horseshoe-Sacramento district consist of barite, quartz, pyrite, sphalerite, galena, argentiferous tennantite, and dolomite. There are limited amounts of argentite, chalcopyrite, and manganiferous ankerite in the ores of the Sherwood mine. Silicified dolomite is associated with the ores and displays a variety of textures.

The generalized paragenesis is: mineralization stage of widespread scope in which broociated country rock was recrystallized and replaced by silica and barite, followed by introduction of vein quartz and pyrite, and accompanied by solution of dolomitic country rock and reprecipitation as dolomite. This merged into the metallization stage during which the early constituents were abstracted, and characterized by loss of iron and sulphur displaced by the replacement of pyrite by solutions which introduced sphalerite, galena, tennantite, chalcopyrite, and argentite. The manganiferous ankerite is thought to have formed during the early stage.

The mineralogic similarities between this area and the previously described outer zone at Leadville impel the
writer to classify the ores as belonging to the 'cooler' mesothermal type. The mineralization at the Sherwood mine at the north end of the mineralized zone is shown to represent the higher temperature end of this category and has certain affinities with the 'intermediate' mesothermal zone.

Although the bulk of the ores belong to a single genetic zone, serial variations of certain features are noted which indicate decrease in temperature characteristics to the south with the Sherwood mine representing the focal point. The variations are not of any single constituent exclusively, but are supported by textural and chemical factors which additively indicate by their overlapping relations the truth of the concept that these ores represent transitions within a single zone.

To mention some of the variable characters: 1) The ratio of silver to lead decreases to the south, 2) Grain size and amount of pyrite decreases to the south, 3) Barite is found in the area removed from the fault at the north but the barite zone is adjacent to the fault at the south, 4) The epigenetic minerals decrease in relative amounts to the south with the exception of barite and silica, 5) Barite is apparently about constant in the middle part of the zone in which it is found although its amounts grade off in either direction, 6) The amount of epigenetic silica is estimated to increase to the south, and 7) Silicification
textures show progressive variations to the south.

The silicification is compared with that of Tintic, Aspen, and Leadville and illustrations given showing that it combines many of the features from each locality. The finest-grained facies, at the Sherwood mine, has barely resolvable grain sizes under high microscopic power. Although undulous extinction is present, it is not thought that a colloidal origin is necessary to explain the texture. This occurrence close to the London fault has neighbors to the south for several miles, each one of which is coarser-grained than the next locality to the north. It is classed as typical jasperoid with allotriomorphic texture. An equally interesting type is found on Sheep Mountain, more remote from the fault, in which the silica formed later than barite and the initial solutions built euhedral quartz grains which contain an abundance of zonally arranged carbonate inclusions. Transitions between this and the typical jasperoid are noted in certain localities north and northwest of this occurrence.

The solutions which carried the hypogene mineralization into the country rock deposited their load under higher thermal conditions in the neighborhood of the Sherwood mine. In the area limited by the London fault, Sherwood, Mudsill, and Sacramento mines, the solutions deposited the greater amount of their metallic load. It is thought that they
emanated from depth in the Sherwood area and spread through the country rocks to the southeast and east losing temperature and depositing metals as they progressed, hence where they arrived in the ground more remote from their apparent focus, their effectiveness was low. The channelways which were open at the time of the metallization served to guide solutions within the favorable area although the trunk conduit from depth was the shattered zone of the London fault. Where favorable conditions of ingress, nearness to source, and shattered condition of the country rock obtained valuable metallization occurred. There is a suggestion in the ores that those which were subject to renewed brecciation after the deposition of barite, received greater amounts of the later solutions.

The area holds but slight geologic promise for undiscovered hanging wall orebodies of the type mined. Not much favorable ground remains unprospected near the surface where the favorable combination of circumstances obtained.

It is held that the Sherwood mineralization and thus the outlying deposits of the barite zone are related to the London ores as a distant facies. Another interpretation would require the Sherwood mine to be characterized as a separate 'center'. It is the apparent center, but the northward direction in which the zonal features point indicates that the source of heat lay at the north. The distance
between the Sherwood and the London mines is not as great as the distance south of the Sherwood to the southern extremity of the mineralized zone. If such comparatively slight changes occur in a greater distance it is not unreasonable to expect that the shorter distance between the Sherwood and the London may have encompassed conditions which were favorable to transitional types of ore. These ore types are not found in the hanging wall, so if present, they lie in the footwall. Exploration will entail search at considerable depth in the east limb of the down-faulted syncline.
INTRODUCTION

SCOPE OF THE REPORT.

The Horseshoe-Sacramento district was first studied by S. F. Emmons in his survey of the geology of the Leadville area. His publication (1)* has been the only one which has discussed the geology of this area in detail although other workers have studied the margins of the area in connection with investigations in Leadville or Alma.

Since the publication of the Emmons report, the area has attained an economic importance to mine operators in the Alma district as indications are that the gold orebodies of the London mine to the north are plunging southward into unexplored ground. For this reason, a resurvey of the area has been undertaken in order to determine if possible whether favorable structural and stratigraphic conditions have a continuation to the south and at what depth they are likely to be encountered. The structural generalizations have been published in a paper describing the geology along the London fault (12).

The present work is concerned with the mineralization east of the London fault to the south of the London mine.

*References are listed in bibliography; first number denotes the publication, second number the page.
North of the London mine, the ore deposits have been found to grade into a less intense phase of mineralization with the dominant metals silver and lead, while, where explored to the south, the continuation of the London ore bodies shows constant mineralogical features and maintenance of the average tenor of the ore. Further south, however, where the London ore bodies would be at a depth of several thousands of feet if they are present, a mineralization has occurred in the opposite wall of the fault which is visible at the present surface. The principal minerals are pyrite, sphalerite, galena, and tennantite in a gangue of barite, carbonate, and quartz. The study of this mineralization forms the principal topic of this report although some of the outlying unrelated deposits which have not been studied previously are described.

The numerous deposits in the area, only three of which had appreciable production, are arranged within a rude semicircle truncated by the London fault. The study has been undertaken with the hope of finding directional features manifested by mineral zoning. If such are present, and if the geologic structure is amenable to lucid interpretation, the paths of migration of mineralizing solutions can be postulated.

The stratigraphic and structural geology is discussed in sufficient detail to provide a basis for the description of the mineral deposits.
FIELD WORK AND ACKNOWLEDGMENTS.

The field work was done in the summer of 1935 under the auspices of the U. S. Geological Survey as a part of the cooperative program undertaken by the federal and state surveys in Colorado. The party consisted of Quentin D. Singewald as chief and the writer as assistant. The writer had been previously engaged as field assistant during the summers of 1928, 1929, and 1930 in the adjacent Alma district, hence the discussion of stratigraphy and structure is somewhat enhanced by generalities permitted by earlier observations.

The writer is especially indebted to Quentin D. Singewald for permission to study the specimens, for numerous courtesies in the field, and for furnishing additional data. Necessarily, much of the discussion on general geology has been a result of his observations. Mr. G. F. Loughlin of the U. S. Geological Survey gave official sanction to the work.

Prof. W. H. Newhouse guided and criticized the laboratory work and contributed helpful discussions of the problem. Any merit possessed by the microscopic work reflects directly or indirectly on him. Dr. Waldemar Lindgren was kind enough to verify the microscopic relations.

It is a pleasure to acknowledge the value of the earlier mapping by S. F. Emmons. While the results of the
recent mapping have necessitated some revision of the old map, its general features of accuracy and interpretation facilitated the present field study. Many of the discrepancies have arisen because of the larger scale of the later mapping and the recent revisions of stratigraphy.

Mr. G. F. Galloway, mineral surveyor, kindly furnished production estimates. Mr. John Singleton, of the Bank of Fairplay, furnished figures for the gold fineness of the various placers. The numerous mining men in the Alma district have been courteous and helpful during the four summers in which the work was done.
LOCATION AND TOPOGRAPHY

The Horseshoe-Sacramento district is situated in Park Co., Colorado, near the geographical center of the state (figure 1). It lies approximately east of the town of Leadville and southwest of Alma. The Alma district, which is northwest of the town adjoins the Horseshoe-Sacramento region on the north; the Leadville district limits its northwestern and western extent; and the Weston Pass district is a few miles to the southwest. The area merges into the flat-lying floor of South Park on the east. The main drainage of the park and the flanking mountains is effected by the middle fork of the South Platte river, whose tributaries, Fourmile, Sacramento and Pennsylvania creeks drain the Horseshoe-Sacramento district.

Alma, located in longitude 106°4' and latitude 39°17', and the neighboring town of Fairplay are the principal settlements near the area. The Colorado and Southern narrow gauge railroad serves both towns.

The district lies on the eastern flank of the Mosquito or Park Range at elevations varying from 10,000 feet on the floor of South Park to nearly 14,000 feet at the crest of the range. Gulches, with steep talus-covered slopes, extend from the Park nearly to the crest of the range where they open into large glacial amphitheatres. The general rugged charac-
Figure 1. Sketch map of central Colorado showing location of Horseshoe-Sacramento district.
ter of the area, caused by the recent glaciation, is compens-
sated to the geologist and miner by the easy accessibility to
a large part of it and by the excellent rock exposures on
the cliffs. Between the gulches, extensive areas of gently
sloping ground express the regional eastward dip of the under-
lying strata.

Roads enter all the gulches, and while their upper
portions are generally impossible to drive in a car, they pro-
vide easy passage by foot or by horse. Should mining operations
be resumed in the area, these old roads could be readily re-
paired.

The elevation of the timber line varies from 11,500 to
12,000 feet thereby placing about two-thirds of the area
which was mapped in detail above timber. The lower slopes of
the mountains are covered by a growth of aspen, balsam, pine,
and spruce. The heavy snows do not completely melt during
the short summer season making water plentiful.

The area embraces some 50 square miles, about half of
which was the subject of detailed geologic mapping. The other
half, largely covered by glacial moraine, was mapped by recon-
aissance methods for delimiting the character of its glacial
deposits.
a. The Horseshoe and the crest of the Mosquito Range. Looking west, this view embraces the southern part of Four Mile Amphitheatre.

b. Mosquito Gulch. The lower part of a glaciated valley. Bald Hill at the right of the photograph. The merging of the lower valley with the flats of South Park is shown.
HISTORY OF MINING OPERATIONS.

Early mining activity in the general Leadville area centered on placer operations for gold. There was a rush to the Leadville diggings in 1860, when it was called California Gulch. The following year saw activity in what is now the Alma district especially in Buckskin Gulch where the rich Phillips gold orebody contributed placer gold to the stream immediately below the outcrop. Almost at once the source of the gold was discovered (7, 149) and the first lode claim staked. The excitement subsided within a year or two as the oxidized outcrop became depleted and once more the country was the scene of placer mining only.

Prospectors undoubtedly examined the gravels in the Sacramento-Horseshoe district during these early years but were unsuccessful as, so far as known, there are no important gold orebodies outcropping in the area which could have contributed gold to stream and glacial gravels. Meanwhile the various placers of the region were exploited: at Alma, Buckskin, Fairplay, Montgomery, Beaver, and Tarryall. The earliest history of the whole region records a search for gold.

During 1871 silver ores were discovered in the Alma district and it is stated (13, 187) that exploration for silver progressed in the Horseshoe district during 1872.
Henderson, quoting Raymond, (13, 191) records some lead and silver production from Horseshoe and Sacramento Gulches during 1875. The data have not been available to the writer which would describe the course of discoveries in the district, but all the mines were discovered and probably largely worked out between the years 1875 and 1900.

At the head of Fourmile amphitheatre, the Hilltop, Peerless, and Peerless Maude mines have had an estimated production of several million dollars, but are not discussed in this paper as they more properly belong to the Leadville environment and have been previously described in that connection (6).
PRODUCTION.

The only mines having had appreciable production which are within the jurisdiction of the present report are the Mudsill, Sherwood, and Sacramento. It cannot be doubted that there was slight production from many of the numerous prospects in the vicinity of these mines, but from the present aspect of these workings it must have been almost negligible. There have been intermittent attempts at exploration of the ground along the London fault continuing to the present day but these have failed to produce sufficient interest to warrant expenditures for thorough prospecting.

The best available estimates of production are:

- Mudsill mine $ 60,000
- Sherwood mine $ 50,000
- Sacramento mine $200,000

The values shown above consisted mainly of silver and the total probably represents 80 or 90% of the production of the area exclusive of the rich mines at the head of Fourmile amphitheatre.

The present report is therefore considering an area from which the total production has been somewhat more than three hundred thousand dollars and is the scene of intermittent prospecting attempts. There are no producing mines at present, but the area is a possible source of both gold
and silver. Gold possibilities are related to finding southward extension of the London orebodies, and silver to discovering orebodies of the same type as those mined but whose outcrops are concealed.
GENERAL GEOLOGY

INTRODUCTORY STATEMENT.

The Horseshoe-Sacramento district as considered in this report consists of the area immediately adjacent to the London fault. The more remote part of the district has been considered as a part of the Leadville district and has been described (6). A general description of the geology along the London fault has been recently published by the authors of the Alma reports (12). Consequently, the present report will emphasize the geologic details adjacent to the fault in the Horseshoe-Sacramento area alone, drawing on previous experience in Alma and the publications on Alma as aids in order to clarify certain points which might otherwise be obscure. To the reader not thoroughly familiar with Alma geology, the generalities given for the Horseshoe-Sacramento district apply there as well, and where points of difference arise they will be noted.

The essential geologic features of the area are listed below:

(1) A basement complex of schists of pre-Cambrian age, consisting principally of pegmatized schist in the Horseshoe-Sacramento district, but in the Alma district consisting also of granites, pegmatites, and granite-gneiss.
(2) The sedimentary series of Paleozoic age which may be divided into the pre-Pennsylvanian sediments of about 500 feet thickness, and the Pennsylvanian sediments of about 2000 feet thickness.

(3) Porphyritic intrusives of early Tertiary age having the form of sills, laccolithic sills, and dikes. Their general composition varies from dioritic to quartz-monzonitic.

(4) An eastward regional dip to the sediments and intruded sills.

(5) The steeply-dipping London fault with its attendant flexure, the vertical displacement due to faulting being everywhere greater than 1500 feet. It is recognized as a reverse fault.

(6) The low-angle Cooper Gulch thrust fault with considerable displacement in the Alma district, but which appears to die out north of Big Sacramento Gulch.

(7) Mineralization related to auxiliary fractures in the hanging wall of the London fault with principal values in silver and lead replacement deposits in limestone. Contrasted to these are the footwall gold veins of the London mine to the north.

(8) Tertiary erosion and two stages of Quaternary glaciation. The last glacial stage formed terminal and recessional
moraines containing valuable placer gold deposits near Alma and Fairplay but not in the Horseshoe-Sacramento district.
PRE-CAMBRIAN FORMATIONS.

An excellent resume of the pre-Cambrian formations of Colorado has been presented by Lovering (14, 63-74). It is obviously impossible to study these from other than the regional viewpoint, and as the present work was unconcerned with rocks older than Cambrian, opportunities for observation were few.

In the Alma district, four separate pre-Cambrian types have been distinguished and mapped (11, 92). These are, in order of increasing age:

- Silver Plume granite
- Granite gneiss
- Pikes Peak granite
- Idaho Springs formation (schist, injection schist grading to gneiss)

Lovering, in his broader study of their relations believes that they are all of Algonkian age (14, 74).

There has been no attempt to distinguish the formations in the mapping of the Horseshoe-Sacramento district. Pre-Cambrian rocks are relatively abundant in the Alma district, whereas here the landscape is dominated by outcrops of sedimentary formations or Tertiary igneous rocks. Schist is the preponderant pre-Cambrian rock, either quartz-
mica-schist or a more or less pegmatized facies of it due to lit-par-lit injection. The pegmatized facies in the Alma district grades over into injection-gneiss while schist characteristics predominate in the Horseshoe area. The schistosity is steeply-dipping and generally strikes north to northeast.

There are a few isolated outcrops of granite and granite-pegmatite. One is worthy of mention. On the south slope of Pennsylvania mountain, 300 feet above Big Sacramento Creek, east of the London fault, and approximately opposite the Majestic tunnel, a contact was observed between a facies of granite and the pegmatized schist. The schist at this point is a medium-grained biotite schist containing numerous thin lit-par-lit injections, the pegmatitic material of the injected bands being generally less than an inch in width. The granite is the "corn rock," which Singewald has stated T. S. Lovering believes can be correlated with granite of Silver Plume age. It derives its name from the arrangement of orthoclase crystals, an inch or two in length, which lie in essentially parallel orientation. Otherwise, it may be considered as a normal porphyritic granite. The steeply-dipping planes of schistosity are cut at nearly right angles by the "corn rock" and the alignment of feldspars in the granite is closely parallel
to the contact. The outcrop was large enough so that there could be no doubt as to the relations. It was relatively unweathered so that megascopic examination sufficed to show that the lit-par-lit structure was cross-cut by the invading "corn rock" and that there is no evidence of contact action. Lovering states (14, 73-74) that the earlier Pikes Peak granite invaded the earlier rocks in the "zone of flowage", and that its contact action was mainly of an assimilative type with structural concordance the rule, and that the pegmatized schist of the Idaho Springs formation is a manifestation of the extent of its metamorphic aureole. He finds that the Silver Plume granite, intruded at a later time, consolidated in the "zone of fracture" and its typical contact relations are discordant.

The contact above Sacramento Creek displays the later age of the "corn rock" granite, and the earlier age of pegmatization as well as the cross-cutting relations of the "corn rock". If pegmatization of schist can everywhere be correlated with intrusion of granite of Pikes Peak age, the "corn rock" granite belongs to a later intrusive period as Lovering has suggested.
PALEOZOIC SEDIMENTARY ROCKS.

General Character.

In discussing the Paleozoic formations of the Mosquito Range it is possible to consider the pre-Pennsylvanian rocks as a unit as they are lithologically different from the Pennsylvanian and later rocks.

Pre-Pennsylvanian rocks in the Horseshoe-Sacramento district consist of quartzites, impure limestones and dolomites, thin-bedded shales, sandy shales, and sandy limestones. Their total thickness is about 500 feet. The only younger formation which has not been completely eroded is of Pennsylvanian age and consists of thin-bedded shales, carbonaceous shales and limestones, and fine grits in the lowermost 300 feet; whereas the upper part of the formation contains an undetermined thickness of coarse arkosic grits and cross-bedded sandstones.

Table I shows the measured thicknesses of members of a stratigraphic section located in Four Mile Gulch. It was impossible to get a continuous measurement across the section so the tabulation represents a composite description gathered from both walls of the gulch. The data for the Pennsylvanian member have been taken from measurements throughout the region (16, 17). Its character is so variable that differences have no significance. For further information
<table>
<thead>
<tr>
<th>Age</th>
<th>Formation</th>
<th>Thickness</th>
<th>Lithologic Character</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleistocene</td>
<td>Unconformity</td>
<td></td>
<td>Gravel and silt.</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Unconformity</td>
<td></td>
<td>Silt and volcanic rocks. Sills are common, and generally occur at certain stratigraphic horizons, especially at or near base of Weber(?) formation where some are laccolithic.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,000‡</td>
<td>Sandstone and grit with some interbedded limestone. Material very arkosic and micaceous. Color in lower part light to dark gray. A few thin red shales.</td>
</tr>
<tr>
<td>Pennsylvanian</td>
<td>Weber(?)</td>
<td>550‡</td>
<td>Gray sandstone and grit with interbedded limestone and shale. Becomes more and more arkosic and micaceous toward top. The beds tend to be lenticular and non-persistent.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50-300‡</td>
<td>Black carbonaceous shale, commonly very sandy. Basal bed generally a thin yellow shale.</td>
</tr>
<tr>
<td>Mississippian</td>
<td>Leadville limestone</td>
<td>112</td>
<td>Dolomite, blue to lead-gray, some beds almost black. Beds massive. Chert nodules and streaks are locally abundant. Sandstone at base, a few inches to 15 feet thick, accompanied by dolomitic breccia. Is upper part of &quot;Blue&quot; limestone of early reports.</td>
</tr>
<tr>
<td></td>
<td>Unconformity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>Formation</td>
<td>Thickness (feet)</td>
<td>Lithologic Character</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------</td>
<td>------------------</td>
<td>--------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Upper Devonian</td>
<td>Cheyenne formation</td>
<td></td>
<td>Gray dolomitic limestone, mainly dark gray but locally becoming lighter at the base. Tends to weather brown or tan. Locally contains sandy and shaly layers, especially toward the base. Is lower part of &quot;Blue&quot; limestone of early reports.</td>
</tr>
<tr>
<td></td>
<td>Parting quartzite member</td>
<td>60-75</td>
<td>White or nearly white sandstone and sandy shale. Largely quartzitic. Some layers of poorly rounded pebbles. Weathers pink to red-brown. Locally contains red and green shale and calcareous shale, especially at the base.</td>
</tr>
<tr>
<td></td>
<td>Unconformity</td>
<td></td>
<td>Thin-bedded light gray dolomitic limestone, very siliceous in places. Contains interbedded shale. The &quot;White&quot; limestone of Leadville district.</td>
</tr>
<tr>
<td>Lower Ordovician</td>
<td>Manitou limestone</td>
<td>130</td>
<td>Shale, thin limestone, and sandstone. Includes &quot;transition beds.&quot;</td>
</tr>
<tr>
<td>Upper Cambrian</td>
<td>Sewatch quartzite</td>
<td>Peerless shale member</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unconformity</td>
<td>Schist, pegmatized schist, pegmatites, and granite.</td>
</tr>
</tbody>
</table>
about the Paleozoic formations of the Mosquito Range the reader is referred elsewhere (16).

Fossils are abundant in certain beds of the Pennsylvanian formation, but are conspicuously absent in pre-Pennsylvanian rocks. Ages have been determined by regional studies and by the presence of fossils from these same beds in other localities.

The Cambrian System.

The Cambrian rocks in the Alma district have been subdivided as follows (8, 297):

- Limestone - shale member ("transition shale")
  - Upper shaly zone
  - Limy zone
- Quartzite member
  - Purple quartzite
  - Upper quartzite zone
  - Thin-beded limy zone
  - Lower quartzite zone
  - Basal conglomerate

These subdivisions are present in the area mapped and their recognition as zones of individual character has proven of assistance in mapping contacts, especially across talus-covered slopes.

The quartzite member is variable in thickness throughout the area of the Mosquito Range. Its maximum thickness in the Alma district is about 130 feet. The basal quartzitic conglomerate nowhere attains a thickness greater than one foot and usually is scarcely discernable from the overlying
quartzite although pebbles up to an inch in diameter are found in the white quartzite matrix. Although the writer has had the opportunity to observe literally miles of linear contact between the basal Cambrian and the pre-Cambrian formations, no irregularities have been noted (2, 25). This again testifies as to the quantity and quality of the great erosion interval which endured in the Mosquito Range area until the close of middle Cambrian time.

Fine-grained, thick-bedded white quartzite overlies the basal conglomerate and constitutes the most prominent subdivision of the quartzite member. This is the lower quartzite zone. Cliffs generally are present where this zone outcrops on the slopes of glaciated gulches, below which the pre-Cambrian formations are covered by gentler-sloping slide rock, and above which the less resistant formations have been eroded leaving talus-covered benches.

The purple quartzite which is considered as the uppermost member of the quartzite member provides a most convenient key horizon. It weathers to a black or purple hue, averages 6-8 feet thick, and is found throughout the area. In the absence of the "red-cast beds" (8, 298) which are quite prominent at Alma, the purple quartzite is the only horizon easily recognizable over large areas between the base of the Cambrian and the top of the Ordovician.
strata. It was possible to map with greater precision and speed by utilizing this bed than if the uppermost Cambrian zone had been used. The ability to recognize the top of the second overlying zone therefore allows one to designate the Cambrian-Ordovician contact.

The Peerless shale member includes the "transition shales", so-called because they supposedly represent the transition between Cambrian and Ordovician rocks. Fossils have been found which indicate they are of late Upper Cambrian age (16, 20). In general, however, the uppermost of these beds resemble the lowermost Ordovician rocks in the field. In places, the uppermost ten feet of the Peerless member may contain one or more thin horizons of red-cast beds. They are regarded as casts of shells.

The Ordovician System.

The Ordovician rocks of this area have been subdivided (8, 296) as follows:

Upper limestone zone
Shale zone
Lower limestone zone

The old miners' term for the rocks of this system, usage of which has continued to the present day, is the "White" limestone. Curiously, the rocks are neither dominantly white in color nor are they dominantly limestones, containing abundant dolomitic horizons. In the Leadville report, these
Figure 3

Weathering of Manitou limestone showing formation of siliceous ribs and nodules.
strata were correlated with the Yule limestone of the Anthracite-Crested Butte area (2, 27), but later work has indicated the advisability of correlating them with the Manitou limestone (8, 298; 16, 21) of the Colorado Springs region.

The lithologic boundaries between the units are not sharply demarcated although the transitions occur in a relatively narrow vertical range. The upper limestone zone is approximately twice the thickness of the combined other two, and is more important from both the stratigraphic and the economic standpoint. The upper limestone zone is nearly everywhere thin-bedded and contains on weathered outcrops conspicuous cherty layers many of which are about an inch thick. The typical thin-beds and chert serve to distinguish it from certain horizons of the "Blue" limestone.

The rocks of the upper zone are white to bluish in color and weather light gray or brown. Whereas the lower limestone zone contains material of calcitic composition in relative abundance, the upper limestone zone is dominantly dolomitic.

The Devonian System

Subdivision.—Rocks of Devonian age are divided into two members: the Parting quartzite and the Dyer dolomite. Both members are considered as the Chaffee formation (16, 23) of upper Devonian age.
Parting Quartzite Member.--It was formerly thought by Girty that the Parting quartzite was of Ordovician age (2, 32, quotation) and Loughlin tentatively accepted this classification in the Leadville report (2, 32). Singewald (8a) called attention to the variations in thickness of the Parting quartzite in the Alma district and considered that an erosional break was indicated at the base rather than at the top of the formation. A recent article (16, 24) has accepted the assignation of Devonian age to the Parting quartzite on the basis of newly-accumulated stratigraphic and paleontologic data.

"Parting quartzite" is used by the miners of Leadville to designate the quartzite bed which separates the "Blue" limestone above from the "White" limestone below. The term was so firmly entrenched in the descriptive vocabulary and everyday terminology of the region that it was thought unwise to abandon it. Consequently, in order that the name might be validly retained, a ridge on the slopes of Dyer Mountain has been designated as the "Parting Spur" thus giving geographic significance to the Parting quartzite (16, 23).

In the Horseshoe-Sacramento area the Parting quartzite is between 60 and 75 feet in thickness. It is a cross-bedded and conglomeratic quartzite containing some sub-angular quartz pebbles. Forming distinct erosional benches along the slopes of gulches, it constitutes a valuable key
horizon for structural interpretation.

Dyer Dolomite Member.—The "Blue" limestone comprises the beds between the Parting quartzite below and the Weber (?) formation above. Formerly, it was considered as a single formation by both miners and geologists even though stratigraphic variations had been noted within it. The recent geological work in central Colorado allowed recognition of three lithologic units (8, 296) and more recently the separation of the formation under different geologic ages has been accepted (16, 24-25). The lowermost unit, primarily from stratigraphic evidence, has been included with the Parting quartzite in the Devonian system under the term, Dyer dolomite. One of the principal evidences is that gradations exist locally between the Parting quartzite and the lower Dyer beds. Furthermore, there is an erosional break present at the top of the member: Devonian sedimentation was both preceded and succeeded by periods of erosion.

The member as a whole contains medium to heavy-bedded, gray, dolomitic limestone which weathers brown, blue, or gray. In the absence of the overlying thin sandy quartzite, one of the upper beds of this formation may prove of value for stratigraphic location. It is about ten feet in thickness, massive, dark blue in color, weathers almost black, and where seen is but a few feet below typical Leadville
beds. Its best exposure is on the ridge south of Big Sacramento Gulch on the west limb of the Sacramento Arch (London Anticline).

The Mississippian System

Subdivision.--The Leadville limestone which is the upper part of the "Blue" limestone of the miners may be subdivided into a basal quartzite member and an upper dolomite member. In this report the limestone member is termed the Leadville limestone but a recent publication (16, 18) has chosen to designate the whole formation under that heading.

Basal Quartzite Member.--Although this member over the whole region should be more exactly termed sandstone, the authors of the Alma reports have called it the "quartzite zone" (12, 7). The precedent is followed herein. A section of this member or zone has been measured indicating a thicker development than elsewhere in the Mosquito Range. The location is on the east point along the crest of the relatively low ridge north of Four Mile Creek. It is about 2000 feet east of the Mudsill mine. The detailed section follows:

Typical Leadville limestone with zebra structure.

3 ft. 6-8 inch beds of limestone, each grading towards sandstone at top, and each capped with 1 inch of sandstone which appears to be lenticular.

3 ft. Massive limestone.

3 ft. Intercalated sandstone and limestone breccia. Breccia has sandstone cement. Weathers light brown. This is the dominant sandstone horizon.
5 ft. Massive limestone with a few narrow zones of sandstone.

1 ft. Basal sandstone. Grain size not appreciably greater than that of other sandstones in the member.

Massive dark blue Dyer dolomite.

For a diagrammatic sketch of this member, Figure 12A which has been prepared for a different purpose may be consulted.

The member throughout the Mosquito Range area appears to be lenticular over short distances. This is attributed to non-deposition in contrast to the changes in thickness of the overlying Leadville limestone which is attributed to pre-Pennsylvanian erosion (16, 27). Where present, this member aids in mapping the base of the Mississippian portion of the "Blue" limestone. It is believed that the member is more persistent in the Horseshoe-Sacramento district than in the Alma district.

Leadville Limestone Member.--This portion of the formation, the upper part of the "Blue" limestone, is probably the best-known rock in central Colorado. It has been the host rock to many of the great replacement orebodies at Leadville, Gilman, and elsewhere. Although fossils are rare, it has been described as the equivalent of the Madison limestone (16, 27).

In the mineralized region of central Colorado, where
present, it is a dolomite although gradations into pure limestone exist in other places. Its color on fresh surfaces is deep blue; weathered surfaces are blue to lead-gray in color. Certain horizons of the massive dolomite weather in such a way as to present on their outer surface tiny, irregular serrate ridges. These are an expression of the preferential solubility of the dolomite over silica which is shown as a slight impurity (2, 35).

The most striking feature of the Leadville limestone is the amount and character of the recrystallization which has occurred within it. A structure which is known under the descriptive term, "zebra rock," has been produced. It appears in hand specimen as narrow irregular zones of white dolomite against a background of blue dolomite. This structure is developed to differing degrees within the formation and there are also areal variations. Mr. G. F. Loughlin (written communication) stated that the structure has been observed in areas far-removed from evidences of mineralization. It may be absent or negligible in places within mineralized areas. The subject is discussed in greater detail in another section of this paper.

The following tabulated characteristics distinguish the three dolomitic limestones from one another:

**Leadville Limestone** - Easily recognizable Weber(?) beds above. Weathers to a smooth surface with "zebra" structure or to a rough surface with serrate ridges. Weathers blue-gray. Beds thick.

Manitou Limestone - Parting quartzite above, shales below. Weathers smooth but with siliceous ribs. Color on weathering usually gray or tan. Thin beds, and intercalated shales.

The Pennsylvania System.

Post-Leadville Erosion.--The Pennsylvanian sediments rest on an irregular surface of Mississippian rocks without apparent angular unconformity. On faunal evidence Johnson (16, 27) states that the interval of non-deposition represents the last half of Mississippian time and part of early Pennsylvanian. According to Singewald, "Where the 'Blue' limestone is thin it is the upper beds that are missing." (8, 300) The abrupt change in the lithologic character of the pre-Pennsylvanian rocks as contrasted with the Pennsylvanian rocks is suggestive of a marked change in conditions of deposition. Furthermore, in certain areas, especially north of London Mountain in the Alma district, the basal Weber(?) bed contains angular fragments of the Leadville limestone. Thus there exists abundant evidence of a break in the sedimentary sequence which followed deposition of the Leadville formation.

Important crustal warping began in Mississippian time in this region (20, 279) and altered the distribution of the
early Paleozoic sea by forming a distinct eastern trough and a deeper western one. The latter had its axis very close to the present area. The geanticline separating the two is considered as the ancestral Front Range. These conditions persisted at least until the early Pennsylvanian. The Weber(?) Formation—"Above the 'Blue' or Leadville limestone....... is a series of strata to which collectively Emmons has applied the names 'Weber grits' and 'Weber formation' and which he subdivided into a lower shaly division called 'Weber shales' and an upper quartzitic and sandy division called 'Weber grits proper.' The name Weber was apparently derived from the Weber quartzite of the Wasatch Mountains of Utah, with which a correlation was made and now seems to be of doubtful accuracy. For the convenience of the mining public, however, the name is retained in this report, the doubt regarding its appropriateness being indicated by a question mark, and its subdivisions are designated by the familiar though questionable terms 'Weber grits' and 'Weber shales.'" (2, 38) The preceding quotation from the Leadville report summarizes the situation of the Weber(?) formation with respect to nomenclature.

Abundant faunal and floral remains collected over a wide area establish it without question as of Pennsylvanian age (16, 28).
The basal bed of the Weber(?) formation is usually a yellow shale, averaging two feet thick. Of all the beds in this thick series, the thin basal bed has appeared to be unusually persistent in both the Alma and Horseshoe-Sacramento districts. Even where porphyry sills have intruded the Weber(?) at the base of the formation, a few inches of the yellow shale remain above the Leadville limestone. Locally, however, as mentioned before, a limestone breccia marks the base. Johnson considers that a basal sandstone is typical (16, 17) but his observations have been taken from an extensive area rather than a localized region.

The lowermost 300 feet of the Weber(?) formation comprise carbonaceous shales, thin sandstones, and thin limestones. These together with the basal bed have been designated previously as "Weber shales". Their lenticular aspect shown by the impossibility of correlation even over short distances as well as their lithologic character suggest they are deltaic in origin.

The remaining 1500 feet of the Weber(?) formation is known as the "Weber grits" although it may be subdivided as shown on the columnar section (16, 17). It should be emphasized that the total thickness of the formation in this area is subject to question as the next higher recognizable formation has been eroded. The total thickness appears to
be at least 1800 to 2000 feet. Even if it were possible to measure the "grits", the variabilities are so great within the formation that the figure would have no significance beyond a radius of a few thousand feet.

The "grits" consist dominantly of thin to thick beds of arkosic and micaceous sandstone. The sandstones are typically cross-bedded, especially the thicker lenses. In places there are quartzite beds. At some distance below the top, there are several thin beds of red shaly sandstone containing mica.

It is thought that the coarser conglomerates of which there are several beds, are to be found in the upper part but not necessarily at the top of the formation. The ridge west of Lamb Mountain contains conglomerate beds in which the cobbles attain diameters of 8 inches. Evidence indicating their stratigraphic position is absent.

The cobbles and larger pebbles which have been observed in the conglomerates and quartzites are sub-angular to rounded in shape and are generally composed of quartz. It is not uncommon to detect mica in the quartz. The texture of this quartz and mica place its derivation from pegmatitic material. As there was no material of this type in the region other than pre-Cambrian, exposed during the Pennsylvanian period, it is necessary to conclude that the material was derived from a pre-Cambrian surface.
TERTIARY IGNEOUS ROCKS.

General Character & Age.

Since the earliest records of the mining operations which centered about the Leadville district, the various intrusive rocks of early Tertiary age have been included under the descriptive terms, 'Gray' porphyry and 'White' porphyry. Recently dated field and petrographic descriptions of these rocks have maintained the use of the terms for convenient broad classification but have separated the rocks into types and sub-types.

The bulk of the intrusive rocks of this epoch have a composition between granodiorite and quartz monzonite in the Leadville, Alma, and Horseshoe-Sacramento districts. The regional petrographic similarity of the Tertiary intrusives in Colorado has long been realized (1a,219-241) and Crawford believes that a single batholith of that composition underlies the mineral belt of central Colorado 1b,365-388). Spurr and Garrey contributed a discussion of the relation of the porphyrites to the mineral deposits and structure, and Ball pointed out that the longer axes of the intrusives have northeasterly trend in harmony with the apparent elongation of the subsurface batholith (1c).

On the basis of regional studies throughout the whole porphyry belt of central Colorado, Lovering has assigned the principal eruptive period to the early Eocene (15a,30).
Igneous rock types which occur in the Horseshoe-Sacramento district can be unquestionably correlated with those to which an early Eocene age has been assigned if petrographic and structural similarities are accepted in evidence. Elsewhere in the region, intrusive and extrusive rocks of other composition and structural relations have been shown to be of other ages (15a,26-30).

The porphyries in the Horseshoe-Sacramento district are the equivalents of those in the Leadville and Alma districts and may be traced across the arbitrary limits of each district, hence it is unnecessary to make them the subject of detailed petrographic discussion inasmuch as there are no known orebodies in the Horseshoe-Sacramento district which have porphyry wall rocks. A comprehensive treatment in the Leadville report provides the most detailed information on the porphyries there (2,43-59), while Singewald has supplied general and specific information regarding the intrusives in the Alma district (9;9a;9b).

Description of the Intrusive Rocks.

The intrusive rocks in the Alma district have been classified on the basis of form under two major divisions: (1) the Buckskin Gulch Stock located at the foot of Mt. Democrat consisting dominantly of granodiorite and quartz monzonite but in which there has been minor development of associated facies; and (2) dikes, sills, and laccolithic sills
of White and Gray porphyry (11,94). The group of dikes and sills in the Alma district has been further subdivided as follows:

<table>
<thead>
<tr>
<th>Late White Porphyry</th>
<th>(present)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite Porphyry</td>
<td>(scarce)</td>
</tr>
<tr>
<td>Gray Porphyry Group</td>
<td></td>
</tr>
<tr>
<td>Lincoln Porphyry</td>
<td>(abundant)</td>
</tr>
<tr>
<td>Quartz monzonite porphyry</td>
<td>(most abundant)</td>
</tr>
<tr>
<td>Monzonitic diorite porphyry</td>
<td>(moderately abundant)</td>
</tr>
<tr>
<td>Early White Porphyry</td>
<td>(abundant)</td>
</tr>
</tbody>
</table>

The preceding tabulation indicates the age relationship of the various porphyries, the lowermost being the oldest. Although there has been but limited opportunity to observe indicative contact relations between them, the weight of field evidence substantiates the validity of the tabulation. Moreover, if the above order holds, it is in accord with that which would be expected from a differentiating magma (9,27) as the groundmass of each type is more salic than the phenocrysts, and the trend of formation was from calcic to sodic.

In the Horsewhoe-Sacramento district the porphyry types are not as diversified. The late White porphyry was not observed although it is so similar to the early White porphyry in appearance, that it could easily not have been recognized as such. There is no granite porphyry. The stratigraphic
and areal position of the porphyries in the Horseshoe-Sacramento district is indicated below:

<table>
<thead>
<tr>
<th>Group</th>
<th>Designation</th>
<th>Stratigraphic position</th>
<th>Areal position</th>
<th>Relative abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray Porphyry</td>
<td>Lincoln Porphyry</td>
<td>Base of Weber(?)</td>
<td>Bald Hill</td>
<td>Only occurrence</td>
</tr>
<tr>
<td></td>
<td>Quartz monzonite</td>
<td>Base of Weber(?)</td>
<td>Throughout area</td>
<td>Most abundant</td>
</tr>
<tr>
<td></td>
<td>porphyry</td>
<td>Sawatch</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Monzonitic</td>
<td>Sawatch</td>
<td>Pennsylvania</td>
<td>Scarcely</td>
</tr>
<tr>
<td></td>
<td>diorite porphyry</td>
<td></td>
<td>Mountain</td>
<td></td>
</tr>
<tr>
<td>White Porphyry</td>
<td>Early White</td>
<td>Base of Weber(?)</td>
<td>West of London</td>
<td>Abundant</td>
</tr>
<tr>
<td></td>
<td>porphyry</td>
<td></td>
<td>Fault, Sheep Mt.</td>
<td></td>
</tr>
</tbody>
</table>

The Lincoln porphyry, which is so abundantly observed in the neighborhood of Mt. Lincoln in the Alma district and also at several places in the Leadville area, is present only in the northeastern corner of the area surveyed. There it underlies Bald Hill in the form of a thick sill near the base of the Weber(?) formation. Its composition is quartz monzonite and its principal distinguishing feature is the abundance of comparatively large orthoclase phenocrysts. The phenocrysts which are generally twinned according to the Carlsbad law, are commonly observed in sizes ranging from one to two inches in length.

The monzonitic diorite porphyry is present only on the north shoulder of Pennsylvania Mountain east of the London
fault. It has intruded the Sawatch formation in sills as in
the Alma district. One narrow dike was also noted which ex-
tended into the pre-Cambrian rocks. This rock is distinguish-
ed by its dark gray color and abundant hornblend or altered
mafic phenocrysts.

The quartz monzonite porphyry is the dominant post-
Cambrian intrusive rock in the area. Several sills of it are
typically observed in the upper parts of the Sawatch formation
although its maximum locus of development appears to be in the
base of the Weber(?) formation. There it has been intruded
in thick sills which are called laccolithic as their thickness
is much greater in proportion to their area than the typical
sills in this district. Sills such as are found in the
Sawatch formation are generally less than one hundred feet
thick and average about forty feet. These laccolithic sills
found in the base of the Weber(?) are more than two thousand
feet thick and areally finger out into many typical sills at
various horizons in the formation. In pre-Cambrian rocks,
quartz monzonite porphyry is found in narrow dikes cutting
the foliation.

It contains numerous phenocrysts of plagioclase and
quartz as well as altered biotite and hornblend. Alteration
has affected it to such a degree, however, that quartz usually
is the only prominent mineral megascopically. The hydrothermally
altered porphyry is a light gray-green in color.
The early White porphyry is so highly altered that exact classification is not possible. Upon computing the modal composition of a Leadville occurrence, Loughlin decided that its abundance of muscovite and high quartz content would favor its designation as a sodic muscovite granite (2,46). Singewald concluded that the early White porphyry was a felsic quartz monzonite, or granite close to quartz monzonite in composition (9b, 529).

It contains rare quartz and dark muscovite phenocrysts and is distinguishable by its gray-white color. Certain facies of the late White porphyry contain orthoclase phenocrysts which serve to identify it, otherwise the White porphyry of the two ages cannot be distinguished unless structural evidences are observed. The intrusion of the early White porphyry preceded faulting.

**Alteration of the Intrusive Rocks.**

Immediately after their intrusion and consolidation, intrusive rocks in the area were subjected to hydrothermal alteration by solutions which have been designated as "end-phase" (9). The solution effects are considered as the aftermath of intrusion but are not termed "deuteric" as evidence is presented which indicates that the system at the time of the alteration was an open one. These "end-phase" alterations are not to be confused with still later metasomatic alteration in
the neighborhood of ore deposits which superimposed other alterations on the earlier. The wall-rock alteration of the porphyries in the Alma district has been described (9b) and does not warrant consideration here as there are no orebodies adjacent to porphyry walls in the Horseshoe-Sacramento district.

Effects of the "end-phase" alteration are abundantly visible microscopically (9b, 525-526). The process took place in four more or less well-defined stages and affected all intrusive facies to some degree. The essential alterations of the stages are listed below:

1) Albitization of plagioclase, development of green mica.
2) Sericitization of plagioclase, chloritization and epidotization of hornblend and biotite.
3) Introduction of carbonate and recurrence of reactions of stage 2.
4) Veinlet stage - white carbonate and quartz.

Megascopic evidence of these alterations are in places pronounced although visible to some extent everywhere. Curiously, solutions did not leave any visible trace of their presence in the surrounding country rock as might have been expected. The porphyries themselves, however, have a characteristic bleached aspect which upon closer examination, shows up in both groundmass and phenocrysts. The groundmass has a 'soft' appearance, with pseudo-granularity in some cases. With the exception of quartz (and some of the hornblend in the monzonitic diorite
porphyry), the phenocrysts have been well-altered but their original crystal form is generally apparent because of pseudo-morphic preservation by the aggregate of alteration products.

It is impossible to determine with any degree of certainty the character of some of the intrusives because of the great amount of alteration which has progressed. Quartz monzonite may have the outward appearance of the early White porphyry and vice versa. Further confusion arises where metasomatic wall-rock alteration has been superimposed; this is especially troublesome underground.

Furthermore, weathering which usually tends to give distinctive appearance to the porphyries; the quartz monzonite weathering gray-green and the early White porphyry light gray to white; introduces in places additional complications of identity because of kaolinization of feldspar. The unique character of the weathering of one of the White porphyries is discussed briefly elsewhere in this report.

The following tabulated summary of the "end-phase alteration is taken from Singewald (9b, 526):
<table>
<thead>
<tr>
<th>Original mineral alteration products</th>
<th>Plagioclase</th>
<th>Hornblende</th>
<th>Biotite</th>
<th>Orthoclase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sericite White carbon-ate Albite (Ab90An10) Epidote Clinozoisite Chlorite</td>
<td>Chlorite Epidote White carbonate Leucoxene Sericite Ferruginous carbonate Magnetite(?)</td>
<td>Green mica Chlorite Epidote Leucoxene and/or White mica White carbonate Sericite Ferruginous carbonate Rutile Magnetite(?)</td>
<td>Sericite White carbonate</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Extent altered in</th>
<th>Lincoln porphyry</th>
<th>Intensely</th>
<th>Completely</th>
<th>Almost completely</th>
<th>Slightly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz monzonite porphyry</td>
<td>Moderately to intensely</td>
<td>Completely</td>
<td>Intensely to completely</td>
<td>Slightly</td>
<td></td>
</tr>
<tr>
<td>Monzonitic-diorite porphyry</td>
<td>Moderately</td>
<td>Moderately</td>
<td>Slightly to moderately</td>
<td>Slightly</td>
<td></td>
</tr>
</tbody>
</table>
QUATERNARY DEPOSITS.

Glacial Geology.

The entire mountainous region of central Colorado, which received several peneplanations and regional uplifts (18, 1336) during the Tertiary, was a gently-rolling upland of moderate relief at the beginning of the Pleistocene. There existed numerous stream-cut valleys which, although not deeply incised, localized the courses of the glaciers that formed during the Pleistocene. There were at least two periods of glacial advance. A possible third (18, 1328), earlier than the others, could account for certain peculiarities observed in Fourmile Gulch, but the evidence was so obscure that the possible earliest moraine has been mapped along with that of the older epoch.

The pre-glacial surface is visible on the broad divides which separate the gulches and around the amphitheatres above the level at which the ice existed. There is no evidence of glaciation on Pennsylvania Mountain, in Spring Valley, or on the east slope of Sheep Mountain.

The principal point of difference between the Fourmile and Sacramento glaciation and that farther north in the Alma district is the presence of rock benches in the Alma district (11, 98) which are remnants of the interglacial surface. The pre-Cambrian granite, gneiss, and schist lies farther from the heads of the Fourmile and Sacramento
gulches than it does in Mosquito and Buckskin gulches in the Alma district, and where it has been exposed, the elevations are relatively low compared to the Alma district where the pre-Cambrian is found on many of the peaks. Furthermore, the dominant pre-Cambrian rocks in the Horseshoe-Sacramento area are schists, while at the heads of the gulches to the north, there is abundant granite, gneiss, and pegmatite. The absence of rock benches is thereby ascribed to the accidents of regional structure, as the relatively soft sediments and schists which are present at the favorable loci for benches could neither receive nor support them.

An earlier study of the glacial geology of the Mosquito Range by Capps (17) did not attempt to distinguish the moraines of the two glacial epochs as has been done on the accompanying map. On the other hand, the present map does not show the fluvio-glacial deposits as they are of small importance economically although a dredge worked the outwash deposits near Fairplay for a number of years.

The map of the Quaternary geology, Plate III, shows the three principal moraines in the district. The South Platte was the master glacier in the Alma area, having flowed first east and then south past the location of Alma and as far as the present site of Fairplay, six miles further
down the valley. The Sacramento glacier was tributary to
the South Platte glacier, but the Horseshoe-Fourmile glacier
flowed independently and a gap of three miles separated
its greatest advance from the frontal lobe of the South
Platte glacier.

The Horseshoe district derives its name from "The
Horseshoe", an exceedingly well-formed cirque at the western
head of Fourmile amphitheatre. It has been carved in the
east-dipping strata on the slopes of Horseshoe Mountain and
is a striking landmark from many places in South Park. Its
span is approximately 0.5 miles and its headwall is more
than 1000 feet above its floor.

The valley glaciation of the earlier epoch was more
widespread than the later. Lovering and Van Tuyl (18, 1328)
state

"During the last (Wisconsin) stage the valley glaci-
ers attained their maximum development. Most of the
striking glacial features seen in the high country today
were caused by this last ice invasion."

They considered the Front Range in particular, hence no dis-
agreement occurs. In the Mosquito Range area, the earlier
glacial advance was more extensive and the later stage less
extensive though the later glaciers may have been thicker
near their sources. Indications are that the headward
erosion of the late stage glaciers was the more vigorous.

It is characteristic of all the gulches that the earlier moraine is not present in the upper parts of the valleys. The later moraine is narrower in extent, its terminals were less advanced, it is found in some amounts far up the valley floors, and terminal and recessional moraines are clearly marked. The lesser extent of the later Sacramento glacier is shown by the location of the corresponding terminal moraine which failed to merge with the moraine of the South Platte later glacier. After the late glaciers had receded to a point about midway in their courses, their retreat ceased for a time sufficient to form considerable accumulations of recessional moraine. Except for the terminal and recessional moraines which are clearly designated on the map, the bulk is either lateral or ground moraine. There are no deposits which could be classed as typical medial moraine.

There are two places in the area illustrative of a form of glacial piracy which differs from the familiar conception of stream piracy. It can be most simply described by comparing it to the attempted cutting-off of meanders of a sluggish stream instead of the headward erosion of one stream tapping the drainage of another. It is similar to pent-up waters behind a dam becoming too great for accommo-
a. Lower valley of Four Mile Creek looking east from the Mudsill mine. The timbered ridge in the center of the photograph has a veneer of glacial moraine. The Sawatch quartzite is seen on the cliffs of Sheep Mountain at the right. Ridges in the middle distance are cuestas rising from the floor of South Park. Skyline is the westernmost ridge of the Front Range.

b. South Mosquito amphitheatre, a typical valley head at elevations around 12,000 feet. Pennsylvania Mountain in the background.
dation at the sluice gates and breaking a new channel ex-
cept the medium was ice and the escaping lobe did not again
attain the main flow. Doubtless, this feature has been
recognized in many a glaciated area, but the writer has not
found descriptions of it in his rather restricted acquaint-
ance with literature on valley glaciation.

The small area of moraine on the southwest side of
Bald Hill is an example. The early glacial stage, during
which the ice stood high on the present valley slopes,
pushed a small lobe from the Mosquito Gulch glacier through
the low gap in the ridge at the west end of Bald Hill and
out into the valley of Pennsylvania Creek. The moraine is
just a slight veneer for the most part, but there are some
rounded hummocks containing pre-Cambrian boulders which
could not have been derived from the slopes of Pennsylvania
Mountain. Inasmuch as there are no vestiges of glacial
debris farther downstream, it is a clear case of a form of
glacial piracy.

It may be remarked in passing, that Pennsylvania
Mountain is a bedrock slope covered by a considerable thick-
ness of soil and rock detritus which in no way could be con-
ceived as having been glacial-derived. Sedimentary rocks of
lower Paleozoic age are present in varying thickness over
the whole slope with the exception of a small erosion window
which has been cut into the pre-Cambrian crystallines along the upper reaches of Pennsylvania Creek. After attempting to trace the detrital material from this window along Pennsylvania Creek, the idea first took form that the pre-Cambrian boulders lower down had not originated on the slopes of Pennsylvania Mountain but had been deposited by an escaping lobe as described previously.

A mile northwest of the indicated point where the glaciers of Big and Little Sacramento gulches joined, the presence of a small lobe jutting downstream from the Little Sacramento glacier is noted on the map. The lobe occupied a small draw in which a stream is flowing at present into Big Sacramento Creek. This is thought to be similar in all respects to the lobe near Bald Hill, it represents overflow of the glacial ice into a region away from the path of principal flow and which region was incapable of supporting its own glacier, and differs from distributary lobes at the terminus of a glacier by being located where active flow was progressing.

In the area between the joint South Platte-Sacramento moraine and the Four Mile moraine of the early stage are many erratics unaccompanied by the other glacial forms. It is thought that these have been derived from the lateral moraines of the glaciers at their highest early stage and
are what is remaining of a thin veneer of fluvio-glacial deposits which spilled-out from the sides of the glaciers over the intervening area.

Alluvium

Alluvial deposits are in the form of slide rock, swamp deposits, recent stream gravels, and soil on the unglaciated uplands. With the single exception of the placer gold deposit on the upper slopes of Pennsylvania Mountain (described in next section), they have no importance other than that they obscure bedrock relations.

There are talus slopes present below all the cliffs but only the larger areas of slide rock have been indicated on Plate III. The talus slopes can all be considered as having been normally developed with one exception. The northern slope of Lamb Mountain contains a sill of White porphyry in the Weber(?) formation which has weathered differently than other White porphyry outcrops. The sill itself weathers to a pale lavender color in contrast to the usual white or light gray color upon weathered surfaces. Moreover, it has broken into slabs and blocks several feet on each side. These blocks have remained perched on a relatively steep slope which one usually associates with the presence of finer fragments. Typically, White porphyry does not weather into large blocks. Travel across this
talus pile is highly precarious.

Swamp deposits and recent stream gravels do not merit description. There has been but slight concentration of placer gold in the recent gravels in the Alma district and none here.

The unglaciated uplands are the remnants of the Tertiary pre-glacial surface. Ore deposits near this surface have undergone thorough oxidation in places (Mudsill Mine). In general, accumulation of recent disintegration products in a soil mantle is indicated.

Auriferous gravels

Extent of Placer Operations.—In the summer of 1935, several hundred men were engaged in placer mining in the Alma and Fairplay districts. The party had the opportunity to visit many of the operations and the following short description is justified because it shows the auriferous character of some of the glacial deposits even though only one is in the Horseshoe-Sacramento district itself.

It was interesting to observe the different methods of mining and washing the gold employed by the operators as without a doubt every scheme invented by the mind of man to facilitate the processes was in operation. There was no dredge in the area but it was rumored that one was to be installed on the Snowstorm placer, a property of many acres extent situated between Alma and Fairplay.
Some of the various mining methods employed were: steam shovel, drag line, drift mining, hydraulicking, automatic diggers, and shovels. More heterogeneous than these, however, were the washing plants which varied from a four-foot trommel in conjunction with corduroy to a sluice 100 feet long and which recovered all of the values in the first two boxes but the other eight were nevertheless faithfully cleaned once a week. It is the opinion of many that as much placer gold is lost as is recovered because of the failure of the operators to adjust their water flow properly.

The Alma, Fairplay, and Beaver creek placers.—The Alma placer operations are located in the South Platte recessional moraine of the latest glacial stage opposite the town of Alma. Values, which run more than a dollar per yard, are concentrated within six inches of bedrock whereas the remainder of the glacial till which may be 40 or 50 feet thick does not run more than a few cents. The operators stated that the best values are obtained from small depressions in the bedrock surface.

Drift mining from either shaft or adit is the favorite method.

The Fairplay placer is situated in the terminal moraine of the South Platte glacier of the latest stage. It was the scene of intensive operations in early days but now supports but a few outfits.

The Beaver Creek placer is located north of the town
of Fairplay. There is good evidence that at a high stage the South Platte glacier spilled detritus into the Beaver drainage as pre-Cambrian boulders have been observed and pre-Cambrian formations do not outcrop within the area of the Beaver drainage. There are two types of gold in the Beaver placer which seem to occur in separate segregations, the finer corresponding to the fineness of gold found along Beaver Creek nearer its head to the north and north of any possible influence of South Platte glaciation, and the other corresponding in fineness to the gold from the Alma or Fairplay placer. It is of interest that there has never been lode gold discovered in the head of Beaver Creek. Tarryall Creek to the east presents a parallel situation, and as the gold is considerably finer than that related to the erosion of Tertiary veins, the statement that the clastic upper Carboniferous formations may carry placer gold derived from the pre-Cambrian mineralization, and which has been concentrated in Quaternary gravels, may carry some weight. The auriferous gravels found near the head of Beaver Creek are stream gravels, the only glaciation in its drainage having been a tiny glacier far up on the slopes of Mount Silverheels which did not attain the main valley floor.

The Pennsylvania mountain placer.—By far the most interesting placer in the whole region is one which is situated
within the area mapped by the present survey. It is located on the broad slope of Pennsylvania Mountain, midway between Pennsylvania Creek and the brink of the cliffs on the north side of the mountain. The elevation of the property is about 12,250 feet.

Pennsylvania Mountain, like other mountains east of the main crest of the Mosquito range, consists of a broad gently-inclined slope bordered on the north and south by the steep cliffs of the glaciated gulches. The mountain itself is unglaciated. The gentle eastward slope is a reflection of the dip of the Paleozoic sediments, 15°. A thin veneer of Cambrian and Ordovician sediments is present on the lower and upper portions, whereas only the Cambrian formations are present in the intervening area. Pre-Cambrian detritus in the bed of Pennsylvania Creek indicates that erosion has somewhere formed a window through the lower Paleozoic beds to expose a small area of pre-Cambrian rocks. The whole mountainside is covered by a variable thickness of soil and rock detritus some essentially in place, the remainder the result of aqueous deposition. It is the opinion of Q. D. Singewald and the writer that a snowbank existed on the upper slopes of Pennsylvania Mountain during the glacial period but the collecting region was not great enough to produce glacial ice. Melting of the snow released great quantities
of water in a form somewhat akin to sheet floods and these piled up the detrital material. The wash varies in thickness from zero to 18 feet on the slope where the placer operations are located.

About 10 yards per day were being washed during the summer of 1935. According to the 1935 operator, Mr. Turk, the gold is found in narrow channels near the base of the detrital mantle. Its size is quite variable, but there seems to be rather more coarse gold here than in the placers at Alma and Fairplay. The ground runs $2.18 per yard on the average.

The operation is severely handicapped by the short summer season. In the drift mines around Alma, digging goes on all winter but on Pennsylvania Mountain, the inclement weather prevents surface operations for eight months of the year. The magnitude of the operation is limited by the water supply. In early summer, melting snows furnish an abundance of water but later in the season the supply depends on the rainfall. An intricate system of pipes and small reservoirs have been constructed which collects and conserves the rainfall but there is not enough to wash more than a few yards a day.

The interesting feature of this placer is the question of the source of the gold. The London fault cuts through
Pennsylvania Mountain immediately west of its crest but
the London vein system apexes more than a thousand feet be-
low the fault outcrop if the rake determined for the known
orebodies persists south of the London and London-Butte
mines. There are some manifestations of mineralization,
however, within the fault zone where it crosses the ridge of
Pennsylvania Mountain. These are described in detail else-
where in the report so it is sufficient to state that the
mineralization consists of quartz and pyrite cementing a
heterogeneous breccia. One tiny mass of galena has been ob-
served here. Several old shafts are present which penetrat-
ed the fault zone at this point, but the indications are
that a valuable metallization was lacking. Inasmuch as the
mountains slope away to the west at this point, it is ex-
tremely doubtful if any detrital gold from this source could
have migrated to the eastern slope of the mountain where the
placer workings are located. The detrital matter in the
placer as well as the gold does not appear to be remote from
its source.

The fineness of the gold in the Pennsylvania Mountain
placer averages 730 fine according to the operator. London
mine gold has a fineness around 800 on the authority of Mr.
Glenn Gately, Ex-superintendent. Gold from the Alma and
Fairplay placers is about 830 fine, as is the gold in Buck-
skin gulch. It is believed that the source of the gold is
or was located in the Cambrian formations which constitute the sedimentary veneer on the slopes of Pennsylvania Mountain east of the London fault. The postulated mineralization would therefore resemble that of the Phillips, Paris, and Orphan Boy mines a mile or so distant (11, 113) and be replacements of calcareous beds in the Cambrian Sawatch formation apparently localized by fissures in the hanging wall of the Cooper Gulch fault.

Some differences are to be remarked. In the first place, the outcrop of the Cooper Gulch fault is far to the east and the Cambrian formation on the upper slopes of Pennsylvania Mountain which is thought to contain the gold is in the footwall. There is a remote possibility, that the gold could have been derived from the Cambrian in the now eroded hanging wall if the Cooper Gulch fault joined the London fault along its dip, as along its strike it gradually approaches the London fault before dying out completely. It would not have required a marked change in dip to have caused the plane of the Cooper Gulch fault to have been present immediately above the present surface of Pennsylvania Mountain because it is quite flat where observed. One could expect, however, that as it approached the steep-dipping London fault, its dip would increase but there is no certainty that they formed contemporaneously. If they were not contemporaneous, there is no necessity of the dip or displacements of one influencing the other.
If, however, the gold has been derived from a mineralization similar to that of the Orphan Boy and Phillips mines, it should have a fineness at least comparable to the fineness of their gold. The best information available for the Buckskin placer whose gold has been almost entirely derived from the immediate Phillips-Paris orebodies shows it is 830 fine. If the gold had been derived from some unknown portion of the London lodes, its fineness should be close to 800 fine.

It is not improbable that the source of the values was neither the London nor the Orphan Boy-Paris-Phillips type of deposit. Cutting the London fault at the brink of the cliffs on the north side of Pennsylvania Mountain, a number of cross-breaks of considerable magnitude have been found. The Cambrian Sawatch formation has been shown to be favorable to the Paris-Phillips type of gold mineralization in the Alma district, and it is not beyond the realms of possibility that the cross-breaks mentioned above provided channelways for further migration to the solutions which made ore in the London veins. Where favorable loci obtained, gold mineralization occurred in the quartzites east of the fault in the hanging wall. The mineralization by quartz and pyrite found in the fault itself on Pennsylvania Mountain might well represent the effects of portions of these solutions.
The operators of the placer are directing their efforts in hopes of finding the source of the gold buried beneath the detrital matter on the mountainside. It will be of great interest to the London mine owners if it is found that solutions of the type which deposited their ore, made orebodies in the quartzites. The Cambrian has not been explored in the London area and provides a possible site for additional ore.

At the present time, it is impossible to reconcile the presence of gold in this placer with its location and fineness, but it is certain that the fineness of the gold differs from other gold in the area, and that the gold has not been derived from London-type veins.

The gold fineness from the different areas is tabulated below:

<table>
<thead>
<tr>
<th>Placer</th>
<th>Fineness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pennsylvania Mountain</td>
<td>730 fine</td>
</tr>
<tr>
<td>Buckskin Gulch placer</td>
<td>830 fine</td>
</tr>
<tr>
<td>Alma placer</td>
<td>830 fine</td>
</tr>
<tr>
<td>Fairplay placer</td>
<td>830 fine</td>
</tr>
<tr>
<td>Beaver Creek placer</td>
<td>870 fine</td>
</tr>
<tr>
<td>Tarryall Creek placer</td>
<td>910 fine</td>
</tr>
<tr>
<td>London mine</td>
<td>800 fine</td>
</tr>
</tbody>
</table>
STRUCTURE

Introduction

The structural generalities of the Leadville-Alma-Horseshoe districts have been known since Emmons published the Leadville monograph in 1886 (1). He was prevented, however, from ascertaining much of the essential data because of the lack of mine openings since available. The London fault, for instance, was described by him as a normal fault and it was not until nearly thirty years later that it was shown to be a reverse fault (7, 191). Later work in the Leadville district by Irving and Loughlin has been published in Professional Paper 148(2). This did not include restudy of the outlying areas of the Leadville district the results of which have been more recently published (3,4,5,6).

The Alma district, also covered by Emmons in his monograph was made the subject of a survey by the State of Colorado and the results were published in 1912 (7). Sixteen years later, under the cooperative program of the United States Geological Survey, the State of Colorado, and the Colorado Metal Mining Fund, the Alma district was again made the subject of study, this time under a much closer scrutiny than had been possible in the limited time allotments of previous efforts. A series of several papers has resulted, which are especially important with regard to the close relation of the ore deposits to the pre-mineral structures (8,8a,8b,9,9a,9b, 10,10a,11,12).
The Horseshoe-Sacramento district, if the small important area of it near the crest of the Mosquito Range be excepted, had not been resurveyed since the time of Emmons until the present party went into the field. Thus, the stretch of ground along both sides of the London fault south of Mosquito Creek had not been visited by geologists for more than fifty years. It was unfortunate, indeed, that all which remained to be studied of several rather large scale mining operations was mineral matter on the dumps. Surface studies, however, have produced additional knowledge of the fault, especially with respect to the hanging wall, because at Alma the hanging wall consists of pre-Cambrian crystalline rocks which do not lend themselves to structural interpretation. A single paper has been written which includes the results of part of the present field study (12), but no wealth of detail could be provided for the particular area as the scope of the paper was the whole area of the London fault. Much of the material included in this section has necessarily been noted in the publication, but on the other hand, details are supplied here which are not available elsewhere.

The reader is referred to the generalized areal map, Plate I, and the sections, Figure 5, in order to follow more closely the discussion of the structural features of the area.

The area lies on the eastern flank of the Sawatch uplift with the sedimentary rocks having a monoclinal dip to the
eastward of about fifteen degrees which, in the following pages, is frequently referred to as the 'regional dip.' There are minor deviations from this dip locally, and major reversals in the neighborhood of the large faults.

Crossing the area in a north to northwesterly direction are two prominent faults, the London and the Sherman. The London fault, by far the more important both from the structural and the economic viewpoint, is located on the western limb of the London anticline which is responsible for the most profound reversal of dip in the area. The fault plane where determined, dips steeply to the east; vertical displacement of about 3000 feet is indicated although much of this is undoubtedly due to folding. The Sherman fault, located about 1.75 miles west of the London fault, crosses Four Mile amphitheatre in a northwesterly direction. It is accompanied by a marked overturning of the beds and is probably similar in most respects to the London fault although much smaller. Very little is known of the Sherman fault except its location, and an inferred steep dip to the east.

In addition to the two faults mentioned, the Cooper Gulch thrust fault is present in the northeast part of the area mapped, and is traceable part way across the broad slope of Pennsylvania Mountain. This fault, of relatively slight displacement compared with the London, breaks across a sharply overturned fold at a low angle of dip.
Auxiliary faults and fissures of pre-mineral age accompanied or followed the formation of the larger faults. These may be grouped into the north to northeast family and the transverse family. The latter displace the major structures. The question of post-mineral faults is unsatisfactory as none have been identified from the surface studies; undoubtedly many are present as in the London mine but each is of slight individual displacement.

Folding

General Features.—The folds within the area may be grouped into the major ones which were later broken by faults, either reverse (London) or thrust (Cooper Gulch) faults, and the minor transverse flexures of which the Sheep Mountain pitching anticline is the sole well-demonstrated example. The major folds are asymmetric anticlines with steeply dipping western limbs accompanied by narrow synclinal zones which are overturned in places.

The London Anticline.—The London anticline and attendant syncline although accompanied areally by the London fault may be considered here apart from the fault. The structure extends for approximately eight miles across the Horseshoe-Sacramento district from the high saddle at the southeast shoulder of Sheep Mountain northwest to the valley of South Mosquito Creek. From this last point, it continues for three more miles to the northwest across the Alma district to finally
cross the crest of the Mosquito Range a few miles south of Climax. The structure, including the fault, has its northern termination at the Mosquito fault which trends in a north-south direction from south of the Leadville district to north of Climax. The southward extent of the London flexure has not been completely investigated but the London fault extends for at least 20 miles from its northern end. It is probable that both fold and fault gradually die out on the surface as they transect the upper Paleozoic beds in going towards the floor of South Park to the southeast.

The crest of the Mosquito Range, trending north-south, lies about five miles west of the London structure at Sheep Mountain, and five miles farther north at Pennsylvania Mountain the crest is but two miles west of the structure.

The maximum width of the fold is less than a mile, figured from the point on the east limb of the anticlinal where shallower dips become apparent to the point on the west limb of the synclinal where normal dips resume. The nature of the fold, however, is demonstrated from the relative positions of the anticlinal and synclinal axes with reference to the fault. If the positions of the axes alone are considered, the fold shows a fair degree of constancy with the distance between the axes varying between one-quarter and three-eighths miles.

The character of the anticline is well-shown in the photographs, figures 6, 7 and 8. Figures 6 and 7 were taken
The Sacramento Arch (London anticline) looking south from the lower slope of Pennsylvania Mountain across Big Sacramento Gulch. Beds at the east (left) are the Sawatch formation while at the west (right) the whole pre-Pennsylvanian section is present. 1) Sheep Mountain, 2) Lamb Mountain, 3) London fault at the crest of the ridge, 4) Minor faults on the anticline, 5) Little Sacramento Gulch, 6) Pour Mile Gulch.
of the anticline in Sacramento Gulch, looking south and southwest towards a low ridge locally known as Dream Mountain. At this point the anticline is called the Sacramento Arch. The contact between sediments and crystalline rocks is readily noted in figure 6; the crystallines are overlain by talus while the Sawatch quartzite forms the lowest cliff. Approximately a 400 feet thickness of sedimentary rocks is present at the crest of the anticline on Dream Mountain although the Leadville has been eroded at this point. The right (west) edge of figure 6 is duplicated on the left (east) side of figure 7. Figure 7 shows the reversal of dips on the western anticlinal limb. The fault itself passes very close to the mine buildings (Majestic property) in the lower right and continues up the slope. At this point, the syncline is narrow, but the broken talus-covered zone west of the fault was not susceptible to interpretation. The arcuate features on the brink of the ridge are Weber(?) quartzite beds sweeping around the hillside with their normal easterly dip. This dip continues, though obscurely, to a point near the fault.

Figure 8 illustrates the London anticline several miles south of Dream Mountain at Sheep Mountain. Part of the outcrop material indicated along the plane of the London fault is silicified breccia. The lighter-colored material in the slide rock to the right (west) of the fault is White porphyry
West limb of Sacramento Arch (London anticline) looking southwest with the camera located in the same position as for figure 6. 1) London fault, 2) Reverse dip of strata, 3) Normal dip of strata west of fault, 4) Majestic prospect, 5) White Ridge.
which has intruded the Weber(?). The anticline is broader at this point than at Dream Mountain (figure 6) because of modification by the eastward pitching transverse anticline on the eastern slope of Sheep Mountain. The axis, however, is less than one-quarter of a mile east of the fault, nearly equal to its closest approach at Little Sacramento Gulch and on Pennsylvania Mountain.

On the north side of Four Mile Gulch, opposite Sheep Mountain, the anticline is observed clearly on the cliff sides and underground in the Mudsill mine. The structure section as constructed from geologic mapping of the Mudsill is shown in figure 11. At this point, the axis and the fault are separated by nearly three-eighths of a mile.

The most information obtainable about the syncline, with the exception of the underground workings of the London group of mines, was observed on the north brink of Pennsyl-

vania Mountain immediately west of the London fault. At this point a portion of the fault zone is a silicified breccia which protrudes sharply above the crest line. This feature, known as 'The Butte', may be seen in the photographs, figures 4b and 10. Immediately south of the Butte, there is silici-

fied breccia in the fault zone, but it does not have topo-

graphic expression. The traverse represented in Plate II, F, taken less than one hundred feet south, consequently does not
show the Butte. The section plotted from this traverse shows overturned beds in the syncline. The western margin of these beds, bounded by a fault, is nearly 700 feet from the eastern margin at the London fault.

The compiled cross sections of the region, figure 5, indicate how the sharpness of the west anticlinal limb varies from place to place. Plate I shows the course of the London fault across the area and the fold is essentially parallel to its course.

The detailed geologic map of the area was not available to the writer after the field season so the following summary has been taken from the generalizations obtained by constructing structural contours on the top of the Leadville limestone (12, 12). The major aspects are apparent in the field.

"In the anticline east of the fault the pitch north of Pennsylvania Mountain is unknown, because the sedimentary strata there have been entirely eroded. Across Pennsylvania Mountain the axis pitches rather steeply towards the north fork of Sacramento Creek, where it flattens abruptly. It continues with southeast pitch to a broad saddle at the south fork of Sacramento Creek, then rises very gently to a structural high on Sheep Mountain, beyond which it again pitches steeply southeast. In addition, there are local variations in pitch, some of which are suggested by bends in the structural contours.
"The pitch of the axis of the syncline west of the fault, although complicated somewhat by faulting, also varies. It is moderate to the southeast from the crest of the range to New York Mountain, steep from that point to the crest of London Mountain, and then gentle as far as Pennsylvania Mountain, where again it steepens. Southeast of Pennsylvania Mountain altitudes at the top of the Blue limestone west of the fault are very uncertain. The most probable interpretation in the absence of subsurface data, however, is that the axis remains about level, at an altitude of about 9,000 feet, as far south as Sheep Mountain. Surface dips in the Weber(?) formation suggest a structural saddle approximately beneath the Mudsill mine, with a very slight northwest pitch from that point to Sheep Mountain, but owing to undeterminable variations in thickness of porphyry sills near the base of the Weber(?), it is impossible to determine how closely dips on beds overlying the porphyries reflect the structure of the pre-Pennsylvanian strata."

In summary, the asymmetric London anticline which is well-exposed in the area, and the syncline which is poorly exposed and inferred in many places, constitute a major locus of folding. The trend of the composite structure is northwest although locally, minor departures of several degrees from the general northwest trend are present. The distance separating the axes of the anticline and syncline, and the direction and
degree of pitch of the axes are subject to variation as is the degree of flexure of the limbs. In one case the synclinal limb has been sharply overturned. It is probable that the closure of the fold before faulting was subject to variation as well. To anticipate, the London fault is located between the two axes and its position is also subject to variation; in places it is close to the anticlinal axis while in others it is closer to the synclinal axis. Faulting has tended to accentuate through drag the degree of folding adjacent to the fault as is illustrated so well in the workings of the London mine.

The Cooper Gulch Faulted-Fold.—The Cooper Gulch fault which has important displacement in the Alma district, is present only on Pennsylvania Mountain and disappears on the surface a few hundred feet north of Big Sacramento Gulch. Although smaller than the London fault, its stratigraphic throw is 450 feet in Mosquito Gulch (11, 101). It is a low-angle thrust, moreover, compared with the nearly vertical London fault, and represents rupture of the overturned fold which it accompanies. Considerable production of gold and silver has been obtained from veins and replacements of lower Paleozoic strata in the hanging wall of the fault.

The Sheep Mountain Anticlinal Nose.—The anticlinal nose present on Sheep Mountain is shown by slight bends on the structural contours (12, 9) and is related to variations in pitch
of the London anticline at that point. The crest of Sheep Mountain corresponds to the structural high on the anticline, from which point it pitches gently to the northwest and relatively steeply to the southeast. The nose or transverse plunging anticline pitches gently about N 60°E. It is important in that numerous indications of metallization are present on the flanks of the nose, the productive mines being located on the gentler dipping north flank, however. In the Alma district, several millions of dollars in silver have been produced from replacement orebodies in similar structural environments (11, 127).

Faulting.
The London Fault.—The London fault is the largest fault on the east side of the Mosquito Range, having a vertical component of displacement of at least 1500 feet and a length of at least 20 miles. It ranks second in length to the Mosquito fault located on the west side of the range.

Over most of its course, the position of the London fault can only be determined by lithologic changes as there are few visible outcrops of the fault zone itself. The disturbed zone adjacent to the fault consists of sediments dipping nearly vertically in the zone closest to the fault, and at progressively gentler attitudes as the distance from the fault increases, to finally attain the axial positions of the adjacent
folds and from there gradually resume normal regional dip. The fault can thus be located within the zone of steeply dipping beds which, fortunately, is usually narrow.

At the northern brink of Pennsylvania Mountain one of the rare exposures of the fault zone is observable. At this point the relations have been readily ascertained and are graphically represented in the section plotted from a horizontal traverse along the brink of the ridge (Plate II,F). The pre-Pennsylvanian strata in the east wall of the fault are the Sawatch and Manitou formations. They have been sheared off abruptly at the crest of the ridge, but further down the slope Sawatch and Manitou strata are found in nearly vertical attitudes where they represent the thinned and dragged-out material along the fault plane. West of the fault vertical beds of the Weber (?) formation are encountered in the immediate wall, but further to the west this same series gradually attains a moderate easterly dip as shown by the section. These east dipping beds are the overturned east limb of the syncline. At this point, also, the zone of disturbance in the west wall appears narrower than elsewhere.

The silification of the fault zone on Pennsylvania Mountain has been studied microscopically and several successive ages of silica introduction have been determined. Incidentally, pyrite is abundant in the silicified breccia at this point.
Details are to be found under the section on mineralization.

North of Pennsylvania Mountain there are several restricted exposures of the fault plane in the workings of the London mine. The dip of the plane in these exposures varies from 60 to 80 degrees to the east. In the footwall, the sedimentary rocks are overturned and dip in sympathy with the fault.

From the outcrop just described, the fault cannot be traced southward across the broad flat top of Pennsylvania Mountain as a considerable thickness of soil and detrital material thoroughly hides bed rock. At the southern brink, however, its location can be ascertained but data as to the attitude of the beds in the walls are unsatisfactory. It appears that the syncline is overturned here as well.

Near the bottom of the south slope of Pennsylvania Mountain, a short adit enters the side of the mountain in a northwest direction and cuts the fault zone. The ground is heavy in the adit and close timbering prevented observation of details. The geologic relations near the breast are plotted on Plate II,D. The face consists of brecciated Weber (?) arkose. A white quartzite is also present but its age cannot be determined; it may be either Weber (?) or Sawatch. A few feet closer to the portal, pre-Cambrian rocks are found. The stretch of ground indicated in the diagram lies within the disturbed zone of the London fault and possibly the shear zone is the whole
fault zone although it is difficult to locate boundaries due to intense brecciation of all rocks. There are no manifestations of mineralization.

On the south side of Big Sacramento Creek, the fault has been located with a fair degree of certainty, but not absolutely as the movement resulted in the Weber(?) formation being present in both walls. This unsatisfactory condition obtains from this point to Sheep Mountain, several miles further south. The exposed walls of the fault are either Weber(?) or porphyry and if perchance the Weber(?) is observed in contact with porphyry it cannot be definitely said to be a fault contact as there remains the possibility of intrusive contact with the position of the fault a short distance removed.

A traverse across the fault along a low ridge about half way between Big and Little Sacramento Creeks showed several hundred feet of vertically standing Weber(?) beds, but the location of the fault could not be located as the grits and micaeous shales of the Weber(?) give no clue to their stratigraphic position within the formation.

The manner in which the porphyries appear to be cut off served to locate the fault on the north side of Four Mile Gulch, but again the fault could not be observed and the faulting indicated on Plate II,B may be an auxiliary fault in the east wall rather than the main London fault. This figure illustrates the typical aspect of the Weber(?) formation above its
lower contact with the Blue limestone with numerous sills of both White and Gray porphyry present. As will be discussed further on, the number of the sills and their diversity is greater in the zone close to the fault; at a distance, especially to the eastward, there is typically a single thick sill of Gray porphyry immediately overlying the Blue limestone.

On the south side of Four Mile Gulch, the fault zone outcrops on the slopes of Sheep Mountain, figure 8. Singewald describes this outcrop as follows: "...... between altitudes of 11,300 and 12,200 ft. There the west wall is greatly shattered White porphyry, and the east wall alternately Parting quartzite and Dyer dolomite; both the Dyer and the Leadville are irregularly thinned by shearing and stretching in the fault. From west to east the shear zone consists of 5 ft. of clay gouge containing crushed fragments of White porphyry, 50 ft. of coarse breccia composed of limestone, White porphyry, and clay gouge, and 75 ft. of irregularly silicified broken limestone and limestone breccia (12, 11).

Within the confines of the Horseshoe-Sacramento district the London fault appears to be vertical although future developments may prove otherwise. Certainly however, the well-exposed silicified zones indicate a vertical attitude.

Information regarding the displacement of the fault is not specific at any one place. This has two causes: uncertainty as to the position of the top of the Leadville
Sheep Mountain looking south across Four Mile Gulch from the Mudsill mine. 1) Axis of London anticline with reverse dip to the west (right), 2) Sheep Mountain, 3) Lamb Mountain, 4) London fault, 5) Contact between Cambrian and pre-Cambrian rocks, 6) Vertical attitude of foliation in pre-Cambrian rocks, 7) Position where beds resume normal east dip to the west of the concealed and down-faulted syncline.
limestone in the syncline and doubt as to how much of the displacement should be assigned to folding rather than faulting.

In the trough of the syncline, the position of the Leadville has to be projected from the west a mile or more down the dip. The subsurface relations of the porphyries are so obscure that it is hazardous to claim great accuracy for this method. Where the position of the Leadville is known on the anticlinal limb and where the projection of it into the syncline has been accomplished within limitations of accuracy, the total displacement may be calculated with a probable error of a few hundred feet, but again the portion of the displacement due to faulting is uncertain because of the dragging of the formations along the fault. In other words, the fault accentuated both the synclinal and anticlinal parts of the flexure as well as effecting a dislocation. According to Singewald (12, 13), the total apparent throw at Four Mile Gulch is 3600 feet with a limit of error of 1000 feet; 800 feet is the minimum displacement of the folding, and 1000 feet the lower limit of the vertical fault displacement. Remaining are 1800 feet for which no accounting can be made. On Pennsylvania Mountain, total vertical distance between the crest and trough is 3000 feet, of which half can be assigned to folding and the other half to faulting. This represents the best figure obtainable as the synclinal beds were not projected from a
Figure 9

Ridge west of Lamb Mountain viewed from the north. Here the beds have their regional attitude. Cliffs are due to porphyry sills within the Weber (?) formation.
distance but were mapped in the workings of the London Butte mine at the foot of the mountain.

To summarize the broader aspects of the fault: it has been traced from its termination at the Mosquito fault on the west side of the Mosquito Range some 20 miles to the southeast where its visible surface effects disappear. Along that part of its trend which has been the subject of detailed geologic mapping, the plane of the fault is confined to the zone between the axes of the accompanying anticline and syncline. The narrow folded zone, with asymmetric anticline and, in places, overturned syncline, varies slightly in its general northwest trend. The fault, located along the asymmetric west limb of the anticline, varies independently in its course within the folded zone. The anticlinal axis, however, is typically twice as far from the fault as is the synclinal axis. Fault movement, of which the best figure shows vertical displacement of 1500 feet, accentuated the asymmetric aspect of the fold and dragged many of the strata along the fault zone. Slickensides in the London mine indicate some of the latest movements had a horizontal component. Divergence between the regional eastward dip of the strata and the London structure has resulted in a southeastward plunge of the sedimentary contacts at their intersection with the fault plane.

Faults and Fissures Associated with the London Structure.--The
auxiliary faults and fissures associated with the London fold and fault are of two principal types: divergent and transverse. Divergent fissures and faults are found in both the hanging and footwalls of the London fault, strike north or northeast and dip in either direction, usually steeply. In the Horseshoe-Sacramento district the opportunities for mapping this type were much better in the anticlinal hanging wall portion of the structure than in the synclinal footwall whereas in the London mines only the footwall is available for observation and the hanging wall consists of pre-Cambrian rocks. Transverse faults have been observed in a few places and it is possible that some of the changes in trend of the London fault (Plate I) are caused by this type.

A great number of divergent faults were mapped in the hanging wall of the fault but have not been shown on the generalized areal map. A displacement of 20 feet was necessary to qualify a fault for mapping, and, needless to state, many smaller faults either were not mapped or escaped recognition. Mineralized fissures, regardless of amount of fault displacement, were placed on the original but not on the generalized map. These faults and fissures can be discussed together as they represent the same type of structure and all gradations exist from fissures of no displacement to faults with vertical components of displacement of more than 100 feet.
As a group, the fractures in the hanging wall diverge from the fault at small angles in a northeast direction but because of the low angle of divergence some of them have slight northwest strike where the strike of the fault is more northwest than north. The fractures, furthermore, appear to have the same characteristics wherever found along the trend of the structure. Their recognition at any place is related to the qualities of the rock exposures; poor exposures show only the larger faults while good exposures show both larger and smaller. Inasmuch as the abundance and individual displacements of the faults decrease with increasing distance east of the main structure, it is possible to generalize as follows: 1) There are no marked changes in quantity or quality of the auxiliary faulting and fissuring in the hanging wall of the London fault along its strike within the confines of the area mapped. 2) Intensity of faulting with respect to abundance and displacement on auxiliary faults and fissures diminishes away from the main structure.

The maximum vertical displacement of auxiliary faults is about 100 feet. To be sure, there are a few that appear greater such as those mapped on the south slope of Pennsylvania Mountain on the east limb of the anticline, but these are not only exceptional but have not been determined with exactitude as they were picked up by changes in the lithologic character of the debris on a talus-covered slope. The two faults
indicated in the photograph of the south side of Big Sacramento Gulch (Figure 6) are typical of the larger auxiliary faults. The eastern fault is located on the anticlinal axis while the other is well over on the western limb. In each case the down-dropped wall is at the west. Similar faults are to be seen on all cliff exposures of the anticline.

Illustrative of more moderate individual displacements but of large cumulative displacement are the faults indicated on Plate II,A. These were seen on the west limb of the anticline on the north slope of Sheep Mountain. North on the diagram is also the downhill direction. The location of these faults may be seen on Figure 8; the lowest outcrop on the indicated sedimentary contact. The total displacement, in 100 feet across the strike, is 150 feet with the lowered wall of each fault on the west. With the exception of the westernmost fault of this group, the attitudes are vertical. It is interesting to observe the profound change in the attitude of the sediments at this point over a comparatively short linear distance. The strike and dip symbol showing northwest strike and 32 degrees dip is but 75 feet from the one indicating northeast strike and 85 degrees dip. It is not known whether rotation of the individual blocks occurred or whether some of the faults had a large horizontal component. If the latter is the case, the west block with 85 degree dip has probably been displaced northward with reference to the eastern
blocks. This is explained by recalling that the dip of the west anticlinal limb steepens as the London fault is approached and that to the south, the north trending faults approach the London fault along their strike. Substantiation is noted by studying the contact relations of the narrow porphyry sill which comes in across the contact. A relative northward movement of the west walls of two of the faults is indicated.

A different type of auxiliary faulting is shown in Plate II,C. Here the western fault appears to be more of the nature of a sympathetic drag fault parallel to the London fault. The location may be found on Figure 7, at the foot of the cliffs downhill from point 2. The northwest trending fault is not more than 400 feet east of the London fault.

The mine map of the old Mudsill property, Figure 11, shows a variety of fissures and one or two small faults. Although a diversity of trends is represented, the two principal fissures strike northeast and dip southeast. These are the pair shown on the east of the plot, through the upper stopes. Prominent oxidation of these fissures indicates they had been mineralized although the principal stopes were down dip to the west.

The most puzzling structure observed in the hanging wall has been reproduced from a field sketch in Figure 12A. Several of these structures have been observed on the cliffs
Underground Workings of the
MUDSILL MINE
Four Mile Gulch
Park Co., Colo.

Leadville limestone
Basal quartzite member
Dyer dolomite

Formation contacts
Strike and dip
Fissures
Fault fissures
about half a mile east of the Mudsill mine where the sediments have their regional east dip on the eastern limb of the anticline and are relatively undisturbed otherwise except for a few small faults found at the pre-Cambrian contact several hundred feet down the slope. The sheeted zone contains Leadville limestone and there are no traces of the sandy limestones or breccias of the quartzite member. The upper part of the sheeted zone appears to grade sharply into normal Leadville above. The planes of vertical sheeting are more prominent than the east dipping ones. Contact with the Dyer formation is sharp and distinct.

Behre decided that bedding plane faults are present in the nearby Weston Pass district and in certain cases localized replacement of the limestone by jasperoid (4, ). He mentions minor slips along bedding planes in the Continental Chief mine (3, 52), and Loughlin (2, 63) states there are small bedding slips present in the Leadville district proper. From a confidential source, the writer has learned of small sheeted zones at this same stratigraphic horizon in one of the large mines outside of Leadville, which, traced along the strike grade into steep faults of 3-5 feet vertical displacement.

The present case indicated by the diagram, is not amenable to either of the interpretations mentioned. The chances are that the sheeted zone came into existence due to
some type of bedding plane slip, but modified interpretations have not served to demonstrate the method. It is most likely that movement was in the direction of the strike, and the sheeted material was dragged in from the Leadville formation where the break became pronounced in the overlying formations. This explanation, admittedly incomplete, is in line with inferred horizontal movements along auxiliary fractures in the east wall of the London fault.

In the syncline, the majority of the fractures diverge to the south away from the London fault. Unfavorable rock exposures at the surface consisting of either porphyries or the Weber(?) formation prevented accumulation of significant information about minor structures in the syncline south of the London mines. The only good exposure on Pennsylvania Mountain showed south striking vertical faults of small displacement with the west walls downfaulted (Plate II,F).

Another exposure of the rocks in the syncline, although not good, has been found on the south slope of Pennsylvania Mountain, about 300 feet west of the fault and northwest of the Berlin adit. This is plotted on Plate II,E; north is the uphill direction. Three small structural units are represented and it is not known whether the quartz monzonite porphyry shown in each is the faulted continuation of the porphyry in one of the other blocks. The 'up' and 'down' notation
on the principal fault were placed on the assumption that the porphyry in the west and southeast block is the same. The complex nature of the structure can be seen in the variation in strike and especially in the dips of the individual blocks. As the London fault trends northwest up the hill near this location and as steep reverse dips are commoner closer to the fault, it is reasonable to assume that the northeast block moved south relative to the western one. The block west of the fault cannot be completely traced to the area of regional dip but the absence of marked irregularities to the west presumably indicates that the dip flattens to the west and this unit of steeper east dip represents oversteepened beds in the syncline. As the syncline was overturned on the north side of Pennsylvania Mountain and probably was between this point and the fault to the northeast, oversteepened beds on the west synclinal limb are not unexpected.

No other specific information could be found with regard to divergent fractures in the synclinal wall of the fault. Doubtless, some of the contacts between porphyries and Weber (?) rocks immediately west of the fault which were mapped as intrusive contacts, are due to faults.

The transverse structural features, which are here considered among the auxiliary structures to the fault, may be genetically distinct. They appear to cut the fault at nearly right angles to its strike, thereby showing a marked easterly
trend. Offset of the whole structure is indicated on the north slope of Pennsylvania Mountain, although the transverse faults are inferred rather than demonstrated. This is the most pronounced zone of transverse displacement known. Near the Sherwood mine, contact irregularities east of the London fault could be explained by a transverse fault of relatively small throw but attempts to pick the structure up west of the fault were fruitless. A major transverse break has been mapped near New York Mountain, north of the London mines.

The transverse structures on Pennsylvania Mountain are indicated by changes in the trend of the fault. See Plate I. The dotted representation of the fault where it crosses the north fork of Sacramento Creek may well indicate another zone of transverse breaks. At several other places smaller irregularities which could not be interpreted are possible loci of other and less severe zones of transverse deformation.

One of the most important and widespread manifestations of the deformation in the zone adjacent to the fault is shown by the brecciation of all the rocks. Microscopic relations prove that brecciation was a long-continued or recurrent process occurring before, during, and after ore deposition. It has proceeded to such an extent that it is impossible to find a cubic inch of limestone or dolomite which is not seamed by small fractures containing later carbonate. The subject of brecciation is discussed at greater length in the section dealing with mineralization.
A summary of the structural features displayed in the underground workings of the London mine is appended at this point in order to clarify insofar as possible the structural picture of the zone of the London fault.

Summary of Structure in the London Mine.—The London group of mines is located immediately north of the northern boundary of the Horseshoe-Sacramento district if the arbitrary boundary is placed at the north brink of Pennsylvania Mountain. Four or five companies are operating or hold ground in the footwall of the London fault for a distance of 1.5 to 2 miles from the southernmost mine, the London-Butte, located at the base of the north slope of Pennsylvania Mountain.

The total value of the metal production from this group is probably in the neighborhood of $20,000,000. By far the greatest part of this sum has been realized from the gold content of the veins, but silver, lead, and copper have contributed to some amount. At present, the grade of the ore mined is less than 1 oz. gold per ton, but formerly, when the bulk of the ore produced from the veins was of shipping rather than milling grade, assays of 4 and 5 oz. were common.

The structure of the productive ground is intimately related to the London Fault. East of the fault, the hanging wall consists of pre-Cambrian schist, gneiss, and granite. West of the fault, the footwall contains Pennsylvania sediments, the Weber(?) formation, with numerous intercalating
sills of White and Gray porphyry, which interfinger complexly among themselves. The Weber(?) rocks exposed in the workings are the lowermost members of the series and in certain places the underlying Blue limestone is observed. The stratified rocks dip with varying degrees of steepness to the west, opposite to their normal dip, and represent the upturned east limb of the syncline. Where observed close to the fault, the beds in the footwall are overturned and dip steeply to the east parallel to the fault which dips from 60 to 80 degrees to the east in the region of the mine. The fault zone contains a sheared and brecciated rubble appearing as a clay gouge 40-100 feet wide.

The vein system consists of at least three more or less continuous parallel fissure veins, filled with quartz, pyrite, chalcopyrite, sphalerite, galena, and gold. The fissures are not as continuous as might be supposed and although there are generally three known veins in any cross-section through the structure, it has not been demonstrated that these are the same three found in another cross-section. The veins dip approximately with the strata, and lying between walls of porphyry of different types, or between walls of porphyry and Weber(?) quartzite, may be thought of as contact veins in the sense that they lie either at contacts or essentially parallel to them. Where the strata overturn in the footwall adjacent to the London fault, the veins behave like-
wise. The veins diverge from the fault along strike and dip and veins and beds both flatten to the west towards the trough of the syncline. Decrease in grade and amount of ore to the west where the veins lie flatter has discouraged exploration.

In addition to the pre-mineral London fault and the principal fissures which were receptive to the mineralization, there are other pre-mineral fissures which exist, some of which are mineralized. These in general dip steeply to the east and strike northwest.

The post-mineral faults may be divided into the flatly-dipping type and the steep type. The flat faults generally have a slight east dip and are not numerous. The steep post-mineral faults strike northeast and dip in either direction. Neither of these types are responsible for profound dislocations of the veins. Another manifestation of post-mineral movement is apparent in the evidences of renewed slip on pre-mineral faults. The London fault itself partakes of this; ore from contiguous veins has been dragged into the zone and is observed in fragmented pieces surrounded by typical fault gouge. Slickensides in the horizontal direction indicate the direction of some of the later movements.

The eastward dipping gouge-filled fault and the westward dipping Weber(?) sediments above the porphyry and vein zone at their base constitute an inverted trough which
effectively guided and retained the mineralizing solutions (11, 118) as the Weber (?) sediments above the porphyry zone consist predominantly of impervious shales. The pitch of this structure is some 12-14 degrees to the south.

The ore solutions are supposed to have risen along the fractured zone in the footwall of the fault, met the impermeable cover of the inverted trough, and migrated along the open fractures provided by the fault movements, thereby forming the veins (11, 118-120). The source of these solutions at depth is imagined to be south of the marginal-type silver-lead mineralization of New York Mountain because "northwest of London Mountain mineralization was progressively less intense and at a lower temperature" (11, 117).

Further details of the structure of the footwall of the London Fault in London Mountain are to be found in two papers by the Alma authors (11 and 12).

The Sherman Fault.--The Sherman fault lies in the southwestern part of the district. It trends northwest, and is approximately parallel to the course of the London fault at the point of closest approach, 1.75 miles. Its attitude is not known but it is supposed to dip steeply to the east. The best exposure is found on the ridge west of Lamb Mountain, but the fault is inferred at this point because of the sharp overturning and upturning of the upper Weber (?) measures which lie in both walls at this point. North of this ridge,
the fault is well-demonstrated without good exposures because of the change in lithology along its trend. The principal mineralization at the head of Four Mile Gulch lies to the west of the Sherman fault and has been described by Loughlin and Behre as belonging to the Leadville environment(6). It is probable that the Sherman fault is a smaller edition of the London fault although too little is known of it, unfortunately.

Post-Mineral Faults.--In the area mapped by the writers only one post-mineral fault has been observed. That was in the lowest level of the workings of the Mudsill mine, at the north end of the level (Figure 11). Doubtless, as has been previously shown for the surrounding area, there are numbers of post-mineral faults of small displacements as well as signs of post-mineral movements on pre-mineral faults. All the faults auxiliary to the London fault cannot be validly assigned to pre-mineral age although doubtless most of them originated, at least, before mineralization occurred.
Origin and Age of Folds and Faults.

Regional Considerations.--The most complete explanation of the regional structure of Colorado is to be found in four papers by Burbank and Lovering (19, 19a, 20, 20a). They point out the following elements all of which influenced the character of the Laramide deformation: northeast trending pre-Cambrian structures; the Front Range massif, a north trending positive area during most of post-Cambrian time; the northwest geosynclinal belt; the northeast belt of Tertiary stocks extending from Leadville to Boulder County, and which, with their associated intrusive forms appear to be localized at the general contact between pre-Cambrian granites and gneisses on the north and schists on the south.

The regional picture is further complicated by the fact that "in southern Colorado the ancient highland on the west was thrust eastward and northeastward........whereas, in northern Colorado the edge of the ancient Paleozoic highland was thrust westward..."(20, 287). Near Dillon, about 25 miles north of the Horseshoe-Sacramento district, Lovering found that the hanging wall of the Williams Range thrust fault had overridden the footwall for a distance of 4.5 miles (19a, 303). This is a low east dipping thrust. Lovering states further that the northwest trend of the asymmetric folds and faults of central Colorado indicates northeast-southwest compression (19a, 304).
From the articles cited, one gathers also that a number of transverse structures are present which cut the north and northwest trend of the principal lineaments. The most common expression of these are the regional array of intrusives along the northeast 'Mineral Belt' and the abundance of northeast fissures, veins, and faults. Horizontal movements are common on many of the fault fissures in the Front Range area (19a, 305), and for the northeast fissures the southeast walls are in places displaced to the southwest, in other places to the northeast.

Local Setting.—Of the major structural elements present in the area, the Alma-Loadville-Horcosnec-Sacramento region contains: northeast trending pre-Cambrian structures, the northwest geosynclinal belt, the contact between pre-Cambrian granite and schist (12, 6), and the belt of Tertiary intrusives. Porphyry dikes and sills are found in relative profusion south of the belt of stocks which roughly coincides with the contact between the pre-Cambrian rock types and within the same areal extent as the dikes and sills is the bulk of the ore deposits.

Rock structures ascribable to Laramide deformation are: the London flexure, the London fault, the Cooper Gulch faulted fold, the Sherman fault, and minor faults and rock brecciation. Laramide igneous activity is manifest in:
porphyry intrusives, their alteration, ore deposits, and other epigenetic features in the country rocks.

There is no evidence to disprove the preceding statement that the principal component of compressive force during orogenesis was in an east-west or slightly northeast-southwest direction and that the structures produced indicate activation from the east. It must be realized, however, that a multitude of major structural elements were involved, and that the local component may by no means represent the initial direction of stress as the major elements could easily exert buttressing effects and produce deflection in the direction of most convenient rock failure, which in this case was an east-west to northeast-southwest direction.

Laramide History of the Area.—As intrusive activity, deformation, and mineralization are so intimately related within the earliest Tertiary time, their sequence is most conveniently discussed in the same section.

Initial effects of Laramide stress is thought to be shown in places in the Alma district where the stratigraphic separation of porphyry sills on opposite sides of faults differs. It is thought that the earliest movement on these faults occurred before intrusion. The intrusion preceded the main period of folding and faulting(11, 100).

The contact relations between the sills in London
mine is considered to indicate that the initial effects of folding were felt before and during the principal intrusive period. Although the underground data are more precise than those from the surface, interfingering sills of both White and Gray porphyry are found only in the upturned basal Weber(?) beds in the eastern limb of the syncline in the London mine and are not observed on the surface at a distance from the fault regardless of the quality of the rock exposure. Furthermore the typical development of porphyries throughout the area beyond the immediate synclinal and anticlinal beds adjacent to the London fault is two sills of Gray porphyry within the Sawatch formation, and a single thick sill of Gray or Lincoln porphyry at the base of the Weber(?). Near the fault, in the anticlinal limb, the profusion of sills above the Blue limestone is indicated in Plate II,B. The evidence suggests that regional compression was first expressed in the zone of the London flexure by slight deformation of the strata there, causing numbers of sills to be localized within the narrow zone whereas outside the initially deformed zone, sills developed in lesser numbers. The fact that in the London mine intricate contact relations between Gray and White porphyry are noted indicates that the stresses continued to be efficient after intrusion of White porphyry and produced fracturing of definite or
incipient nature which acted more or less as bedding planes in guiding the emplacement of the later Gray porphyry.

The major folding and faulting affected porphyry intrusives and strata alike. The principal effects were the formation of the London fold, the London fault, the Sherman fault, and the Cooper Gulch faulted fold. The writer is of the opinion that the London fault, however, belongs not to the main compressive period of the orogenic movements but to a slightly later period even though it is the major structure of the district. Formation of the London fold and the Cooper Gulch fold and thrust fault should be considered as having been contemporaneous.

The literature records opinions that the Cooper Gulch fault and the London fault represent folds broken by the continuation of stress (12, 8-10). Of the Leadville area, Loughlin states "The earliest faults are reverse faults which were formed at the same time as the folds and broke their western or southwestern limbs" (2, 60). It is considered here that the Cooper Gulch fault broke the Cooper Gulch overturned fold as a further expression of the compressive stress, but the London fault breaking the London fold is not a further expression of the same compressive stress but of a later shearing stress.

Initial effects of compression were developed in
the longitudinal zone of the London fold and took place before the intrusive epoch had attained full development and was expressed in fracturing along which sills made their way. Following intrusive activity, compressive stress gradually exerted its maximum force, forming a broad fold which later became asymmetric and in places overturned. The major component of force was directed slightly south of west.

The Cooper Gulch fold developed in like manner except that it was considerably smaller and as the compression increased the rocks yielded to form the low-dipping Cooper Gulch thrust fault.

In order to preface later discussion concerning the London fault, the differences between it and the Cooper Gulch structure are to be remarked. The shortening effected by the Cooper Gulch fault is large compared with the shortening caused by its fold whereas the shortening caused by the London structure is almost totally expressed in the folding. The Cooper Gulch thrust dips flatly to the east at about 25-30 degrees whereas the London reverse fault dips steeply to the east between 60 degrees and the vertical. Moreover, the average dip of the London fault is probably about 80 degrees although insufficient data accompany this expression to warrant its complete acceptance.

If the Cooper Gulch fault is therefore accepted as
an expression of the principal compressive period, the dis-
similarity between it and the London fault (and likewise
the Sherman) can be most readily explained by assuming a
later period or direction of force in which the principal
component was expressed in the vertical direction.

Following the principal period of folding, later
stresses produced the London fault and accompanying auxili-
ary faults and fissures, of which many of the latter were
eventually mineralized. There undoubtedly was early develop-
ment of many of the smaller faults, especially those along
the anticline, accompanying the folding, but with renewed
movements and development of others in response to the fault-
ing. Brecciation of the dolomitic horizons accompanied the
movements and a later period of normal faulting ensued from
the close of the orogenic period until recent times.

There are four possible interpretations for the
London fault. The first is that it is similar to the Cooper
Gulch fault, a thrust, and has a flat-dipping plane in the
pre-Cambrian basement which steepens in the sedimentary
rocks. Everywhere observed, one or both walls are of sedi-
mentary rocks and erosion and mine development have not
penetrated to sufficient depth to ascertain the true case.
It would therefore represent a continuation of the compres-
sive era if viewed in this light.

The second is that which is usually accepted. The
fault was due to continuation of the compressive stresses
but subsurface causes induced the principal movement in the vertical direction rather than in the horizontal. The writer does not favor this interpretation.

The third and strongest possibility from the present standpoint is that the fault formed in the period after the principal compression had waned. The later stresses had a strong vertical component in contrast to a horizontal component of the principal compressive period. There are suggestions that the walls of auxiliary faults immediate to the London fault had relative horizontal movement as well as vertical (Plate II, A and E). If this occurred, the east wall moved south relative to the west wall, and the region underwent the effects of a small horizontal shear even though the principal displacement was vertical.

A fourth conception may not be unlikely, in that it combines the good points of both the second and third. The folding was due to shearing movements from the northeast and continuation of these movements caused rupture of the folds along their weakened limbs, the contrasting dips of the London & Cooper Gulch fault planes being fortuitous. The later stresses had a strong vertical component.

The writer favors the third possibility, although it does not completely explain all the elements in the picture.

Principal movement of the London fault was accompanied by dragging and thinning of the beds along the fault
plane. In places, the beds are dragged for considerable vertical distances. Faults and fissures which are closely parallel to the London structure are observed in places, and on the south side of Little Sacramento Gulch there are a number of mineralized fissures which strike more to the northwest in opposition to the usual trend. There are also northwest striking veins in the London mine, but these are not members of the principal vein system. In general, however, auxiliary faults and fissures to the London diverge at a small angle, but typically with northeast trend. Minor faults have dominant northeast trend in the Alma district.

The Sherman fault is considered to be smaller but otherwise similar to the London.

After the major structural adjustments had been completed, mineralization occurred, related principally to northeast trending fissures and visible as narrow bedded replacements of the favorable dolomite strata. Brecciation of minerals shows that movements occurred during the period of ore formation.

Later post-mineralization normal faulting which is not well shown in the area but is abundantly proven elsewhere in the region took place on earlier formed faults as well as along later lines. The sequence of intrusion, folding, faulting, and mineralization is represented below:
White Porphyry......---
Gray Porphyry....... ---
Folding..............- - ----- 
Thrust Faulting..... ----- 
Reverse Faulting..... ----- 
Auxiliary Faulting...- - --------------- - -
Mineralization......---- - -(?) 
Normal Faulting.....----- - -
STRUCTURAL FEATURES ADJACENT TO THE LONDON FAULT

MINOR FAULTING, NORTH SLOPE OF SHEEP MTN.

TRaverse across overturned beds, north slope, four mile gulch

AUXILIARY FAULTS, SOUTH SIDE, BIG SACRAMENTO GULCH

REVERSE DIPS, SOUTH SLOPE, PENNSYLVANIA MTN.

ZONE OF OVERTURNING, TOP OF CLIFFS, NORTH SIDE, PENNSYLVANIA MTN.
LINE OF SECTION - N 60° E

LEGEND

- Gray Porphyry: Early Tertiary
- White Porphyry
- Weber (?) Formation: Pennsylvanian
- Leadville (Blue) Limestone: Mississippian
- Dyer (Blue) Dolomite
- Paring Quartzite
- Manito (White) Limestone: Ordovician
- Sawatch Quartzite: Cambrian
- Schist, Granite, Gneiss: Pre-Cambrian
- Strikes and Dips
- Faults
GEOLOGIC HISTORY.

Pre-Cambrian.

The pre-Cambrian rocks, tentatively correlated by Lovering as Algonkian, comprise schists, gneisses, injection schists and gneisses, granite gneiss, granites, and pegmatites. The oldest sedimentary formation now represented by quartz-mica schists was subject to metamorphism and injection contemporaneously with the intrusion of the older granite, the Pikes Peak, and its associated rocks. A later intrusive period resulted in the emplacement of the Silver Plume granite, thought to have been intruded in a shallower zone than the older granite.

This great crystalline complex underwent erosion to base level before deposition of Cambrian sedimentary rocks occurred.

Cambrian to Mississippian.

The history from Cambrian to Mississippian may be considered apart from the post-Mississippian history in that the later rocks are lithologically distinct. The upper Cambrian sea encroached on a land surface which had been base-leveled during the later pre-Cambrian and early and middle Cambrian times. The residual materials on the surface were washed, sorted, and deposited as massive sandstone strata with a thin conglomerate zone at the base of the formation.
Later consolidation produced the rocks we recognize as the Sawatch quartzite.

The seas gradually deepened and the muds and impure limestone oozes which later were lithified into the Peerless or Transition shales were deposited. Further changes in the depositional environment resulted in formation of limestones and dolomites during early Ordovician times. A break in the stratigraphic sequence occurred at the end of the early Ordovician, and Devonian rocks were deposited in angular conformity with the Ordovician beds although upper Ordovician and Silurian strata were not deposited. The basal Devonian beds, parting quartzite, are overlain by the Dyer dolomite of upper Devonian age. Following deposition during Dyer time, an erosional unconformity developed before the lowermost Mississippian beds were formed. The basal quartzite and breccia of the Mississippian, although found over wide areas, is composed of a number of small lenses of limited areal extent. In the Alma district this horizon is not as persistent as in the present mapped area. The basal quartzite grades into the Leadville limestone, a massive persistent dolomite horizon, usually more than 100 feet thick. Following Leadville deposition, profound physiographic changes ensued which are expressed in the contrasting character of Pennsylvanian and later rocks.
Pennsylvanian to Cretaceous.

The pre-Pennsylvanian uplift strongly modified the physiographic character of the region by producing a geanticline in the present Front Range area and another far to the southwest. The uplift is thought to represent an early stage of the Wichita orogeny (quoted; 20, 279). The basin between these geanticlines received Pennsylvanian sediments in great thicknesses, and neglecting minor reversals, was a down-sinking geosynclinal area until the Mesozoic.

The general character of the lower Pennsylvanian sediments, the Weber(?) shales, contrast with the upper measures of conglomerates, coarse arkosic grits, cross-bedded sandstones, and quartzites which comprise the Weber(?) gritty. The size of the pebbles and general coarse character of much of this series shows that the adjacent land mass which furnished the sedimentary material stood at a higher elevation than in early Weber(?) time and was closer to the area of deposition. Small beds of shale and limestone in the upper measures reflect minor oscillations.

The Weber(?) beds are the youngest sediments found in the area. Just outside the area, however, where erosion has not been so active or where structural accidents have placed them below the reach of past erosion, later members of the series are observed. These consist of Permian red beds principally.
The record is lacking for the Mesozoic in the area but Burbank (20, 282) states that broad crustal warpings in the earlier Mesozoic were followed by the tremendous inundation of the upper Cretaceous.

Early Tertiary.

The earliest Tertiary was accompanied by the great orogenic disturbance which folded the strata, and raised the area above sea-level where it has remained since. In the Alma district there are suggestive indications that a small amount of minor faulting preceded intrusive activity, and in the present paper the writer calls attention to the development of interfingering sills in the disturbed zone of the London fold as an indication that movements accompanied their intrusion. Initial movements, small in effect, were followed by profound intrusive activity after which the major structural features of the region were accomplished. Mineralization occurred after the orogenic activity had waned, although post-mineralization normal faulting and recurrent movements on pre-mineral faults took place at later times and doubtless accompanied all the later uplifts of the region. As Lovering on regional evidence places the major intrusive activity as post-lowermost Eocene (15a, 30), there seems to be certainty that intrusion, deformation, and mineralization in this region occurred at that time because before mid-Eocene time
was achieved, the area had been eroded to a baselevel known as the Flattop peneplane.

Later Tertiary and Quaternary.

Later physiographic changes allowed renewal of erosion and a Miocene baselevel was produced known as the Rocky Mountain peneplane. By upper Pliocene time the area was rolling country of moderate relief and then underwent marked physiographic changes in response to a major uplift. Accompanying climatic changes initiated and glacial epoch of the Quaternary. Two periods of ice advance can be proven, and a third suggested. The ice advances left typical morainal and fluvio-glacial deposits. The rugged character of the headwalls of cirques suggests that the last vestiges of the ice disappeared a comparatively short time ago.

Oxidation of ore deposits was accomplished during the Tertiary and data are too inadequate to assign the effects to a particular epoch or erosion surface.
DISTRIBUTION OF THE ROCKS.

Pre-Cambrian Formations.

Plate I has been included in order to show the distribution of the rocks. The writer confesses to its inadequacy and inaccuracy but it was the only one available to him after the field season. It is especially deficient in showing the areal distribution of the pre-Cambrian formations. The generalization on the map has been carried so far it does not show that in the gulches within the area the pre-Cambrian formations outcrop east of the London fault. The true aspect is illustrated in Figures 6 and 8.

Tertiary and Quaternary erosion has exposed the pre-Cambrian formations over an area of about one square mile in Four Mile Gulch east of the fault. Paleozoic formations border the fault on the slopes and it is probable that beneath the glacial debris in the floor of the gulch there is some thickness of these rocks between the fault and the crystallines. The same situation obtains in Big Sacramento Gulch where another square mile of these rocks is exposed. Pre-Cambrian rocks are in contact with the London fault on the north side of this gulch, however. A small window exposes pre-Cambrian rocks in the floor of the Horsehoe cirque. A minute area of them is also located somewhere along the drainage of Pennsylvania Creek. Its location has not been ascertained and is known only through fluvial debris.
Lower Paleozoic Formations.

With the exception of the areas noted above which contain pre-Cambrian rocks, distribution of the lower Paleozoic measures is fairly well represented on Plate I. The lower Paleozoic section, composed of the Sawatch, Peerless, Manitou, Parting, Dyer, and Leadville formations, measures 500 feet thick, but the effective thickness is augmented by 100 feet or more due to the presence of several porphyry sills located for the most part in the Sawatch. The relatively broad outcrop of these measures is due, however, to near coincidence between the dip of the strata and the erosion surface rather than to their actual thickness or effective thickness. The broad band of them which parallels the London fault includes the London anticline and a zone of normal dip east of the anticlinal axis and their eastern contact shows the location where they dip below the overlying measures.

West of the fault, the normal dip carries these beds upwards to the west from the down-faulted trough of the syncline to their outcrops in Four Mile and Big Sacramento amphitheatres. West of the Sherman fault, the normal dip causes them to be exposed near the head of the range, and although some distance from the Sherman fault they are not as far removed as are the beds emerging from the syncline of the London fault.
Pennsylvanian Formations.

Pennsylvanian strata are represented by the Weber(?) shales and grits. These underlie the area east of the lower Paleozoic formations which dip below the Weber(?) on their regional dip. Narrow zones of Weber(?) are also found here and there along the east wall of the London fault where they have been folded into reverse dip by the anticline and dragged and thinned by the faulting. Unfortunately, the generalized areal map does not differentiate between Weber(?) and intrusive rocks.

It is to the west of the London fault that Weber(?) rocks are observed in profusion. Unless interrupted by intrusives, the bedrock geology in this area is rather monotonous as it is not possible to distinguish in more than a general way the various parts of the formation.

Tertiary Igneous Rocks.

Tertiary igneous rocks are found in dikes, sills, and laccolithic sills which have not been differentiated on the generalized map from the Weber(?) formation. The two principal types in this area are the quartz monzonite type of Gray porphyry and White porphyry. Other types are found in restricted development as has been mentioned on a previous page.

East of the London fault there is but little White porphyry observed. The crest of Sheep Mountain, however, contains a thick sill of White porphyry located just above the
base of the Weber(?) formation. The sill partakes of the
tectonic structure and may be seen in Figure 8; it is in
the east wall of the London fault and the light slide rock
is notched parallel to the fault. The sill has been cut by the
fault but a portion of it has been dragged down the footwall
so that the fault here contains White porphyry in both walls.

North of Sheep Mountain, there are usually two narrow
sills of Gray porphyry in the Cambrian formation, and where
the Weber(?) is exposed north and northeast of Sheep Mountain
a thick sill of Gray porphyry is located immediately above
its base.

West of the London fault, the area indicated in Plate 1
as containing undifferentiated Weber(?) and Tertiary intrus-
ives shows the greatest development of White porphyry of the
whole region, but the Gray porphyry is nevertheless nearly as
abundant. Immediately above the base of the Weber(?), ex-
tending from the upper part Big Sacramento Gulch to Four Mile
Gulch, is a tremendous area of White porphyry in the form of
a laccolithic sill. Its root or one of them is visible just
east of the Sherman fault where a thick mass of it has broach-
ed the lower Paleozoic formations, and after having attained
the stratigraphic position of the lowermost Weber(?) made
out into a great conformable mass occupying many square
miles. White Ridge is the most prominent outcrop of this
laccolithic sill which has a maximum thickness of at least
2000 feet.
West of the fault near the head of Little Sacramento Gulch, a thick sill or laccolithic sill of Gray porphyry overlies the White porphyry and extends northward into Big Sacramento Gulch. Its thickness is between 1500 and 2000 feet. In the northern portion of Big Sacramento Gulch, the White porphyry is lacking and the Gray occupies the stratigraphic position that the White has where present, namely the base of the Weber(?). This Gray porphyry mass splits into numerous fingerling sills in South Mosquito amphitheatre.

In addition to the occurrence of the larger bodies of porphyry there are numerous sills of both White and Gray porphyry at the base of the Weber(?) where the large laccolithic sills are not present. This is especially true along the immediate wall of the London fault from Four Mile Gulch northwards. In the London mines, interfingerering sills of both types have provided wall rocks for most of the ore.

Pre-Cambrian rocks contain narrow dikes of both types of porphyry. Other types of porphyry are discussed in the section describing the intrusive rocks.

Pleistocene Glacial Moraine.

The distribution of glacial debris is denoted on Plate III and full details are to be found in the section on the Quaternary.
ORE DEPOSITS

LOCAL DESCRIPTIONS

The Sheep Mountain Claims.

Geology of Sheep Mountain.—Sheep Mountain is an unglaciated peak, rising to an elevation well over 13,000 feet and situated a few miles east of the crest of the Mosquito range. The glacier which formerly occupied Four Mile gulch emphasized the ruggedness of the northern slope which falls away in sharp cliffs over 2000 feet from the unglaciated upper slopes of the mountain.

The cliffs on the north side of the mountain contain a complete section of lower Paleozoic rocks. A capping of the Pennsylvanian Weber(?) formation overlies these, but the upper part of the mountain is comprised primarily of a thick sill of White porphyry. Erosion has removed much of the section on the east slope so that the Leadville formation outcrops in a narrow zone across the east face high on the hillside. The lower contacts of the Leadville as well as the other formations have been obscured by glacial and detrital material.

The flexure of the sedimentary beds where they depart from their regional low easterly dip to form a sharp anticline merging with the London fault is well-shown on the north face. A structural high along the anticlinal axis has resulted in an eastward pitching anticlinal nose on Sheep Mountain. The north flank of the nose is gentler than the south. The fault crosses the western ridge of the mountain
and is closely parallel to the ridge which extends southeast from the peak. Mapping has shown the presence of many small faults and fissures of a general north to northeast trend in the hanging wall.

There are no manifestations of important mineralization on the crest of the anticline or where the beds dip west on the west limb between the anticlinal axis and the fault. There are, however, a number of prospects present on the east limb, where the beds have their regional dip and are likewise cut by small fissures. The prospects are about equally divided in the Leadville and Dyer formations; much of the Leadville has either been eroded or hidden so that it cannot be stated whether or not it made a more favorable host to the mineralizing solutions.

The following pages contain a summary of the mineral relations observed at the more important localities on Sheep Mountain. As far as known, production from this area has been negligible; the size of the workings shows that there was certainly but a small production, if any.

Structurally, the deposits are narrow replacements in dolomite, localized by northeast trending fissures.

The mineralization is characterized by the presence of barite. Other gangue minerals are quartz, a dolomitic and a ferriferous carbonate. Metallics, present in small amounts, in order of relative abundance, are: galena, sphalerite,
pyrite, and tennantite. One locality, however, contained as much galena as the other prospects combined. Microchemical tests have shown that tennantite in the whole district is argentiferous, while galena is not. The scarcity of tennantite in the ores from these claims presumably indicates low silver assays as no silver minerals have been observed from this area.

The specimens examined present minor differences in paragenetic relations, which, although not dissimilar in their broader aspects, suggest that the mineralization history of the different prospects has not been parallel throughout the complete course of events.

The generalized paragenetic relations for the Sheep Mountain area are:

<table>
<thead>
<tr>
<th>Recrystallization</th>
<th>Brecciation</th>
<th>Silicification (quartz)</th>
<th>Ferruginous carbonate</th>
<th>Barite</th>
<th>Dolomitic carbonate</th>
<th>Pyrite</th>
<th>Sphalerite</th>
<th>Galena</th>
<th>Tennantite</th>
</tr>
</thead>
<tbody>
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</table>

Several points with regard to the paragenesis are worthy of mention. The above tabulation should not be considered as that from any one locality on Sheep Mountain, as not all of the relations can be ascertained at one place. Furthermore, various minor contradictory observations and
obvious overlappings lead one to suspect that the solutions at one place were not necessarily similar to those at another at any given time. In fact, if the region had been undergoing slight structural readjustments during the period of activity of mineralizing solutions, different relations would be expected at different sites. The fissures are relatively small, probably distant from the main solutionways, and with dilute solutions, slight changes in the courses of the solutions could have effected marked mineralogic changes.

The principal stage of barite formation has been taken as a basis, it is believed, from which to date the relative stages of the formation of other minerals. Barite fills fracture zones, and in places is fractured. It antedates much of the silica yet postdates the formation of jasperoid.

In general, it can be stated that the earlier quartz caused the formation of jasperoid, and the later quartz did not effect complete silicification but more closely resembled vein quartz, as its place in the paragenetic sequence indicates it occurred during the career of activity of the solutions which effected mineralization. There are textures present in some of the outlying claims in the Sheep Mountain area which suggest that after brecciation of recrystallized carbonate and barite, some of the epigenetic quartz associated with carbonate took the general form of the silica in the jasperoid. It is possible that the early siliceous solutions
produced a jasperoid where they hadingress, and the later siliceous solutions produced silicification resembling jasperoid in places, in other places produced replacement textures more like those of vein quartz, and in the closing stages of activity, formed typical quartz veinlets. In the Sacramento mine, for instance, which is not of the Sheep Mountain group, there is an early stage of jasperoid silica followed by later stage of typical vein quartz. It is entirely possible that, if there were two periods of quartz deposition instead of one continuous period in the Sheep Mountain area, the two periods were so closely associated in time, thereby having been susceptible to the same general environment, their effects are similar in places. The writer believes that the introduction of silica was essentially a continuous process, interrupted in different places, however, by the occurrence of different events; beginning in different places at different times; and everywhere reflecting the various environments in which it formed.

Carbonate is difficult to assign. In the first place, there is no certainty as to what has been introduced and what has recrystallized. At Leadville, it has been found that recrystallized carbonate in the Leadville formation corresponds in composition (minus impurities) to the original dolomite (2, 219). Much of the recrystallization here occurred before brecciation ceased and is comparatively easy to recognize in
thin section, while the remainder may represent introduced material, perhaps however derived from nearby sources. The ankeritic carbonate, which weathering shows to have an appreciable content of iron, may represent recrystallization in the presence of iron-bearing solutions. The whole carbonate problem is susceptible to such a variety of interpretations based on its paragenetic relations which typically show overlapping relations to other minerals, that it seems best to treat it broadly. In general, it is believed to represent carbonate of sedimentary origin, recrystallized essentially in place during the whole period of mineralizing activity, and in places having relations of introduced material although derived from a nearby source through the dissolving and re-precipitating action of the solutions. The principal period of recrystallization occurred at a comparatively early stage in the mineralization, perhaps before the formation of jasperoid. Where dolomitic carbonate is indicated on the paragenetic chart, it should be understood that it may represent original material, but that cross-cutting relations visible either microscopically or megascopically justify its position among the introduced minerals.

The definite position of the sulphide minerals within the sequence could not be completely determined. It can be stated, on good evidence, that sphalerite, galena, and tennantite are later than quartz; that this same quartz was
later than barite and seems to have been contemporaneous with pyrite; and that galena was later than barite. Thus by neglecting carbonate, a simple process of mineralization can be pictured: silicification followed by barite deposition with the later stages of silicification overlapping and accompanied by pyrite; and then sphalerite, galena, and tennantite forming in that order. The qualifying statement with respect to carbonate completes the picture: early recrystallization of country rock occurred and during the succeeding course of mineralization, several periods of carbonate formation took place, the later carbonate having probably been derived from the country rock and representing recrystallization with or without accompanying migration. Brecciation initiated the introduction of solutions and continued intermittently at least until some of the barite had been deposited.

Viewed in this light, there are no serious discrepancies between these relations and those described by Loughlin and Behre for the outer mesothermal zone at Leadville (6, 223). As could be expected for areas in which numerous structural complexities exist (6, 216), variations such as are shown in the Sheep Mountain area are the rule rather than the exception.

Of the many small prospects on the upper slopes of Sheep Mountain which have been visited by the party, only a few justify description. On the areal map of the district,
Plate I, these are located in order to show the approximate limits of the visible effects of mineralization.

An attempt has been made to present evidences of the age relations of the minerals through photomicrographs. Where the relation is definite, a photograph is more convincing than description, and where the age relations are vague, an endless amount of discussion will not clarify the picture. Wagner Group.

Geology.—The Wagner claim group is situated on the north slope of Sheep Mountain at an elevation of 12,000 feet. It is seven miles by road from Fairplay to a point in the valley below the claims. They lie on the brink of the talus cliffs about 2000 feet above the road and are only accessible to pack animals via one of the abandoned trails leading up the east face of the mountain.

The principal working is a caved adit which penetrated the hill perhaps a hundred feet in a southerly direction. There are numerous shallow shafts but no mining proceeded from these, hence any production was realized from the adit level.

All workings are in the Dyer dolomite, 15 to 50 feet above its base. The sedimentary formations here have their normal regional strike and dip, as the property lies approximately 0.8 miles east of the London fault and is east of the region of the sharp westerly dipping flexure and the horizontal
strata on the crest of the anticline which parallels the fault. Detailed structures are indeterminate because of the covering of soil above the cliffs, and the talus on the cliffs immediately below the property. The relations of the formation contacts, however, suggest the presence of a north-striking fault in the vicinity of the claims. This fault, if present, has its east wall downthrown about 40 feet. The mineralization took the form of narrow bedded replacements of the dolomite, localized by north-trending fissures.

For the purpose of discussion, three contrasting types of primary mineralization have occurred: silica-barite with accompanying small disseminated sulphides, brecciated and thoroughly recrystallized Dyer dolomite with sphalerite, and brecciated but only partially recrystallized Dyer dolomite cemented by a breccia of which the matrix is a ferruginous carbonate and with galena contained in the breccia zones. In the above designation, no age distinction is intended, and as the specimens have been gathered from the dumps, it is most reasonable to assume that the type differences are primarily due to location within the mineralized zone.

Silica-barite Ore.—Barite, although extensively developed in the country rocks, is not abundant in the ore. The barite-rich portions of the country rock megascopically resemble ferruginous sandstone containing barite plates of two inches maximum dimension. The silica-barite mineralization
with accompanying minor amounts of sulphides evidently represents a gradation from the silicified barite-rich country rock towards sulphide ore. In thin section, this mineralization is seen to consist principally of silicification of the dolomite which accounts for the resemblance of hand specimens to a ferruginous sandstone (Figures 14a & 14b). No relict structures survived the silicification, and although there is an appreciable carbonate content, it does not appear to have been recrystallized in situ.

The introduction of silica into the Dyer provides a possible point for controversy especially because the hand specimens resemble sandstone. Inasmuch as the Dyer does not contain any sandstone beds or lenses either in this immediate area or elsewhere, the field evidence supports the contention that the texture has resulted from introduction of silica. Furthermore, the microscopic evidence militates strongly against a sedimentary origin for the quartz. The silica, which is in the form of granular quartz instead of the familiar jasperoid, occupies some 60% of the area of the sections examined. Where more barite is present, the percentage of quartz decreases accordingly. Hypidimorphic texture has resulted where the original quartz euhedrons have been enlarged by successive additions of material but euhedral growth of the nuclear crystals is clearly visible. Where quartz has been observed within or projecting into barite crystals, it has
euheral form. There are no rounded grains which have received accretions of material, and not all of the euheral grains have been enlarged by later growth. Loughlin (2, 172) states that in the Leadville district "a perfect crystal of quartz will be seen embedded in an anhedral grain....the structure showing that the development of perfect quartz crystals is the first step in the process of silicification .......of limestone....."

An interesting feature of this mineralization is the presence of abundant inclusions of carbonate within the quartz crystals. A typical cross-section of a quartz euherdon shows a small nucleus of clear quartz, a zone of quartz containing carbonate inclusions parallel to crystal boundaries, and lastly a narrow rim of clear quartz. It is not uncommon to observe two or even three zones of inclusions within a single grain. The entire euherdon may or may not show further enlargement accompanied by destruction of crystal form, but if accretion did occur, it maintained the optical continuity of the original nucleus (Figure 15). The carbonate inclusions are minute blebs, impossible to analyze exactly because of their small size, but rotation of the microscope stage shows a wide difference in refractive index for their two extinction directions. Between crossed Nicols interference colors similar to those of rhombohedral carbonate have been observed. Their lower refractive index is appreciably higher than that of
quartz and their relief at the other index position is clearly very high, presumably indicating that their composition is ankeritic or sideritic. Furthermore, a slight effervescence has been detected by treating a polished section of quartz with dilute acid. Inclusions have been noted in some of the quartz from Leadville (2, 172) but were so tiny that they were indeterminate, and are thought to be similar to dusty inclusions in vein quartz elsewhere in the Horseshoe-Sacramento district.

As noted previously, barite is present in greater or less amounts but is more abundant in the country rock than in what is considered as the ore proper. The size of the barite plates ranges from microscopic to two inches. Radiate growths of several plates from a common center is more typical than isolated crystals. Microscopically, the barite appears to have been the earliest mineral introduced. A truly insignificant amount of microcrystalline barite, formed along cleavages of large barite and within quartz may represent a rejuvenation of barite deposition incurred possibly by the replacement of early barite by quartz. Coarse barite is replaced by quartz and the age distinction is clear (Figure 16b). In the case of carbonate, however, the observed age relations are not amenable to complete interpretation.

Carbonate, like quartz in these ores, manifests zonal growth. Many of the grains which have undergone
surficial alteration have iron-stained cores and relatively clear peripheries. In addition, transecting veinlets of clear carbonate have been observed within the iron-stained material (Figure 16a). It is possible, of course, to attribute other agencies as the causal factors such as the bleaching and dissolving action of later solutions. It is believed, however, that the solutions which formed the carbonate underwent a rather abrupt change at about the middle stages of the carbonate deposition, and became less ferruginous than formerly.

There are suggestions that certain masses of carbonate, generally without an appreciable iron content, are recrystallized remnants of the Dyer dolomite.

The sulphide minerals are not discussed in this section as they are so sparsely distributed that tangible data are not available.

Recrystallized dolomite-sphalerite type ore.—The brecciated and recrystallized Dyer dolomite was host to a sphalerite mineralization in the second type of ore observed at this property. Brecciation occurred after the earlier recrystallization had progressed to some extent as shown by the variable texture of fragments on smoothed surfaces of the ore (Figure 13b). Fragments of different crystallinity may be seen separated from one another by narrow areas of carbonate which cemented the breccia. The breccia zones appear to be more than several inches wide, and it is impossible to distinguish original walls in the hand specimens.
That some of the ferruginous carbonate evidently had been introduced prior to cessation of brecciation is indicated by the microscopic study. More or less angular masses of it have been cemented into the aggregate by extremely fine-grained carbonate containing euhedral quartz crystals with zonal arrangement of carbonate inclusions. None of the euhedral quartz is fractured and as it has exactly the aspect of quartz observed in the silica-barite mineralization in the country rock, and which was responsible for the general silicification, it is necessary to assign a post-brecciation age to the silicification. This question is further discussed elsewhere.

A still later generation of both quartz and carbonate is visible both under the microscope and in hand specimens where the late carbonate is observed in small masses and veinlets, its white color contrasting strongly with the blue-gray of the early recrystallized and the fine-grained cementing facies. The late carbonate does not react to weathering by turning brown as readily as do the earlier generations. In addition, it is present in vugs together with quartz, sphalerite, and in places, tennantite. Many masses of ferruginous carbonate are either partially or wholly rimmed by carbonate of later age, and invariably are cut by small veinlets of non-ferruginous carbonate. It is questionable whether the bordering carbonate represents zoning or a distinctly later generation where associated with brecciated ore. Quartz, associated with this later
carbonate, is completely anhedral, relatively sparsely distributed, and not present outside of areas of this type of carbonate. Where present in vugs, however, both carbonate and quartz show crystal forms.

Brecciated dolomite-galena type.--Galena, the most prominent in sulphide mineral, occurs principally/brecciated zones in Dyer dolomite which has undergone but slight recrystallization. Breccia zones are not more than a few millimeters in width as compared with those of the sphalerite-type ore where they are several inches, and are clearly demarcated. Within the fractures, is a breccia of angular fragments of the country rock, some fragments recrystallized, others not, and cemented by ferruginous carbonate; the whole cut by narrow veinlets of quartz. The healing process was not thorough, however, and many vugs testify as to its inefficiency. Galena formed entirely in the brecciated zones by replacing the cementing material and filling open spaces (Figure 13a).

Sulphide mineralization.--The sulphides present in these ores merit but a brief description. In order of relative abundance, they are: galena, sphalerite, pyrite, tennantite.

Pyrite is disseminated throughout the ores, usually in quartz. Its total amount cannot be greater than 1% of the total sulphides. The grain size averages 0.5 mm. diameter.

Sphalerite, tennantite, and galena have been discussed. It is worth mentioning, however, that galena shows distorted crystallographic directions. It is relatively coarse-
Figure 13


.a. Silicification of Dyer dolomite showing euhedral quartz with carbonate inclusions. c - recrystallized carbonate. Wagner group, plane light, x 31.

Detail of quartz euhedron containing carbonate inclusions. Entire field except for carbonate blebs is quartz. Euhedral core of central crystal is optically continuous with some of the surrounding quartz. Wagner group, crossed nicols, x 200.
a. Ferruginous carbonate cutting silicified Dyer dolomite. Outlines of euhedral quartz are seen in the silicified rock. The ferruginous carbonate is transected by a tiny veinlet of white carbonate. SD - silicified Dyer dolomite, f - ferruginous carbonate, c - white carbonate. Wagner group, plane light, x 40.

b. Barite crystal (black) containing euhedral quartz along cleavage planes. The tiny veinlet represents a late generation of microcrystalline barite (b). Wagner group, crossed nicols, x 26.
a. Pyrite (white) and sphalerite (light gray) in gangue (dark gray). Wagner group, reflected light, x 50.

b. Structure of galena brought out by polish etch. Wagner group, reflected light, x 25.
grained, and cleavage pits formed in polishing indicate the
distortion remarkably well (Figure 17b).

The paucity of tennantite in the ores suggests a low
silver content inasmuch as microchemical tests have shown that
tennantite and not galena, is the carrier of the silver values.

Glacial erosion did not attain the elevation of the
Wagner claims, hence products of the Tertiary oxidation have
been preserved. Supergene sulphides have not been observed, and
oxidation products are few and not abundant. In fact, the dearth
of oxidation products indicates as much as anything, the poverty
of the area in metallic minerals. The products of oxidation are:
iron oxides, anglesite, cerussite, smithsonite, calamine, mala-
chite (small pisolithic incrustations), and iron-stained carbon-
ates.

Nelson Claim.—The Nelson claim is located on the east slope of
Sheep Mountain at an elevation of 11,500 feet. Heavy barite-
galena mineralization is found in the Dyer formation unaccom-
panied by visible quartz or vug carbonates.

The country rock underwent brecciacion and recrystal-
lization, the recrystallization involving a slight increase in
grain size and elimination of impurities. Barite occurs in
radiate intergrowths of comparatively large platy crystals,
many of the crystals over 2 inches in maximum dimension, and
in many places so thoroughly intergrown as to appear as massive
barite. Microscopically, barite plates are fractured, and show
prominent undulatory strain effects (Figure 18a). It is evident
that fracturing continued after the introduction of barite and before the formation of later minerals. It is not clear from the sections or the hand specimens whether barite replaced the brecciated country rock or formed partially in open spaces.

Subsequent to the movements which fractured barite, carbonate and quartz formed in the breccia, cementing fragments and replacing barite. Every barite plate observed in section bears evidence to the replacing action of the solutions which deposited these minerals. Margins of the plates are serrate from corrosion and some of the quartz and carbonate has formed along barite cleavages as well as within microfractures. A slight amount of quartz is present in well-formed crystals but most is irregular. The introduced carbonate along with the anhedral quartz has allotriomorphic texture, in which the average grain size is 0.03 mm. The carbonate may be very slightly ferruginous. It is impossible to detect an age distinction between the quartz and carbonate.

Galena replaced the matrix of the breccia, barite, and country rock. The coarsest galena observed in the whole district occurs here, while barite is as large as any found elsewhere. The striking feature, in fact, at this locality is the size and amount of barite and galena. Where galena occurs in isolated, though abundant, masses in the country rock dolomite it is not associated with barite in contact relations as barite is confined to the breccia zones. Where galena is associated with barite, it can be seen to replace it along fractures and
cleavages, though favoring barite masses at their contacts with
the matrix of the breccia.

There are minor amounts of tennantite in the ore al-
ways contained within galena. The largest mass observed had a
diameter of one millimeter. A semi-quantitative estimate indi-
cates that less than one percent of the total sulphide is ten-
nantite. It is thought that tennantite formed later than galena.
Tennantite contacts are relatively straight in many places and
where straight, correspond with galena cleavage directions.

More than half of the minerals in the specimens are
represented by galena and barite, divided in about equal
amounts.

The vicinity of this claim is a place that is not to
be neglected in further prospecting even though the Leadville
limestone has been eroded. The Dyer is a favorable horizon,
and the fact that the heavy barite-galena mineralization is
present shows that channelways to this site were open to solu-
tions during the time of ore deposition, and that relatively
intense deposition occurred. The paucity of tennantite indi-
cates low silver values are to be expected in the area.

The paragenesis is:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Relative Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brecciation</td>
<td></td>
</tr>
<tr>
<td>Recrystallization</td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td></td>
</tr>
<tr>
<td>Carbonate</td>
<td></td>
</tr>
<tr>
<td>Quartz</td>
<td></td>
</tr>
<tr>
<td>Galena</td>
<td></td>
</tr>
<tr>
<td>Tennantite</td>
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</table>
a. Barite crystals showing undulatory extinction. The fine-grained carbonate and quartz cut fractured barite and have replaced it along crystal margins. Nelson claim, crossed nicols, x 26.

Brown's Pass Prospect.--An adit enters the Dyer and Leadville formations immediately north of the Brown's Pass road at an elevation of 10,950 feet. The Brown's Pass road climbs from the low country southeast of Sheep Mountain to a low saddle, Brown's Pass, situated on the ridge extending southeast from the top of Sheep Mountain. The London fault and the ridge are parallel, so that the fault is not more than 1,000 feet horizontally from the prospect. Most of the area here is covered by soil and timber making it impossible to discover more than the character of the underlying formations.

The mineralization at this prospect is entirely within the Leadville formation. There are several other prospects in the immediate neighborhood in the various pro-Pennsylvanian formations but none of these others shows signs of mineralizations. The London fault is relatively close to the anticlinal axis. In the vicinity of the prospect, the formations have their normal east dip, but flatten to the west as the fault is approached and then dip west sharply near the fault.

This prospect is the farthest south of any seen in the field and the mineralization, although weak, is readily apparent. Structural features in the ore itself show that as much brecciation occurred here as did further north. Specimens from the dump consist of angular and sub-angular fragments of Leadville limestone in all stages of recrystallization from unaffected to massively recrystallized and 'zebra rock', transected by brecciated zones from one-half to several inches in width.
that contain many smaller fragments of the various recrystal-
lized facies of the Leadville formation as well as angular
fragments of dark chert and silicified limestone. The silice-
ous material is not abundant. The rubble in the breccia zones
has been consolidated by the introduction of carbonate and
finely crystalline barite. Scattered small masses of galena
are found only in the breccia zones.

Under the microscope, the filling in the breccia zones
is seen to consist of fine-grained carbonate and barite. The
carbonate, which weathers brown more readily than the carbonate
of the recrystallized country rock, probably contains an ap-
preciable amount of iron. Barite is finely crystalline and much
could be called microcrystalline. The age relations of carbon-
ate and barite could not be ascertained; it is not unlikely that
they were contemporaneous. Introduced silica is lacking. There
are no features worthy of mention in connection with galena at
this prospect.

Other Areas.--

Prospect, 2400 ft. N 45°E of Sheep Mountain.—The mineral-
ization at this locality bears strong resemblance to that at
the nearby Wagner claim with the exception that here barite is
entirely lacking. The prospect, several shallow pits, pene-
trates the Dyer formation. Carbonate is the principal gangue
material with which is associated subordinate amounts of quartz.
A small amount of pyrite in scattered grains, a few masses of
brownish green sphalerite, and numerous but small masses of galena are the only metallics observed. Weathering has produced scant oxidation products of these sulphides in addition to a negligible amount of malachite, from which the inference is drawn that there was a small amount of tennantite in the primary ores.

There is much of the country rock in its original state although it is impossible to mark the division between certain masses of the coarser carbonate which may be either recrystallized or introduced. The rocks are transected by narrow brecciated zones and veinlets which contain quartz and carbonate. The presence of clastic fragments associated with quartz and carbonate serves to delineate certain areas in which carbonate has probably been introduced but the absence of such fragments does not identify recrystallized areas.

The course of events seems to have been as follows: recrystallization and brecciation occurred in the dolomite with the recrystallization decidedly subordinate as compared with that at the Wagner; the rubble was cemented by the introduction of quartz and carbonate which formed interlocking microcrystalline texture without apparent age difference; microfractures in the fragments provided channelways along which the same solutions migrated, depositing, however, coarser quartz and carbonate with carbonate deposition overlapping that of quartz at both ends (Figure 19); and closing with the deposition of sphalerite and galena in open space and by replacement of earlier minerals
and fragments in the brecciated zones. Small amounts of brown-weathering carbonate coat galena crystals in the vugs.

The carbonate in the veinlets varied in its iron content if the manner in which it oxidizes is a criterion. There are hints that the ferruginous variety deposited subsequently to quartz; several veinlets, 0.2 mm. in width, consisting of both quartz and ferruginous carbonate contain medial fractures present in quartz which are filled with ferruginous carbonate in crystallographic continuity with the principal vein masses. Veinlets of carbonate cut quartz and vice versa; the post-quartz veinlets are ferruginous carbonate while the earlier ones are not. This being the case, quartz occurred during the middle stages of carbonate deposition, with pre-quartz carbonate non-ferruginous and post-quartz carbonate ferruginous, and the latter is possibly correlated with the ferruginous carbonate found in the vugs which was the latest mineral to deposit.

The sequence can be represented:

Brecciation................... ___
Recrystallization.............. ___
Carbonate....................... ___
Ferruginous carbonate.......... ----- -?
Quartz............................ ___
Pyrite............................ -
Sphalerite....................... -
Galena............................ ___

Another feature reminiscent of the Wagner mineralization occurs at this prospect. Small areas of unrecrystallized dolomite contain areas of carbonate of the same texture as the rest but whose grains are more transparent in plane transmitted
light under the microscope. These areas have hexagonal outlines as shown in Figure 20. Under cross-polarized light, it is possible to demonstrate that euhedral but skeletal crystals of quartz are responsible for the shape of the areas. About 5% of the areas is quartz, the remainder is clear carbonate. The introduction of quartz evidently purged the dolomite of its impurities without effecting recrystallization. It is not difficult to reconcile this incipient silicification with the observations made on Wagner specimens where quartz euhedrons contain well-demarcated narrow zones of carbonate inclusions. There, carbonate, present to the amount of 10-5% compared with 90-95% quartz, was rearranged in oriented blebs as the quartz euhedron was forming. Here it seems as if the carbonate is relict. The fact that good euhedral forms of quartz are observed here within breccia zones (Figure 19) while the skeletal quartz is found only in the country rock indicates that accessibility of solutions to the unfractured remnants of country rock was difficult. The most plausible explanation is that small amounts of quartz introduced into the dolomite formed skeletal euhedrons and the solutions dissolved impurities from dolomite grains, while greater amounts due either to higher original concentrations or continuation of the process formed solid euhedrons in breccia zones.
Veinlet of quartz (q) cutting ultra fine-grained Dyer dolomite (black) and apexing in spearhead form within a breccia zone previously filled with fine-grained carbonate and subordinate quartz. The veinlet, outside the field, contains dolomitic carbonate in grains as large as the apex. Euhedral quartz present in small amount in the breccia zones (eq) formed later than fine-grained quartz. Small amounts of carbonate of unknown derivation (c) are observed. Prospect, 2400 feet, N45E of Sheep Mountain, plane light, x 31.
Skeletal formation of quartz euhedron within Dyer dolomite. More than 90% of the area of the euhedron is occupied by dolomite of the same texture as surrounding country rock but which contains less dark-colored material. Prospect, 2400 feet, N 45 E of Sheep Mountain, plane light, x 210.
Adit, 2180 feet, S 54°E of Sheep Mountain.—A short adit in the top of the Leadville limestone at this point displayed the relations of carbonate and barite better than elsewhere. The original limestone underwent brecciation which appears to have been accompanied or preceded by irregular recrystallization as some of the recrystallized limestone is fractured. Subsequently, ferruginous carbonate that shows coarser texture than any of the recrystallized material, was introduced into the breccia and replaced fragments marginally.

Barite, in plates 0.5 inches in diameter or less, formed during and after the introduction of carbonate. Carbonate cleavage directions exert influence on the direction and continuity of margins of barite plates, and the cleavage of barite has influenced grain form of a little of the carbonate. A small amount of microcrystalline barite is best interpreted as being later than all of the carbonate.

There are no sulphides present, but in hand specimen, scattered casts of oxidized pyrite are apparent. The usual diameter is about 1.0 mm. In thin section, where one of these casts could be observed, the original pyrite appears to have cut and partially replaced several barite plates. It is not certain that such is the true relation, as oxidation effects may have obscured the primary one. There is no quartz present.
Ridge, south of Sheep Mountain, 12,300 feet elevation.—The ridge which extends southeast from the crest of Sheep Mountain gradually approaches the London fault as one goes southeast from the peak. The ridge itself contains the crest of the anticline east of the fault. There are several shallow prospect shafts in the Leadville limestone on top of the ridge at an elevation of 12,300 feet, all lying between the axis of the anticline and the London fault.

A breccia composed of fragments of Leadville limestone and white porphyry has been silicified along a narrow fractured zone, with additional mineralization of pyrite and barite.

Barite occurs principally in vugs as small colorless plates, 0.5 inches in diameter and in microcrystalline form within the jasperoid. Under the microscope (Figure 21a), complete silicification is apparent with the quartz grains in microcrystalline allotriomorphic intergrowth. Some of the larger quartz grains show strain effects whereas the majority of the late microcrystalline silica shows undulous extinction under crossed nicols. Small barite plates are sparsely distributed throughout, many of them shattered, and with veinlets of microcrystalline quartz along their crystallographic directions indicating the continuance of silicification after barite deposition (Figure 21b). The principal habitat, however, of barite is in the vugs. It is not

b. Replacement of barite (light gray) by silica. The crystallographic directions of barite influenced the direction of maximum replacement effects. Margins of the barite show evidence of replacement by silica as well. Ridge south of Sheep Mountain, elevation 12,300 feet, crossed nicols, x 200.
impossible that carbonate was originally present with barite in the breccia but the only vestiges of it remaining are in a few tiny inclusions within some of the quartz.

The material gathered from these prospects has undergone thorough oxidation, leaving cellular jasperoid and limonitic casts of a few pyrite crystals. Highly weathered jasperoid is colored bluish gray, indicating that such iron as did deposit was subordinate in amount. This is to be contrasted with the bulk of the jasperoid on the north side of Sheep Mountain which weathers deep red or brownish purple.

Crest of London anticline, north side of Sheep Mountain.-- The widespread occurrence of silicified dolomite in both the Leadville and Dyer formations immediately east of the London fault on Sheep Mountain has produced large conformable lenses of jasperoid within the formations. Several horizons have been susceptible to the silicification which apparently was localized by numerous small fissures and breccia zones bearing north to N 20°E. In places, especially close to the fault, the Manitou formation has been silicified with preservation of original structures so that the cherty layers are clearly discerned within the jasperoid. All the jasperoid on fresh surfaces displays a bluish-gray color but weathering affects the various lenses to different degrees, some turning brown and red, others tending to remain gray. This, without a doubt due to weathering of pyrite, is not
susceptible to more than suggestive generalization with respect to areal or structural location.

The two most favorable horizons for the formation of jasperoid have been the upper parts of both the Leadville and Dyer formations and the most favorable locations have been regions of fracturing. As the subsidiary fractures to the London fault are numerous and intersect the susceptible beds, areas of jasperoid as could be expected, tend to be found within the structural aureole of the fault. There are many locations exceedingly close to the fault which have not been silicified, however, and these may or may not have had extensive recrystallization of the dolomitic formations.

On the crest of the London anticline on the north slope of Sheep Mountain, barite is abundant in the jasperoid at the top of the Leadville limestone. The barite plates, rarely more than 0.5 inch in length, are found in veinlets or in individual groups of crystals. Nearly all the barite crystal observed gave microscopic evidence of corrosion by solutions which deposited fine-grained silica. Barite, however, is seen to cut jasperoid in veinlets. Figure 22 shows a veinlet of barite cutting jasperoid with plates arrayed normal to the veinlet walls but elsewhere in this same slide the platy structure is parallel to the walls. There are suggestions that the major silicification preceded barite deposition and definite evidence of later overlapping age
Tarite veinlet cutting jasperoid. The variable but fine-grained texture of the jasperoid is clearly shown. Crest of London anticline, north side of Sheep Mountain, crossed nicols, x 26.
as quartz replaced barite along cleavages and crystal margins. The later quartz has the identical texture of the early, but follows the barite veinlets and appears to be more free from impurities in plane transmitted light. The impurity-free silica may represent a slight reworking or recrystallization of jasperoid under the influence of the solutions from which barite precipitated. Certain microcrystalline barite in small amounts represents a second generation.

The paragenetic relations are:

Silicification........... ---
Barite................

It is important to contrast this type of silicification with that shown at the Wagner prospect, a few hundred yards to the east. There, barite formed earlier than quartz. The quartz at the Wagner displays medium-grained euhedral habit, with later accretion in places welding the crystals into hypidiomorphic texture but not destroying the original nucleus. The resultant rock, after weathering, has somewhat the appearance of sandstone. The silicification at this locality produced a dense flinty rock of typical jasperoid aspect which under the microscope reveals allotriomorphic texture without traces of euhedral cores. The average grain size is about 0.03 mm. and, although some irregularly distributed grains are several times larger, many are less than
0.01 mm. Much of the finest silica displays undulous extinction between crossed nicols.

The above discussion intimates that two types of silicification have occurred in the district, one fine-grained and allotriomorphic, the other coarser-grained and hypidiomorphic in general aspect though essentially idiomorphic before final enlargement of nuclear crystals.

Loughlin believes (2, 218) that there were two stages of silicification in the Leadville district, and that the interval between them saw the deposition of the bulk of the sulphide ores. He was unable to distinguish them texturally, however, and considered that the initial stages of silicification consisted of the formation of euhedral quartz grains (2, 172). It is extremely doubtful, if, at this locality, there was any development of euhedral grains. There is certainly no hint of them shown in thin section.

Prospect, Four Mile Gulch.—At the northeastern base of Sheep Mountain, the Leadville limestone together with the other sedimentary formations, crosses Four Mile Gulch. Several small prospect adits and shafts are present near the top of the formation and specimens from one serve to illustrate the slight activity of metallizing solutions at this point. Carbonate and galena are the only minerals present.

The mineralization is related to a small fissure, striking N 10°E and dipping 60°NW. Slickensides have been
formed but the contact indicates there has been no appreciable displacement.

Combined megascopic and microscopic examination indicates there are six separate stages of carbonate formation at this locality. These are considered in their genetic order as follows:

1) Original dolomite of the Leadville formation, which accompanying or following initial brecciation formed

2) Irregularly recrystallized masses of slightly coarser texture. Continued brecciation produced irregular small fractures which were healed by the introduction of

3) Brown-weathering carbonate (slightly ferruginous dolomite). More severe brecciation produced angular fragments of varying sizes, which contain carbonate of stages 1, 2 and 3. Introduction of milky white

4) Dolomite recemented this brecciated material. The angularity of fragments and sharpness of contacts is thought to prove introduction of this generation. Small fractures transecting earlier structures were partially filled with

5) Ferruginous dolomite but filling was incomplete and led up to a vug stage. Many of the vugs contain ferruginous dolomite only, but in certain places the formation of
6) Glassy calcite took place within the vugs.

It is not clear whether calcite in this occurrence is related to mineralization or to later supergene action. Certainly, however, stages 3, 4, 5 represent activity of hypogene solutions. Figure 23 indicates the appearance of the breccia.

Several tiny crystals of galena occur, but on the whole, this sector appears to contain the weakest mineralization of the entire Sheep Mountain area.

The Mudsill Mine and Adjacent Prospects.

The Mudsill Mine.--The Mudsill mine is situated 8 miles from Fairplay by road, the route leading across the flats of South Park and up the valley of Spring Creek. The mine is accessible to automobiles. It lies below the crest of a relatively low ridge and overlooks Four Mile Gulch to the south.

Geologically, it is located on the west limb of the London anticline in the Dyer formation. The strike of the sedimentary beds is approximately north-south in this vicinity, and in the mine their dip varies from 45° west to horizontal, and a short distance east of the mine the normal easterly dip is resumed.

The mine workings are in an excellent state of preservation, and this is the only one of the main productive mines in the district which is accessible. There are a series of small stopes entirely within the Dyer formation,
Brecciated and recemented Leadville limestone. 1) Original dolomite, 2) recrystallized dolomite, 3) irregular veinlets and masses of ferruginous dolomite, 4) dolomite, 5) vein stage of later ferruginous dolomite, 6) vug calcite. Prospect, Four Mile gulch, incident light, x 5.
immediately below a silicified bed which lies about 20 feet below the base of the quartzite member of the Leadville formation. The upper workings show several small fissures which strike N 15°E, and dip 50-70 SE. The gouge in these fissures contains an abundance of limonitic material where observed on the surface. Numerous small pockety masses of yellow clay gouge are found throughout the mine. The mine map, Figure 11, shows the visible geology.

The mine was located before the turn of the century and had a reputed production of $60,000, for the most part supposed to have been from silver. The peculiar situation that an intense search of the workings and waste dumps failed to find a single trace of material that could be called ore exists, so that the study of the slight mineralization found 200 feet east of the Mudsill workings is utilized to determine the probable character of the hypogene mineralization within the Mudsill mine. The specimens from the Mudsill, however, show that the primary ores underwent thorough oxidation. This is borne out by the physiographic study, which indicates that the Quaternary glaciation did not reach the ridge on which the mine is located. The ridge must have been exposed during a long period in the later Tertiary and undergone long-continued oxidation. It is peculiar that comparatively abundant galena may be observed 200 feet to the east, but at that place the sediments have
their normal flat east dip, and it is entirely possible that the slight mineralization at this point reflects the absence of numerous fractures in the rocks and that the more numerous fractures at the Mudsill gave access to surficial solutions more readily.

The traces of mineralization at the Mudsill may be summarized: brecciation, and recrystallization where small amounts of original dolomite have escaped silicification, silicification of the bed overlying the ore into a dense, dark-weathering jasperoid as well as silicification of some of the mineralized ground which has been mined, and metallization of lead and copper denoted by cores of galena crystals nearly destroyed by anglesite and a small amount of malachite.

The prospect 200 feet to the east contains brecciated and recrystallized dolomite, quartz, barite, pyrite, galena, tennantite, and oxidation products. The proximity of the two locations, their presence in the same host rock, the Dyer, and their generally similar characters appears to justify describing them as one, realizing that the prospect manifests a less extensive mineralization of the Mudsill type as far as the relations of the metallic mineralization is concerned.

The silicified breccia from the Mudsill mine contains scattered masses of dolomite in minor amounts which appears to be remnants of recrystallized Dyer dolomite. By
far the dominant microscopic characteristic is the silicification, with microcrystalline quartz present in a felted aggregate as shown in Figure 24. The average size of the lath-shaped quartz crystals is 0.1 mm. long and 0.03 mm. wide. Some of the finest-grained quartz has undulatory extinction. Tiny veinlets of crystalline quartz transect the silicified rock. Quartz in the veinlets is coarser, average grain size 0.5 mm., and does not contain the products of oxidation with which the other material is stained. Small casts throughout the slide indicate that pyrite was originally disseminated throughout.

The ore from the prospect 200 feet east of the Mudsill mine does not display as much silicification, but does show a great amount of brecciation and recrystallization. Microscopically, fragments, in all stages of the recrystallization process from original dolomite (practically unresolvable grains) to masses in which the grain size of the carbonate is one or two millimeters, are seen to be cemented into an aggregate by quartz and carbonate. The cementing carbonate is fine-grained.

Of special interest is this epigenetic quartz as it shows transitional features from the Mudsill type of silicification (similar to the jasperoid on the north face of Sheep Mountain) to the Wagner type, in which a granular aggregate was welded by later accretion. Here perhaps 20%
of the quartz is of the Wagner type. It contains phantom euhedral cores containing carbonate blebs and has been enlarged by a small amount of later quartz grown in crystallographic continuity. Its average grain size is about 0.5 millimeters. The remainder of the quartz is present in a felted aggregate in which most of the individual grains have widths and lengths comparable, and with a coarser grain size than the felted quartz at the Mudsill. It is difficult to strike an average grain size for this type, but it is about 0.4 millimeters, or approximately four times as great as that at the Mudsill.

Most of the dolomitic carbonate, in the absence of definite evidence, however, seems to have formed contemporaneously with quartz and contributed to the matrix which cemented the brecciated dolomite. There are a few veinlets of carbonate which formed at a late stage. Barite is of post-brecciation, post-recrystallization age.

The metallic minerals, pyrite, sphalerite, galena, and tennantite, are found in greatest development where associated with silicified country rock, although scattered masses of galena are observed in drusy cavities in dolomite and along veinlets containing late carbonate as well. Pyrite appears to be confined exclusively to masses of quartz. Galena replaces both pyrite and quartz while its relations to tennantite are not clear. Small amounts of quartz and
Texture of jasperoid, Mudsill mine, crossed nicols, x 26.
carbonate in vugs probably has little significance.

Contrasted to certain localities on Sheep Mountain which have been described in the preceding section, this prospect presents a high ratio of tennantite to galena. The total amount of sulphides, however, is so small that it was not possible to make a mine. On Sheep Mountain, with one exception, the amount of sulphides is small and everywhere the tennantite-galena ratio is low.

The paragenesis of the minerals combined from these two localities is tabulated:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recrystallization</td>
<td></td>
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<tr>
<td>Brecciation</td>
<td></td>
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<tr>
<td>Silicification</td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td>__</td>
</tr>
<tr>
<td>Carbonate</td>
<td>___</td>
</tr>
<tr>
<td>Pyrite</td>
<td>___</td>
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<tr>
<td>Galena</td>
<td></td>
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<tr>
<td>Tennantite</td>
<td>___</td>
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</table>

Prospects East and North of the Mudsill Mine.—About half a mile east of the Mudsill mine, a prospect has been examined in which the mineralization occurred along minor joints at the top of the Dyer formation. These mineralized joints strike northeast.

The ore is considerably oxidized but enough has escaped to show that the principal minerals were galena and carbonate. In polished section, galena shows oxidation along cleavage directions and between boundaries of crystals. There is no tennantite associated with the galena and oxidation has not produced copper stains.
North of the valley of Spring Creek, 450 feet east of the London fault, and about midway between the Mudsill and Sherwood mines, a short adit (caved portal) enters the Leadville limestone and trends northward into the hillside. The sedimentary beds are downbent on the west limb of the London anticline at this point. East of the portal, 100 feet, a mineralized fissure striking N 40°W and dipping 60°NE has been noted. Mineralization at this point has been slight, if the few specimens found on the dump are a criterion. The only mineral of epigenetic origin is pyrite, while the rest of the material is either original dolomite or dolomite which has recrystallized in situ.

Veinlets of pyrite, shown in Figures 25 and 26a, interlace the dolomite and are typically about one millimeter in width. The grain size of the pyrite varies between 0.05 and 0.5 millimeters. Where several veinlets approach one another the country rock, which has uniform grain size about 0.08 mm., has recrystallized into masses in places where the grain size is between one and two millimeters. The recrystallized material is much clearer in transmitted light as shown in Figure 26a. Bordering many of the pyrite veinlets are narrow zones less than 0.1 mm. wide, which contain clear carbonate. The zones cut the carbonate of the country rock in such a way that one portion of a tiny grain may be clear
Veinlet and cross-section of ring-veinlet of pyrite in the Leadville limestone. Adit, north of Spring creek, reflected light, x 50.
Figure 26

a. Leadville limestone containing pyrite veinlets (black). Dolomite of the Leadville is dark-colored, while vein margins are light. Coalescing veinlets surround areas of light carbonate which have recrystallized to larger grain sizes. Adit, north of Spring creek, plane light, x 51.

b. Leadville limestone transected by apex of veinlet which contains medial pyrite outside the photographic field. The veinlet (light) has its grains in optical continuity with the unaltered Leadville limestone. Adit, north of Spring creek, plane light, x 210.
carbonate, while the rest of the grain is the original darker carbonate. Optical continuity between the two portions of the grains is maintained. Elsewhere, a tiny pyrite veinlet may become discontinuous or peter out but the zone of clear carbonate may persist, suggesting the possibility that the solutions which cleared the country rock of its impurities were more pervasive than those which deposited pyrite. The recrystallized carbonate which is present in larger grain sizes has formed in part, at least, subsequently to pyrite. Figure 26b shows a portion of a veinlet beyond the extent of pyrite with veinlet walls lying within carbonate grains, and with optical continuity between veinlet and wall. This is probably the weakest type of wall-rock alteration manifested in the district. It is to be understood, moreover, that this in no way resembles the so-called 'zebra rock' or other types of recrystallization. There is no white carbonate in these specimens or suggestions of linear structures; they are merely pyritized dark dolomite with accompanying small masses and narrow seams of carbonate of recrystallization derivation.

There are numerous prospects at the head of Spring Creek and on the ridge overlooking Little Sacramento gulch and the Sherwood mine. In a general way, these show various degrees of recrystallization of the dolomitic country rock,
with quartz present in crystalline form rather than jasperoid, as well as pyrite, galena, oxidation stains of copper, and brecciation. Barite is conspicuous by its scarcity. The typical gangue is dolomite, moderately recrystallized. Prospecting in this area has been in hopes of finding duplication of the Sherwood and Mudsill orebodies but has been unsuccessful. The majority of the prospects are situated on the western limb of the anticline, where a narrow zone of Leadville limestone outcrops parallel to the fault and some 400 feet east of it. The Leadville has been almost completely eroded where the beds flatten out along the anticlinal axis.

The Sherwood Mine.

The Sherwood mine is located on the south side of Little Sacramento Gulch, 200 feet above the stream. It is seven miles by road from Fairplay to the mine, but the last two miles are impassable to automobiles. The mine is reputed to have had a production of $50,000, principally from silver. The workings are inaccessible but abundant evidences of the character of the hypogene mineralization are to be found on the dump.

Geologically, the mine is situated on the west limb of the London anticline about midway between the anticlinal axis and the London fault. The workings, three adits, enter the hillside at the base of the Weber(?) formation and penetrate
the Leadville formation a short distance from their portals along their southeast bearing. The mineralization occurred at the top of the Leadville. West of the mine there are successively: Weber(?) shales, gray porphyry, Weber(?) shales, and then the beginnings of a thick section of coarse grits. The change from shales to grits is hidden by soil but is thought to indicate the location of the London fault as coarse grits are typically absent in the lower part of the Weber(?) formation. The flexure east of the mine is relatively compact, and the sediments take their normal easterly dip a few hundred feet distant.

A group of prospect pits trend N 45 W along a sheeted zone and contain fractures striking N 60 W, dipping 80 NE. The area is complex structurally, as are all areas close to the London fault. A major cross-break exists a few hundred feet south of the mine which apparently has displaced the axis of the anticline and perhaps even the fault. It trends approximately east-west. Similar cross-breaks are found elsewhere in the district and in the Alma district north of London mountain where they displace the fault.

As far as could be ascertained, the formation of the ore can be related to fissures, auxiliary to the London fault but which trend northwest, in contradistinction to the majority of the mineralized fissures in the hanging wall of the fault which trend north or northeast.
The ore replaced the Leadville limestone. In places the visible ore minerals, pyrite, sphalerite, galena, and tennantite, are so closely intergrown as to have the semblance of massive replacements yet closer inspection shows unreplaced limestone in easily recognized fragments, and veinlets of the ore minerals, especially galena, transect these limestone fragments. Elsewhere, pyrite is observed individually disseminated in limestone, in veinlets composed of irregularly disposed grains, and in intergrowths of vein quartz and coarsely crystalline pyrite.

The principal gangue minerals are carbonate and quartz, and there are comparatively little of them in the ore itself. Part of the limestone has been recrystallized, but it is as common to note contacts between ore and unaltered limestone as otherwise. There is no barite.

The bulk of the specimens collected from the lowermost mine dump shows the country rock in various stages of recrystallization, an abundance of pyrite, associated with quartz, and not much sphalerite, galena, or tennantite. The specimens from the upper dump, 120 feet higher on the cliff, contain sphalerite, galena, tennantite, and subordinate pyrite associated with original limestone. The different types of ore may represent different locations within the mine. It would be interesting to determine in the mine if
a structural significance is attached to this difference, as so far as the writer is aware no distinctions between mineral facies have been noted within a single mine of this type, either in the Alma district or along the hanging wall of the London fault.

A specimen of 'zebra rock' gathered in the vicinity of the mine shows interesting relations. Megascopically, a sub-parallel arrangement of alternating blue and white dolomitic lenses, 1 to 3 mm. wide, and having irregular contacts with one another, is observed. The bluish zones, although partially recrystallized, have a finer grain size than the white and both are cut by later veinlets of white dolomite, the later dolomite in places occupying fractures of small displacement as shown in Figure 27a.

Microscopically, the separate bands are readily distinguishable. The recrystallized layers that have retained the blue color of the original rock consist of intergrown dolomite crystals of average size, 0.1 mm., while the layers which are white have recrystallized to average grain diameters of 0.3 mm. Here and there are more sharply defined bands, which though of the same dimensions, crystallinity, and arrangement, seem to have formed after the 'zebra' structure. These are characterized by sharp contacts with the bluish material and under the microscope one border of a band usually has a thin opaque selvage between it and the blue
a. Zebra rock. Recrystallization of original dark dolomite of the Leadville limestone into sub-parallel stringers of impurity-free white dolomite. Later veinlets cutting the zebra structure are seen. Sherwood mine, incident light, x 5.

b. Veinlet of late dolomite (horizontal) with branch veinlet (inclined) offsetting zebra structure (vertical). Dark material is impure Leadville limestone. Sherwood mine, plane light, x 31.
dolomite. The selvages are about 0.01 mm. wide and probably could be termed stylolites of hydrothermal origin. Veinlets of micro-crystalline quartz and dolomite transect the above structures, Figure 27b. A latest generation of dolomite occupies minute fractures which displace the earlier structures as much as one centimeter.

The development of the zebra rock took place as follows: 1) Initial recrystallization of the rock in the presence of small amounts of transient solutions which had the power to remove some of the impurity content, (2) Where solutions could remove material, sub-parallel and closely spaced zones of white dolomite formed, and within these zones recrystallization was more effective, 3) Later recrystallization in the presence of solutions which removed dolomite but did not transport the remaining impurities leaving minute selvages, 4) Introduction of quartz and dolomite into small fissures, 5) Formation of dolomite along fractures which displaced earlier structures.

The complete mineralogy of the deposit is: pyrite, sphalerite, galena, chalcopyrite, tennantite, argentite, jasperoid, quartz, manganiferous ankerite, dolomite, and limestone. These will be discussed individually below.

Pyrite occurs principally in two manners. It comprises the bulk of the ore specimens found on the lower dump of the Sherwood mine, associated and intergrown with quartz.
The microscopic relations of this type indicate that for the most part, the deposition of the pyrite succeeded that of quartz. The other sulphide minerals are observed replacing pyrite and filling small fractures within it. Figure 28a illustrates the typical pyrite-sphalerite relations. One centimeter is the limit of pyrite crystal size. The typical habit is euhedral. It is also observed in disseminated crystals in original or recrystallized limestone, in most places associated with small amounts of quartz. The former occurrence is as massive replacement of original material by quartz and pyrite, the latter is about equally divided between disseminated replacements of limestone and cross-cutting veinlets which may, however, be primarily of replacement origin. A small number of veinlets composed of microcrystalline pyrite and quartz have been noted cutting sphalerite, Figure 28b. Their formation preceded the deposition of galena and indicates a minor period of later pyrite deposition.

Sphalerite is as abundant as pyrite and the two constitute about 75% of the sulphides present in these ores. The sphalerite is in massive intergrowths, with maximum dimensions of cleavage surfaces about one centimeter in size. It is of a gray-brown color, which is not to be confused with the dark brown color of marmatite from the Tri-State district. Qualitatively, iron is present. Elsewhere in the district, sphalerite is distinctly green. Sphalerite replaces
a. Pyrite and quartz cut by veinlet of sphalerite. p - pyrite, s - sphalerite. Sherwood mine, reflected light, x 25.

b. Sphalerite (gray) veined by a later generation of fine-grained pyrite (white). Sherwood mine, reflected light, x 140.
a. Sphalerite (black) within brecciated and unrecrystallized Leadville limestone (dark). Sherwood mine, incident light, x 5.

b. Leadville limestone (dark) cut by early dolomite veinlets (v), in turn offset and cut by fractures filled with later dolomite (d) and sphalerite (black). The sphalerite replaced the unrecrystallized country rock adjacent to the fractures along which it formed. Sherwood mine, plane light, x 31.
pyrite, quartz, and limestone. Where observed in replacement relations with unrecrystallized limestone, small areas of dolomite are noted adjacent to sphalerite. Under the microscope, many of the limestone masses which it has partially replaced are angular, and the relations of sphalerite to carbonate veinlets indicates that the solutions from which it precipitated entered a brecciated limestone, the deposition of sphalerite having aided in cementing the rubble by effecting partial replacement of the limestone.

The sphalerite is intimately associated with dolomite veinlets (d of Figure 29b) which probably represent recrystallized and transported country rock dolomite. Both sphalerite and its associated dolomite formed later than other veinlets of dolomite in the limestone (v of Figure 29b). In addition there are small masses of dolomite adjacent to sphalerite which have been recrystallized in situ. At contacts between sphalerite and limestone there is present in most places a narrow rim of opaque material presumably consisting of the impurities of the limestone which the sphalerite-forming solutions did not have the power to transport.

Galena has, for the most part, replaced either sphalerite or limestone. In the limestone, its typical replacement relations are indicated in figure 30. The small veinlets usually appear unrelated to fractures in limestone,
Figure 30

a. Replacement veinlet of galena (white) within limestone (dark). The irregular sharp contact indicates selective replacement of individual carbonate grains. Sherwood mine, reflected light, x 140.

b. Typical marginal replacement of limestone by galena. The reticulate structure of galena in the limestone is controlled by carbonate grain boundaries. Dark - limestone, s - sphalerite, g - galena. Sherwood mine, reflected light, x 140.
although in places it has formed along dolomite veinlets, with its later age apparent. It is thought that the carbonate in these veinlets is identical with that which formed in advance of the zinc-bearing solutions as galena cuts both sphalerite and dolomite. Microchemical tests failed to indicate a silver content, and etching did not reveal the presence of disseminated silver minerals within galena.

The relations between tennantite and galena are not susceptible to exact interpretation. In places, where galena is subordinate, a poorly developed pseudo-eutectic structure has developed in which it appears that galena formed later (Figure 31a), other places where galena is more prominent the same structure appears to indicate that tennantite was the replacing mineral. As a rule tennantite is observed in irregular masses with smooth contacts within larger masses of galena as illustrated in Figure 31b. Galena, moreover, is present without tennantite but tennantite is everywhere observed in intimate association with galena. Certain minute relations, where tennantite veinlets cut galena are also suggestive. The weight of the evidence, throughout the specimens from this mind as well as from the rest of the district, is favorable to the conception of the period tennantite deposition overlapping in age that of galena. Dr. Waldemar Lindgren, who was kind enough to view the writer's sections, stated "tennantite is the later mineral"
Figure 31

a. Intergrowth of galena (white) and tennantite (gray) in which tennantite is the more abundant mineral. Black spots are imperfections in the section. Sherwood mine, reflected light, B filter, x 140.

b. Typical relations of sphalerite (s), galena (g), and tennantite (t). Tennantite is exclusively confined within masses of galena. Sherwood mine, reflected light, B filter, x 140.
An insignificant amount of chalcopyrite has been noted. It is not associated with small tennantite masses within galena, but with veinlets of tennantite (with minor galena). It has been formed in tiny masses along the veinlets, especially where they are a trifle enlarged.

Argentite, in very small amounts and of microscopic dimensions, has been noted here and there within tennantite. It replaces tennantite, particularly at contacts with galena. It is not associated with any supergene products, does not follow fractures, and is everywhere associated with tennantite. It is considered hypogene.

A picked sample of the ore yielded an assay of 192 ounces of silver to the ton (assay by Michael Kuryla). It was chosen for its comparatively high content of tennantite, low galena, and no apparent argentite. About 60% of the sample consisted of sphalerite. Tennantite from this specimen, as from others in the district in which argentite was not visible, gave a microchemical test for silver. It is the opinion of the writer that tennantite is argentiferous, as the approximately 0.8% of metallic silver indicated by the assay would require an argentite content of more than 1%. It is unlikely that this amount could escape notice, and those specimens containing the most argentite are estimated to contain considerably less than 1% of it.

The specimens examined indicate that sphalerite and
pyrite comprise 75% of the metallic minerals, with the galena content being between 15 and 20%, with the remainder consisting of tennantite and small amounts of chalcopyrite and argentite.

The gangue mineralization is subordinate to the metallization at this property. There is evidence of silicification, and vein quartz is typically associated with pyrite. The principal gangue material is original limestone or subordinate amounts of its recrystallized facies. In addition to dolomite of recrystallization derivation, there is a small amount of manganiferous ankerite. With the exception of a slight quantity of dolomitic carbonate and quartz which cut some of the ore minerals, the gangue represents an early stage in the mineralization.

The jasperoid observed here weathers gray. Microscopically, it presents features which serve to distinguish it from other bodies of jasperoid. The matrix of the jasperoid, consisting of ultra-fine-grained silica, contains rounded areas of coarsely crystalline quartz in places with associated carbonate. Veinlets of microscopic width composed of carbonate and quartz cut both siliceous matrix and crystalline nodules of quartz. Pyrite has formed along these veinlets and in irregularly disposed aggregates of euhedral grains. Figure 32 indicates the typical relations that have been observed.
The matrix of the jasperoid presents a finer texture at this locality than elsewhere in the area. Much of the material is between 0.002 and 0.005 mm. in size although some is finer and there is an irregular distribution of slightly larger grains. All the readily resolvable grains show undulous extinction under crossed nicols. In places, the same undulatory shadow is continuous through several adjacent grains. The texture of the matrix is illustrated in Figures 32 and 33.

Two textures of quartz are present within the rounded areas. The margins of these masses, in most places, consist of an allotriomorphic intergrowth of fine grains with average grain size 0.02 mm. The centers of these masses contain crystalline anhedral quartz of grain size varying from 0.1 to 0.5 mm. In places, the finer material is not continuous around the margin of a mass, and the coarser material is in contact with the matrix. Contacts between matrix and crystalline quartz of the nodules are not gradational (Figure 33), although/microserrate structures along some of the contacts are suggestive.

It is believed that the initial stages of the silicification produced the jasperoid matrix and that at some later time partial recrystallization ensued which did not greatly affect some of the matrix. The coarsest recrystallization took place around randomly distributed centers
a. Texture of jasperoid. The dark material shows the fine-grained character of the matrix while the light indicates centers of recrystallization into coarser quartz. A later veinlet of quartz and carbonate is observed at the upper right. Pyrite (black) is present in the lower portion of the photograph. Sherwood mine, plane light, x 31.

b. Same field as Figure 32a. Although overexposed, the coarser grain sizes within the nodules are seen. Sherwood mine, crossed nicols, x 26.
Figure 33

Detail of contact between jasperoid (right) and quartz of one of the nodules (left). Quartz of the jasperoid exhibits prominent undulous extinction. Sherwood mine, crossed nicols, x 200.
in the matrix and was followed by the introduction of quartz and carbonate in veinlets. Pyrite formed subsequent to recrystallization.

Vein quartz, more coarsely crystalline than other types of quartz previously described, is intergrown with pyrite in relations which indicate that pyrite deposition ceased after quartz. Its individuals are in places about a centimeter in diameter. Lines of dusty inclusions are apparent. It shows minor strain effects.

The manganiferous carbonate has not been observed in relations to ore minerals or quartz. It comprises but a small part of the specimen which contains it. Presenting a distinct pinkish color, it has been replaced to great degree by later carbonate. One of its indices of refraction, omega, is 1.697 ±0.002 which corresponds closely with that of ankerite. Microchemically, it yielded a faint test for manganese. Tests for calcium, magnesium, and iron have been obtained, but the material was so impure due to the introduction of other carbonate, that these tests are not distinctive. Its index of refractive, considerably higher than that obtained from any other carbonate in the district, shows it to be of a different species. The test for manganese has not been obtained from other carbonate. It is therefore concluded that this carbonate has a composition of a slightly manganiferous ankerite, formed during an early
stage of the mineralization (at least before much of the other carbonate), and demonstrates a possible relation to a zonal conception.

Massive recrystallized dolomite presents no features which distinguish it from similar rocks elsewhere in the district. Unrecrystallized limestone, however, which is abundant in the ore in angular fragments and is the most common gangue material, contains zones and masses of recrystallized material which appear to be most closely related to the solutions which have deposited sphalerite. Sphalerite replaces recrystallized dolomite, original limestone, pyrite, and quartz. Where observed replacing original limestone, a narrow selvage of carbonaceous material is present at the sphalerite-country rock contact. It is thought that the slight recrystallization, which is not present unless associated with sphalerite, occurred previous to and during the sphalerite deposition, but that sphalerite completed its formation after recrystallization ceased as indicated by evidences of replacement of carbonate by sphalerite.

Carbonaceous partings have been formed which are readily visible in hand specimen. Those noted are present in limestone which has undergone partial recrystallization but has retained its original color. It is probable that these, contrasting to the microscopic selvages similar to stylolites which have been described previously as marginal
to recrystallized carbonate and sphalerite, represent production of carbonaceous matter caused by folding or faulting.

To summarize the Sherwood mineralization: pyrite, sphalerite, galena, and tennantite, with minor amounts of chalcopyrite and argentite, in a gangue of quartz, manganeseiferous ankerite, and dolomite have replaced the brecciated upper part of the Leadville limestone on the west limb of the London anticline. The ground in the area is broken up by fractures and it is likely that mineralization was, at least in major part, localized by the presence of fissures although underground workings were inaccessible. Silicification and recrystallization of the Leadville formation occurred, and pyrite typically associated with a small amount of vein quartz is noted in greatest development as replacements of the recrystallized facies. The bulk of the sphalerite is associated with fragmented but largely original limestone as breccia fillings and replacements. It has been impossible to determine whether any of the dolomitic carbonate represents introduction of material from outside sources. It is probable that where it appears to have been introduced, it has merely been transported a short distance and was derived from the Leadville formation.

The paragenesis has been found to be:
Recrystallization
Breciation
Silicification
Manganiferous ankerite
Dolomite
Quartz
Pyrite
Sphalerite
Galena
Tennantite
Chalcopyrite
Argentite

Prospects Between Sherwood and Sacramento Mines.

Prospect East of the Sherwood Mine.--A small fissure which strikes due north and dips 60° W has a 60-foot adit driven along it in the base of the Dyer formation, a few feet above the top of the Parting quartzite. It is situated at about the crest of the anticline east of the Sherwood mine a few hundred feet. The Dyer has not been recrystallized nor silicified. Veinlets of quartz and dolomite cut the country rock, in places the dolomite making out into small replacements which are typically vuggy. Sphalerite veinlets transect dolomite, while galena is found both within carbonate veinlets and in vugs. Where present in vugs, it formed on carbonate. One crystal, 0.5 cm. in size, has the cube truncated by minute octahedral faces. Such developments are rather characteristic of galena formed at relatively low temperatures, such as the Tri-State galena. This was the only octahedral galena observed, however.
Prospect, Top of Cliffs, South Side of Little Sacramento Gulch.—This property is situated about midway between the Sherwood and Sacramento mines. The mineralization occurred near the top of the Leadville limestone, and was related to a series of small north-trending fissures. The ore is considerably oxidized as glaciation did not reach this spot. A number of disseminated pyrite grains, about 0.5 mm. in size, and a slight amount of galena are the only sulphide minerals observed. The presence of abundant copper stains, however, suggests the primary mineralization contained tennantite as well.

Recrystallized carbonate, barite, and quartz constitute the gangue. The limestone here has undergone thorough recrystallization to coarse textures. Under the microscope, recrystallized rock fragments are seen cemented by quartz and dolomite. The aggregate which has effected the cementation contains a multitude of fine clastic carbonate remnants. There is also some typical vein quartz which has been replaced by galena. The ore minerals developed in the matrix of the cemented breccia. Relations of barite are unknown other than that it was an early mineral. The sequence and the appearance of the minerals at this locality are similar in general aspect to the Sacramento ores.
Recrystallized Leadville dolomite (L) in brecciated fragments cemented by quartz (q) and dolomite. About half of the fine-grained cementing material is quartz. Much of the cementing dolomite appears to be fragments of the Leadville. Strain effects are visible in the coarser fragments. Prospect, top of cliffs, south side Little Sacramento Gulch, crossed nicols, x 26.
Sacramento Mine.

The Sacramento Mine has been the largest producer in the Horseshoe-Sacramento area. Its production has been reported at $200,000, the principal values having been derived from silver.

The mine is situated on the southeast flank of the low ridge between Little Sacramento gulch and Spring Valley. A passable road connects the mine with the town of Fairplay, 7 miles distant. All openings into the mine have caved and the old buildings are in the last stages of deterioration as it has been some 40 years since the mine was actively producing. Numerous dumps about the old caved shafts and adits testify as to the considerable magnitude of the operation as compared with others in the district.

The immediate country rock is the Leadville limestone which is overlain by one to six feet of the basal shales of the Weber(?) formation. Above this slight thickness of shales, a thick sill of quartz monzonite porphyry outcrops east of the mine. The porphyry and the shales have been eroded in the neighborhood of the mine. The Sacramento mine lies 3,500 feet east of the London fault. Numerous small faults approximately parallel to the London fault have been noted on the ridge between the mine and the fault although only the more conspicuous have been mapped. A cross-break
of questionable magnitude has been found east of the fault on the north slope of the ridge. This is the same cross-break which has been noted in the discussion of the Sherwood mine. The ore bodies were contained in the upper part of the Leadville formation as indicated by the character of the material on the dumps. A stope map, not included herewith, shows that all mining took place up the dip to the west of a steep fissure which strikes N 30°E.

The only examples of the character of the ore in the Sacramento mine were found in a small sorted heap on one of the westernmost dumps. Veinlets of galena, 3-5 millimeters wide, are observed within a silicified gangue which has been partially replaced by barite and carbonate. Although this paucity of metallic minerals presents a serious obstacle to the study of the Sacramento ores, an excellent suite of gangue mineral specimens has been obtained in which the relations are clearly defined.

The principal gangue minerals are barite, silica, and rhombohedral carbonates. Other minerals, related to the oxidation of the deposit are anglesite, cerussite, gypsum, limonitic material, and aragonite.

Barite occurs in fine to relatively coarse crystalline intergrowths, the plates varying from 0.1 inch to 1.5 inches in size and also as small, more or less independent, platy crystals replacing silicified or partly silicified
Leadville limestone, with crystal terminations projecting into cavities here and there.

Three types of silica are megascopically defined. The earliest-formed consists of chalcedonic silica which silicified the Leadville limestone with preservation of texture and the original dark blue color. Where this process occurred on a larger scale as is manifest elsewhere in the district, a massive bed of typical jasperoid of deep red to purple color might be the result. The second type of silica occurs as veinlets and replacement segregations of quartz. The quartz cuts the earlier-formed chalcedonic silica in veinlets with well-defined walls. The veinlets may coalesce and form small masses of milky quartz within the chalcedonic silica but always distinguishable from it by color and texture. As in the case of the veinlets of this same generation of quartz, the masses of milky quartz which presumably formed by replacement of the chalcedonic silica, are characterized by sharp boundaries. This period of silica introduction occurred after the bulk of the dolomite recrystallization took place as shown by many of the specimens where masses of milky quartz have replaced dolomite. Minute crystals of clear quartz which are observed in vugs may represent either the second or a later stage of silica introduction.

Microscopically the following primary minerals have
been discerned: pyrite, galena, tennantite, barite, quartz, and dolomite. It is not unlikely that some sphalerite was originally present, although secondary zinc minerals could not be found in the specimens.

The ore minerals have been noted in very small quantities. The deposit escaped the effects of glaciation, and as it lay as a bedded replacement close to the pre-glacial surface, it underwent considerable oxidation. It is probable that the ore as mined was largely of the oxidized type, certainly what traces of ore remain on the dumps indicate intense weathering. A few corroded remnants of pyrite have been observed within galena. Its grain size is about 0.1 mm. There is some limonitic material in the oxidation products, but it is not enough to indicate the oxidation of a heavy pyritic deposit.

Galena is found in narrow irregular veinlets intergrown with barite and quartz. Curiously, the relative ages are indeterminate. Several microscopic areas of tennantite, too small for microchemical tests, have been observed within galena. Much of the galena is altered to anglesite along vein margins and cleavages of individual grains.

Masses of dolomite which have retained their original color but have been recrystallized to various degrees are observed as angular fragments cemented by carbonate, vuggy in places. Large masses of this coarsely crystalline
carbonate, observed with limestone show sharp contacts. The carbonate does not contain iron microchemically, and its refractive index corresponds exactly with that of ordinary dolomite. Some of the cleavage surfaces on the large masses are several centimeters in size. Masses of coarse quartz replace dolomite, but are in turn replaced by a later generation of carbonate as shown in Figure 35a. The quartz shows slight strain effects and evidently had been fractured before the introduction of the later carbonate which formed along grain boundaries and in veinlets having geometrical pattern within single grains. Replacement took place along the veinlets. This type of quartz contains indeterminate dusty inclusions.

Carbonate which cuts quartz, Figure 35a, has a slight iron content. It weathers brown, demarcating it from the earlier generation, and has a higher refractive index. It corresponds to a ferruginous dolomite.

Barite formed earlier than vein quartz but its relation to carbonate are not apparent. It is present in more abundance at the Sacramento mine than elsewhere in the district if the Nelson claim on Sheep Mountain is excepted. Microscopically, its plates which are in contact with quartz, everywhere have irregular basal planes. The terminations of the plates in most instances are even more irregular.
a. Geometrical array of ferruginous dolomite veinlets in vein quartz (black and gray). The quartz shows slight strain effects. Sacramento mine, crossed nicols, x 26.

b. Corroded remnants of a single barite crystal (gray) within a crystal of vein quartz at extinction position (black). Sacramento mine, crossed nicols, x 200.
Small areas of barite within several quartz individuals extinguish simultaneously under crossed nicols indicating replacement of barite by quartz. Furthermore, barite cleavages appear to have exerted control on the distribution of the quartz. Figure 35b shows corroded remnants of a barite crystal within a single crystal of vein quartz.

Discussion of the silicification at this locality has been purposely postponed until last as it deserves a few qualifying remarks. The first apparent effect of the siliceous solutions was to produce a jasperoid (Figure 36a & b) which retained an appreciable amount of the original carbonate as a multitude of minute inclusions within quartz, (Figure 37a). The grain size of the jasperoid averages 0.1 mm. The texture is allotriomorphic but here and there grains show euhedral aspect, with zoned carbonate inclusions, and enlarged by later accretion. Typically, however, the carbonate blebs are randomly arranged throughout quartz. There are but few traces of undulous extinction.

The type of quartz just described composes about 50% of the section examined. The rest consists of clear quartz containing but a small amount of dusty inclusions, similar to the vein quartz which replaced dolomite at this mine (Figure 35a). Its grain size as veinlets and segregations in the jasperoid varies from 0.2 to 1.0 mm. Where associated with dolomite, it is much coarser, however. The
a. Structure of jasperoid (dark). Traces of crystalline carbonate are observed. A veinlet of clear quartz (white) cuts the structure and accompanying areas of clear quartz show replacement. Sacramento mine, plane light, x 31.

b. Texture of jasperoid. Same field as a. The carbonate inclusions within the fine-grained quartz of the jasperoid are visible. Sacramento mine, crossed nicols, x 26.
a. Structure of jasperoid showing a multitude of irregularly distributed carbonate inclusions. Sacramento mine, crossed nicols, x 200.

b. Veinlet of ferruginous dolomite cutting jasperoid remnants within coarser quartz (white). Replacement by the later quartz has proceeded to a greater extent than in field of Figure 36a. Nodular remnants of dark jasperoid are typical. Sacramento mine, plane light, x 31.
interesting feature presented by the two types of quartz is the aspect of their contacts. The earlier quartz is in small nodular masses, everywhere rounded and both bordered and transected by the later. Without crossed nicols, the curious relations are well-displayed as shown in Figure 37b.

Recalling the features of the various silicified limestones which have been described, the similarity of the Sacramento jasperoid to that developed east of the Mudsill mine may be noted. That also contained suggestions of slight amounts of early idiomorphic quartz. As is discussed elsewhere in this report, there are different types of silicification which not correlating with host-rock, presumably indicate variations in the solutions which caused the formation of the jasperoid.

The available data indicate the following paragenesis:

<table>
<thead>
<tr>
<th>Recrystallization</th>
<th>Brecciation</th>
<th>Silicification</th>
<th>Barite</th>
<th>Dolomite</th>
<th>Quartz</th>
<th>Ferruginous dolomite</th>
<th>Pyrite</th>
<th>Galena</th>
<th>Tennantite</th>
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Dream Mountain Prospect.

Dream mountain is a small ridge located on the south side of Big Sacramento gulch. The cliffs on the north side
of Dream Mountain show a fine section of the lower Paleozoic rocks bent into the anticlinal flexure east of the London fault. Locally, the flexure is known as the Sacramento arch. The prospect is situated on the south side of the ridge, 350 feet S 50°E of the peak and about 1000 feet east of the London fault. The workings evidently follow a small fissure trending approximately north-south. In the Dyer formation a few feet below a sill of Gray porphyry.

The visible mineralization consists of carbonate, barite, galena, and quartz. There are traces of copper stain in the oxidation products, but no visible tennantite. Oxidation at this point has been thorough, yet there is but slight development of iron oxide, indicating that the primary pyrite content was negligible. In appearance, the ore resembles those of Sheep Mountain. Barite and galena are associated, and the vein quartz, in places as coarse as 0.3 x 1.0 inch, seems to have been a late product, though not necessarily of post-galena age.

Microscopic relations are intermediate between those of the barite type described from the Wagner claim and the Brown's pass prospect. The majority of the quartz grains have sizes between 0.1 and 0.5 mm. The larger may have zonally arranged carbonate inclusions but the development
of them is not as prominent as at the Wagner. Recrystallized dolomite, some of which is slightly ferruginous, is earlier than both quartz and barite. The clastic appearance of some of the masses indicate brecciation with subsequent introduction of barite and quartz into the fractures. Barite is observed replacing carbonate and both are replaced by quartz.

This is the only barite occurrence in the area north of Little Sacramento Gulch, excepting of course, that far to the east which is shown to be associated with the projections of the Hock Hocking-Orphan Boy veins of the Alma district.

Majestic Adit.

The Majestic adit is located about 300 feet east of the London fault on the south side of Big Sacramento gulch. At this point the sedimentary beds dip steeply to the west. The portal is at the base of the Weber (?) formation but a mine map shows that the workings must have immediately entered the Leadville formation. The general trend of the workings (from an old map dated 1910, not included herein) is southeast. The exploration totaled 1200 feet.

The type of abandoned machinery in the boiler room indicates that the major part of the activity took place at about the turn of the century. The exploration evidently
was directed towards finding orebody similar to the Sherwood, some two miles south, as the general structural relations which obtain at the Sherwood are duplicated here. From the character of the material on the dump, the search was futile. No production record of this property has been recorded, not does the mine map show any stopes.

It could be almost said that there are no indications of mineralization at this point. The only traces of it are pyrite and quartz and only one or two specimens of these could be found. Microscopically, a little recrystallization of limestone is indicated. Euhedral pyrite grains of maximum size 1.0 mm., are scattered throughout the recrystallized limestone and are contained in quartz veinlets. Where observed in quartz, the pyrite euhedrons have been corroded, and sharp crystal faces are scarce while the pyrite in the limestone shows sharp angles. From this evidence, it is suggested that quartz deposition overlapped or succeeded that of pyrite. A few veinlets of ferruginous carbonate cut the other minerals.

Prospect in London Fault, Pennsylvania Mountain.

The London fault cuts through Pennsylvania Mountain opposite the London mine. On the upper cliffs, the location of the fault is discernable, but with the exception of a short extension close to the north brink of the cliffs,
it is not possible to trace it across the flat crest of the mountain. There are several prospect shafts in the fault zone itself where it is exposed near the north edge of the mountain. Plate II, F indicates the attitude of the fault at this point where the fault zone is about 150 feet wide.

One of the prospect shafts contained a mineralization of abundant quartz and pyrite; one tiny cube of galena was noted. The material is thoroughly oxidized, so it was indeed fortunate to have found any traces of hypogene metallic mineralization. The material is a highly silicified breccia composed of small angular fragments of jasperoid and White porphyry cemented by quartz.

Under reflected light, pyrite grains varying in size from less than 0.01 mm. to 1.0 cm. are seen to have been fractured, and then veined and replaced by quartz as shown in Figures 38a & b. It is in thin section that the most interesting relations are displayed. The hydrothermal minerals observed are quartz, sericite, and pyrite.

There are four types of quartz present. A fine-grained type, which resembles that of the Sacramento mine as far as ghost structures are concerned and that of the Sherwood jasperoid in texture, has grain sizes at about the limits of microscopic resolution. A coarse type, which
a. Fractured pyrite (white) veined and replaced by quartz (dark). London fault zone, Pennsylvania Mountain, reflected light, x 25.

b. Fractured pyrite (white) and later quartz. London fault zone, Pennsylvania Mountain, reflected light, x 50.
anyone would admit bears a marked resemblance to vein quartz, is also present. It contains rows of dusty inclusions, has grain sizes over 1.0 cm., and shows marked strain effects. Small nodular masses within the fine-grained quartz are cut by the coarser quartz, indicating its later age. A third type, composed of grains about 0.01 mm. in diameter, cuts both the others. It fills fractures in the coarse quartz, and has formed marginal veinlets to many of the grains. The last type consists of the quartz which seems to have effected the cementation of the breccia. Most of its grains average about 0.1 mm. in size. It is intergrown in allotriomorphic texture around the cataclastic fragments of the breccia. The brecciated fragments other than pyrite, jasperoid, and fragmented coarse quartz, are highly sericitized White porphyry and rounded quartz grains occurring individually or in aggregates which were originally contained in some of the arenaceous rocks cut by the fault plane. Sericite occurs in tiny veinlets and around the margins of coarse quartz grains.

No matter what interpretation is placed on the occurrence of this type of material in the London fault zone, it clearly is different than the breccias observed further to the south which did not contain sericite. It is most reasonable to consider that the broken ground produced by
Fine-grained jasperoid (lower left) in contact with strained vein quartz (upper right). Both types are cut by later veinlets of microcrystalline quartz. London fault zone, Pennsylvania Mountain, crossed nicols, x 26.
the fault movements in places either did not cut the forma-
tions which were favorable to the production of heavy clay
gouge, or that the auxiliary structural features which ac-
companied the fault permitted migration of solutions, there-
by forming a non-valuable mineralization a considerable
vertical distance above the apex of London vein structures.
On the other hand, if one prefers to consider this mani-
festation as faulted London vein material, it must be
remembered that the great fault movement occurred before
mineralization and that the known London vein structures
are raking in such an attitude as to be at least 2,000 feet
below the top of Pennsylvania Mountain. That the minerals
have been fractured by faulting and that a breccia is
present is not denied, but these minerals did not form in
the London veins themselves, but represent vertical leak-
age of mineralizing solutions to higher regions, and, after
deposition and fracturing have been cemented by later solu-
tions which followed similar paths.

Outlying Areas.

Introduction.—With the preceding description, the known
orebodies along the London fault have now been described
(11 & 12). The Leadville authors have described the out-
lying regions of Leadville (6), and Weston Pass (4). The
Hilltop, Peerless, and other mines which are situated at the
head of Four Mile amphitheatre, though topographically a part of the Horseshoe-Sacramento district, have been rightly considered as more closely related to the centers of mineralization at Leadville than to the mineralization along the east wall of the London fault and have been described in that connection. There are a few properties, however, not included in any previous descriptions which are unrelated to the present problem of the mineralization along the London fault, but which merit description.

Prospects south of Hock Hocking Mine.—A valuable mineralization in the Alma district has formed in the hanging wall of the Cooper Gulch thrust fault (11, 101), a low-angle east-dipping thrust which has a maximum stratigraphic throw of 450 feet. The Paris, Phillips, Orphan Boy, and Brownlow mines produced gold ores, while the Hock Hocking mine, at the extreme south end of this group of mines produced silver. At the north end, there are a number of silver mines in the Leadville limestone which, although on the trend of this structure, can be more closely related to pitching shallow anticlines which interrupt the continuity of the east dip of the sediments (11, 123). The total production of these latter counted into the millions, and their ores were quite similar to those of the Sacramento mine.

The prospects south of the Hock Hocking mine con-
stitute the most southerly manifestation of mineralization along this trend. The workings are aligned along a small fissure which strikes N 17° E, and dips 85 NW. The northernmost of these prospects is only a few hundred feet south-west of the Weston shaft of the Hock Hocking mine. The ore consists of brecciated and recrystallized Dyer dolomite, coarse-grained barite, light brown sphalerite, galena, minor coarse quartz, and carbonate. Although the ores are near the top of the Dyer formation and must have been close to the surface during a long period in the later Tertiary, there are but slight traces of oxidation. There is no pyrite in the ores. Copper stains have been noted, however.

Microscopically, carbonate (dolomite) veins and replaces barite and sphalerite (Figure 40a). Galena formed later than barite. To summarize the relations: partially recrystallized dolomite underwent brecciation, and barite and fine-grained dolomite were introduced into the fractured zone, with the deposition of dolomite closing well after barite ceased to form. Sphalerite and galena replaced the minerals of the matrix, and small veinlets of carbonate closed the sequence. Barite is the most abundant epigenetic product.

The Alma authors describe essential features of the mineralization of which this ore is the most remote type. They consider that the center of intensity of deposition
a. Veinlet of dolomite cutting recrystallized Dyer dolomite, barite (crystal), and sphalerite and galena (black). The black rim around the barite crystal and the black patches in the recrystallized dolomite represent galena. Prospects, south of Hock Hocking mine, plane light, x 40.

b. Barite remnants (b) which extinguish simultaneously are shown replaced by later dolomite. Prospects, south of Hock Hocking mine, crossed nicols, x 33.
is in the lower Loveland Mountain area (11, 125-126). They relate the structural location of the deposits to favorable host rocks in the Sawatch quartzite, east of the easternmost branch of the Cooper Gulch fault. The deposits are replacement veins and accompanying narrow replacements of certain horizons. The comparative slight amount of gouge along the Cooper Gulch fault (due in part to the character of the rocks it cuts) permitted migration of mineralizing solutions into the hanging wall. They also suggest that a zonal arrangement in an elongated north-south direction is present, indicated by relative metal content. The dominant metal on Loveland Mountain is gold, while to the south in the Hock Hocking mine, silver and lead are dominant. Accompanying the metallization of gold are abundant pyrite, dark sphalerite, galena, chalcopyrite, quartz, and dolomite. In the prospects described herein, the mineralization is most similar to that at the Hock Hocking mine, which incidentally is the only major producer in this group located in the Manitou and Dyer formations, and represents the southern extension of the ore zone where the conditions of mineralization had lower temperature characteristics. At the Hock Hocking mine, the principal values are silver, whereas the mineralogic indications are that these prospects are relatively poor in silver. As will be shown in the general discussion, one of the suggestions of zonal arrange-
ment of the deposits in the east wall of the London fault is the presence of a lower ratio of silver to lead in those locations thought to be more remote from the 'center'.

The Search Mine.--The Search mine is situated near the head of Big Sacramento amphitheatre several miles west of the London fault. An erosion window has exposed the upper part of the Leadville formation at this point. A thin layer of Weber(?) basal shales overlies the Leadville, and is overlain by two exceedingly thick laccolithic sills of porphyry, one White, one Gray. The location is 0.8 miles north of the Continental Chief mine.

There was no material on the dump that could be with certainty assigned to the Dyer formation and from the length of the rope on the hoist it seems improbable that the shaft has gone deep enough to reach the Dyer formation. Several narrow replacement veins are present near the shaft; they strike N 35°E and dip steeply to the southeast. To the north of the headhouse, 300 feet, a northwest(?) trending fissure contains a mineralization of quartz and pyrite.

The ore found on the dump shows various stages of oxidation. The hypogene mineralization consisted of pyrite, sphalerite, galena, barite, quartz, and carbonate. Sphalerite, galena, and barite are prominent, while the others are inconspicuous--with the exception of the pyrite-silica north of the mine. The barite replaced a brecciated and
silicified limestone, forming radiate platy intergroths whose individual diameters range from microscopic to 1.5 inches. Cleavage faces on galena exceed 1.0 inch. Sphalerite has not been observed in contact with the other sulphides.

The oxidized ores are widely developed, and the only sphalerite noted was contained in a siliceous boxwork as small light yellow kernels. The original content of sphalerite was probably high, as the most abundant product of oxidation is crystalline calamine. There is relatively little limonite, a few traces of copper stain, and anglesite. Cerussite and smithsonite are probably present in greater amounts than the observations indicate. The ores appear to have been massive and coarsely crystalline originally so it is probable that the cavities in which oxidation products have deposited have resulted from meteoric solutions. Calamine however has been observed in replacing relations to barite. This may have been inherited as in places there are suggestions of calamine forming in situ from sphalerite similar to the development of anglesite from galena.

The small fissure to the north of the mine which contains a quartz-pyrite mineralization presents an interesting contrast to the barite-galena-sphalerite mineralization nearby. Replacement of the Leadville formation by fine-grained silica and pyrite along a small fissure was the
initial stage. The quartz grain sizes ranging from 0.1 to 0.5 mm. for the majority. In hand specimen the quartz is slightly bluish in color. All the fine-grained pyrite (1.0 mm. and less) which shows excellent pyritohedral development is confined to masses of this quartz. Later white quartz in straight-walled veinlets cuts the earlier quartz and pyrite, making out into small replacement masses here and there. This is coarse-grained, and in places comb structures and cavities are discernable. Masses of granular pyrite of 1 or 2 cm. diameter appear to be associated with this later quartz generation.

The mineralogic description (6, 231-236) of the ores from the Continental Chief mine, 0.8 miles south of the Search mine, shows that the ores from the two mines are similar in all major respects, if not in minor as well. The only possible difference arises in that the presence of re-crystallized Leadville limestone is not mentioned for the Continental Chief mine, while in the outcrops near the Search property, it has developed extensively.

There is a large block of ground in the area between these two mines which deserves further prospecting. The Leadville formation beneath the crest of the range at this point is at some depth, and covered by great masses of porphyry. The mineralization at both properties is similar, and is related to zones of northeast fissures. The
mineralization at the Search mine is best related to the outer mesothermal zone at Leadville, and because it denotes the former presence of identical metallizing solutions well-removed from the vicinity of the Continental Chief mine, there are strong possibilities that the area between may contain similar ores near the top of the Leadville formation.

Prospects in Four Mile and Horseshoe Amphitheatres.—West of the Sherman fault which displaces the sedimentary beds in the same direction but to a lesser degree than the London fault, are a number of prospects and mines in the upper part of the Leadville formation. The important ones have already been described (6). At the south end of this large amphitheatre, the mineralization took the same form as at the Hilltop and Continental Chief mines, although the amount of mineralization hardly justifies the term ore. Narrow fissures of north to northeast trend influenced the formation of narrow replacement bodies, characterized by quartz, pyrite, barite, and galena. Barite and galena are most prominent. From the size of the mine workings, it appears that the area offered but little encouragement to exploration. The deposits can be classed as outliers of the intermediate mesothermal zone, and structurally more closely related to the Continental Chief and Peerless mines than to those along the London fault.
MINERALOGY OF THE ORES.

Introduction.

As the mineralization in the hanging wall of the London fault is the principal topic of this and succeeding sections, the following descriptions of the minerals pertain only to this area. The outlying areas, the Search mine, the prospects in Four Mile amphitheatre, and the prospects south of the Hock Hocking mine belong to other structural environments and constitute geographical outliers of the critical area. Details of the occurrence of minerals in these localities are to be found in the preceding section.

Metallic Minerals.

Pyrite.--Pyrite is widely distributed throughout the mineralized area although it is subject to variations in amounts and textural characteristics at different places. At some of the prospects, it was not even found although there may have been a small original amount which succumbed early to the oxidation agents without leaving visible relicts.

It is most abundant in the ores of the Sherwood mine where it comprises about 40% of the metallic mineralization. At this place the pyrite, which is intergrown with either quartz or sphalerite, attained its greatest crystalline size of anywhere along the hanging wall zone of the London fault (grain diameter, 1 cm.). Elsewhere, as at the
Wagner prospect group on Sheep Mountain, it is present in fine grains and comprises but a small fraction of the total metallic mineralization. The Sheep Mountain area as a whole, however, is characterized by the paucity of pyrite.

At some of the mines and prospects, the original character and abundance of pyrite could not be completely ascertained due to oxidation. Among others, the Mudsill and Sacramento mines are in this category.

The paragenetic position of pyrite in the mineral sequence is well-established from abundant observations. It formed after deposition of most of the vein quartz but in places, the overlapping age of quartz is suggested by the relations. As an early mineral, pyrite is replaced in most instances by sphalerite. The other ore minerals tended to replace sphalerite or wall-rock rather than pyrite. The only example of a second generation of pyrite is illustrated in Figure 28b. This is from the ores of the Sherwood mine, and the relative amount of late pyrite is negligible. It formed in the interval between sphalerite and galena deposition, as satisfactory relations have been observed showing that galena was later.

Sphalerite.—Sphalerite is not as widely or abundantly distributed as is pyrite. In the Sheep Mountain area it is present in greater abundance than pyrite (Figure 17a) at
the Wagner claim group, but the total amount is, nevertheless, very small. At most places on the mountain, it was not observed.

It is found in greatest abundance at the Sherwood mine where it is estimated to comprise some 35% of the metallic minerals. The thoroughly oxidized remnants of ore from the Mudsill and Sacramento mines contained no sphalerite and there were no secondary zinc minerals noted megascopically or microscopically.

The Sherwood sphalerite is of a grayish brown color in contrast with the sphalerite from the Wagner group which is lighter-colored and grayish green. The Wagner sphalerite appeared yellower in the bright mountain sunlight when gathered than it does at present. Sphalerite from both these localities contains iron but there was no determinable difference in refractive index between the two. Through the kindness of Dr. Richard E. Stoiber, a spectrographic analysis of these two sphalerites was made. The lines of the two spectograms are identical within the quantitative limits of the method employed. This statement refers to minor elements as well as iron.

Sphalerite from all the mines and prospects has a constant niche in the sequence of mineral deposition between pyrite and galena. It typically replaced pyrite, calcareous country rock, or the recrystallized equivalent of the latter.
Galena.—Galena has been observed throughout the area as the most persistent of the ore minerals as it is found in some amounts where pyrite is negligible or lacking (Brown's Pass). This, however, may not be strictly true as pyrite could easily have been removed by oxidation while the comparatively resistant galena still remains. Furthermore, its quantitative variations are not as great as pyrite and sphalerite, because where most abundant at the Sherwood mine, it comprises only about 15% of the total ore minerals.

It has been observed in replacement relations with earlier barite, sphalerite, and facies of the dolomitic country rock. In replacing the country rock, the solutions which deposited galena made their way between grain boundaries and selectively attacked individually, and apparently randomly disposed grains. The beautiful structure which resulted is illustrated in Figures 30a & 30b. In many of the Sheep Mountain ores it has been observed both in replacements of country rock and replacements and open space fillings in brecciated zones containing barite, dolomite, and quartz. Near the Sherwood mine, a tiny cube which formed in a cavity had microscopic octahedral truncations of the cube corners. The writer considers that this cube has but minute local significance, if any, and that generalizations as to the temperature of formation of the
Sherwood ores are not justified by this nearby octahedral galena, inasmuch as the character of the Sherwood ores are so markedly contradictory to this single tiny cube.

As shown by the etch pattern brought out by polishing which is represented in Figure 17b, some of the coarser galena reveals distortion of its crystallographic directions. This feature is noted in galena from the Wagner but the writer feels that its development was due to crystallization rather than tectonic causes.

Microchemical tests of galena from the different localities has shown that in every case it does not carry silver. Care in selecting the material was exercised by making a shallow cleavage gouge on a polished surface remote from tennantite if present. At the same time tennantite from the same polished surface was sampled if it was present. After making the tests, the surface was ground and repolished to the level of the bottom of the gouge, re-examined microscopically, and the test approved if masses of other mineral were not adjacent to the test gouge. Not infallible, these precautions are sufficient for shallow sample gouges, especially in the light of the constant results.

Galena formed after sphalerite in the ore mineral sequence, and is interpreted as being older than tennantite although the latter relations are none too satisfactory.
Tennantite.—Tennantite occurs in small amounts in most of the ores which contain galena. The Sherwood mine contributed the specimens which showed the highest relative amount. It is present in the ores of the Sacramento mine and Mudsill area and in many of the Sheep Mountain ores, excepting those of Brown's Pass.

Microchemically it contains silver. The precautions outlined in the preceding section were taken but as argentite is present, the affirmative tests for silver in tennantite are not as sure as the negative tests for silver in galena. Argentite is present in exceedingly minute masses associated with the Sherwood tennantite, but has not been observed in the ores from other localities. Inasmuch as an assay showed 192 oz. of silver per ton from a picked sample of Sherwood ore, and as the Sherwood ore is estimated to contain too little argentite to account for this value, and as reasonable precautions were taken to secure a pure sample for microchemical analysis, it is believed the affirmative test for argentiferous tennantite is valid. The positive test for silver from other tennantite localities such as the Wagner, where no argentite was observed strengthens the conclusion that tennantite is argentiferous although it does not necessarily represent the total silver contained in the ores. Copper and arsenic tests were positive; antimony indistinct or absent.
Microscopically, tennantite is a delicate green shade in the same field with galena. Its age relations are not clear although there are suggestive data. It is everywhere associated with galena, and although in places observed in contact with sphalerite there is no evidence of replacement of sphalerite and the tennantite seems to be confined by the replacement activity of galena in sphalerite (Figure 31b). Certain areas as indicated in Figure 31a, have the appearance of irregular galena veinlets in tennantite. The writer was unsuccessful in an attempt to determine galena orientation in such areas. These areas grade over into more typical areas having less tennantite within the galena as shown in Figure 31b. In ores other than the Sherwood, minute masses of tennantite having smooth contacts within galena present the same paragenetic problem.

Dr. Lindgren, who viewed the writer's slides, is of the opinion that tennantite is the younger mineral. The intimate association with galena is presumptive, especially as there is much galena showing no tennantite. It is preferred herein to consider that tennantite and galena were formed at about the same time, the galena with the power to replace sphalerite and the tennantite without, and that galena deposition began before tennantite and tennantite deposition ceased after galena.

Chalcopyrite.—Only two or three microscopic masses of chalcopyrite have been observed during the microscopic work on
the ores. These were noted within veinlets of galena and tennantite which transect sphalerite in one of the specimens from the Sherwood mine. The veinlets are of microscopic width and the chalcopyrite has made at slightly widened portions. It is in contact with tennantite and although there is some galena in the veinlets the chalcopyrite appears more closely related to tennantite. There is no apparent age relation except that it is later than sphalerite. It is probable that its position in the paragenetic sequence is with tennantite.

There are no blebs of chalcopyrite within sphalerite in the district in contrast with their abundant development in the sphalerite of the London mine to the north.

Argentite.--The only ores containing argentite are those of the Sherwood mine. It is visible microscopically as tiny masses of lighter color than tennantite and of a slightly bluish hue. Etching tests checked for argentite with those listed in the standard references. The masses are so small that etching reagents could not be applied with the customary looped platinum wire, and it was necessary to apply them as a tiny droplet or film on the end of a straight wire. Even thus, the reagent might affect tennantite matrix as well because of the small diameter of the masses of argentite.
The structural aspect of argentite within the ore is similar to that of tennantite. Argentite is observed associated with tennantite and although abundant galena is in the microscopic vicinity, argentite preferred to deposit within tennantite areas. Etching did not reveal argentite within galena, and microchemical tests indicated silver is not present in galena. Argentite is related to tennantite and galena, as tennantite is related to galena and sphalerite respectively.

The question may be raised as to the hypogene origin of argentite. It is considered hypogene because there are no signs of textures or structures admitting of supergene origin. The ore minerals are fresh and there is no obvious relation of argentite to tiny fissures or other structures. Moreover, its relation to tennantite is similar to chalcopyrite relations with tennantite and the hypogene origin of chalcopyrite is not questioned. If it were supergene and had been derived from the oxidation of argentiferous tennantite, there should be signs of it in some of the argentiferous ores from other localities.

Summary.—The metallic minerals which have been observed in hand and polished samples of the ores are as follows: pyrite, sphalerite, galena, tennantite, chalcopyrite, and argentite. The last two of this list, chalcopyrite and
galena, are present in microscopic amounts in the ores of only one of the mines of the area, the Sherwood.

**Gangue Minerals.**

*Manganiferous Ankerite.*—This mineral has been found only at the Sherwood mine. It is present in corroded remnants which have been seamed and replaced marginally by later dolomite. It is reddish pink to reddish brown in color.

Its index of refraction, omega, is 1.697 ±0.002 which agrees closely with the listed index of ankerite, 1.698. Inasmuch as a microchemical test yielded a faint show of manganese it is likely that this is a slightly manganiferous ankerite. The sodium bismuthate test was used, but the amount of manganese was so slight that only 2 of 7 tests were positive.

It formed early in the mineralization sequence and manganese and iron represent epigenetic elements.

*Ankeritic dolomite.*—In many places on previous pages the term ferruginous dolomite has been used to describe one of the rhombohedral carbonates which is here considered as ankeritic dolomite. As shown by its index of refraction, omega 1.684 ±0.002, it is very close to dolomite in composition. It weathers brown or yellow in contrast with ordinary dolomite. It has developed in small amounts in many of the deposits within the area and its position in the
paragenetic sequence cannot be specifically correlated between occurrences. At the Wagner claim for instance, ankeritic dolomite is earlier than other dolomite and ankeritic cores are rimmed and veined by dolomite whereas in the nearby claim (2400 ft. N 45°E of Sheep Mts.), ankeritic dolomite was the later mineral. In the Sacramento ores, it replaced quartz (Figure 35a).

Dolomite.—By far the bulk of the rhombohedral carbonate in the area is nearly pure dolomite. It does not show iron microchemically, and its index, omega, is 1.680. It is usually milk white in color and attains considerable grain size in places.

The question of the origin of this dolomite is interesting. The writer considers that there are two main types of dolomite other than original in the ores and rocks of the area:

1) Early recrystallized dolomite involved in the principal brecciation.

2) Epigenetic dolomite derived from the sedimentary rocks, which has migrated far enough to denote introduction.

In many places such as is illustrated in Figure 34, clastic fragments of dolomite are found within breccia zones which cement coarse recrystallized and twinned dolomite. It is difficult to distinguish much of this type, and in many places, impossible to diagnose the affiliation. The zebra
rock which has been described on pages 147-149 merely represents one of the recrystallized facies of the Leadville. In some of the Sacramento ores, large masses of coarsely crystalline dolomite have been partially replaced by vein quartz.

Analyses of the Leadville limestone (2, 35) show that minus its impurity content, it corresponds closely with pure dolomite having but slight lime over the theoretical amount. It has been figured that in the Leadville district, the early replacement minerals would have liberated more than enough dolomite to account for all the epigenetic material in the area (6, 253). Comparable lime-magnesia ratios are present in the Dyer (6, 253).

If the reader accepts the statement that the dolomite of epigenetic origin represents material removed by replacement and redeposited elsewhere, it is easy to account for the varying position of dolomite in the mineral sequence from the different localities. The position of dolomite in the epigenetic sequence depends therefore not only on the favorable physical and chemical conditions of formation but also requires that replacement of country rock facies has occurred. Thus the numerous minerals which are found in the limestone as replacements may have incurred the formation of dolomite at the time of their deposition or slightly later, and in close areal association or relatively remote
depending on the nature of the environment. The common minerals in the area which replace country rock are: barite, quartz, jasperoid, pyrite, sphalerite, and galena.

It is the suggestion of the writer that the ankeritic dolomite previously described may well be dolomite of country rock derivation and that the slight amount of contained iron has been due to impurity content of wall rock through which the solutions passed or to replacement activity which also affected pyrite. If the latter is the case, ankeritic dolomite should be paragenetically later than pyrite. It is later than vein quartz for the most part and the close relation of quartz and pyrite is suggestive but nothing more.

A varying position in the sequence of deposition is inferential evidence that the carbonates in a region such as this have been in large part derived from the country rock.

Another interesting occurrence of dolomite has been described from the Wagner ores where zonally arranged blebs are observed within euhedral cores of quartz grains. These are interpreted as being inclusions of the country because of their variable amount in different crystals. If they had been carried in solution along with the quartz and precipitated zonally, one would expect approximately the same number of zones and the same amount within most of the quartz
grains in a microscopic field which is not the case. The writer does not deny that there must have been slight solution and recrystallization activity which contributed to the arrangement.

Calcite.—Calcite is not prominent in the district. Where found it is present in small colorless crystals lining vugs and narrow fissures associated with oxidation products. At the Sacramento mine, it is intergrown with crustiform layers of fibrous aragonite. Its index of refraction checks for pure calcite. It is not a primary mineral.

Barite.—Barite is characteristic of the Sheep Mountain deposits and the Sacramento mine. Elsewhere it has been deposited either in negligible amounts or is lacking entirely. Its greatest development is in the gangue of the Sacramento mine and the Nelson prospect. The distribution of barite in the area is indicated in Figure 43.

Barite varies in its crystalline size throughout the district. The barite from the Nelson claim is relatively coarse whereas the Brown's Pass barite is fine-grained. The Sheep Mountain barite is typically medium- to coarse-grained. The barite from the Sacramento mine resembles that from the Hilltop mine at the head of Four Mile amphitheatre.

Most of the barite in the area is milky white and
present in the country rock in individual plates or radiate bladed aggregates in which the crystalline size is about 0.5-1.0 inch. On the north side of Sheep Mountain and along the southeast ridge of the mountain, there is barite in vugs within the jasperoid which is in colorless plates.

The composition of barite is constant within the area. Dr. Richard E. Stoiber examined several of the barites from the different localities and did not detect variations in spectroscopic amounts of impurities nor in the kinds of impurities. The refractive index determinations on all the barites were identical.

The paragenetic position of barite is early. At different places it has been observed as the early mineral replaced by later dolomite, ankeritic dolomite, quartz, and galena. Pyrite is shown to be later than the vein quartz which replaces barite and sphalerite is later than pyrite. Barite is thus one of the earliest of the epigenetic minerals although in places as on the north slope of Sheep Mountain, it is later than much of the jasperoid silica. A later generation of micro-crystalline barite which has been observed in some of the specimens has no special significance.

Silica.--

Introduction.--Two types of silica are clearly defined within the area, quartz of the jasperoid and vein
quartz. The jasperoid quartz is present in replacements of one of the dolomite horizons of the district whereas vein quartz is observed in fissure fillings and replacements of earlier minerals among which is barite. The jasperoid silica is universally older than barite for the most part. Two additional types are present and seem to represent a stage of silica introduction in which the quartz shows transitional features with both jasperoid and vein quartz. One of these types contains an abundance of carbonate inclusions, zonally arranged, and the other contains some grains with zonally arranged included carbonate but with the bulk of the material resembling typical jasperoid to a greater degree. A tabulation showing average grain sizes and numbers of the illustrations in the text is appended.

<table>
<thead>
<tr>
<th>Location</th>
<th>Average Grain Diameter, mm</th>
<th>Figure</th>
<th>After page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sherwood mine</td>
<td>0.003</td>
<td>32b</td>
<td>154</td>
</tr>
<tr>
<td>N. side Sheep Mtn.</td>
<td>0.03</td>
<td>22</td>
<td>132</td>
</tr>
<tr>
<td>Mudsill mine</td>
<td>0.06</td>
<td>24</td>
<td>140</td>
</tr>
<tr>
<td>Sacramento mine</td>
<td>0.1</td>
<td>36b</td>
<td>165</td>
</tr>
<tr>
<td>Ridge south Sheep Mtn.</td>
<td>0.15</td>
<td>21</td>
<td>130</td>
</tr>
<tr>
<td>200' east of Mudsill</td>
<td>0.5</td>
<td>--</td>
<td>---</td>
</tr>
<tr>
<td>Wagner claim</td>
<td>0.5</td>
<td>14b</td>
<td>120</td>
</tr>
</tbody>
</table>
Jasperoid.—Figure 41a which shows the type of silicification in the different localities indicates the distribution of the jasperoid. The typical jasperoid as discussed in this section is characterized by fine-grained allotriomorphic texture, flinty appearance megascopically and absence of included carbonate blebs.

Microscopically, its texture shows wide variation. The masperoid from the Sherwood mine is exceedingly minute whereas a rock of the same megascopic appearance from the south ridge of Sheep Mountain is relatively much coarser. The textural variations are indicated on Figure 41, but the tabulation on the preceding page gives more exact data. All the typical jasperoid, however, presents the same relations between its individual components whether small or relatively large.

Some of the jasperoid, particularly that from the Sherwood mine, is distinguished by undulous extinction between crossed nicols. Under high microscopic power, undulous extinction sweeps across most of the grains as the stage is revolved. The writer's observations indicate that this extinction is highly irregular with respect to the location of its axis of rotation. The axis may be at one edge of a grain or near the edge. Centered axes within grains are uncommon. In addition, many of the undulous zones include numerous grains rather than a single one. In such
cases, the undulous zone seems to be hemispherically located with respect to its hub.

In jasperoid other than the Sherwood, there are evidences of undulous extinction in many of the grains, but the observation is not universally applicable. In all the jasperoids, the microscopic grain boundaries are indistinct even under high resolution. Between grains are indistinct hazy zones in which the extinction does not seem to belong to one grain more than the other. In fact these minute hazy zones in most places represent transition between the bounding grains without necessarily showing related undulatory extinction.

Some of the jasperoids present a vuggy appearance on weathered surfaces. Such vugs are either empty or partially filled with minute colorless quartz crystals or barite plates which project outward. The unfilled vugs are irregular in shape and presumably indicate the former occupancy of coarsely crystalline dolomite which is to be distinguished from the minute blebs of oriented carbonate inclusions from the idiomorphic-type silicification and from later cross-cutting epigenetic veinlets. Numerous observations show that much of the jasperoid is characterized by irregular small patches of this coarse dolomite which has been derived from country rock recrystallization.
In addition to carbonate and vug quartz, the Sherwood jasperoid shows pods of more coarsely crystalline quartz in great abundance, and the Sacramento jasperoid contains transecting veinlets of coarser quartz. See Figures 32, 33, and 36. The veinlets in the Sacramento jasperoid bear close resemblance to vein quartz present in other specimens of the ores although the texture is somewhat finer than that of the characteristic vein quartz. The pods from the Sherwood jasperoid are areas of recrystallization of jasperoid in which grain growth was successful in attaining larger sizes. The grain size is of about the same order as the grain size of the jasperoid from the south ridge of Sheep Mountain. Inasmuch as there are no criteria of vein structures or of other epigenetic features this interpretation seems most reasonable.

The veinlets in the Sacramento jasperoid which contain coarser textures than the surrounding jasperoid are related to epigenetic agencies as shown by the structures illustrated in Figures 36 and 37b. The cleared quartz does not have the abundance of included carbonate blebs. Rather than stating confidently that the clarified quartz from the Sacramento jasperoid represents a later introduction, the writer prefers to mention the possibility that later solutions could have effected solution of carbonate blebs and effected recrystallization into coarser texture. If these
solutions had been active under the same conditions or at the same time as vein quartz was being deposited, the resemblance of the clear quartz to vein quartz is not surprising.

The jasperoid is confined within the area to replacements of either the Leadville or Dyer formations. The most prominent occurrence of typical jasperoid within the Dyer is at the Mudsill mine where a thick mass of it lies in stratigraphic conformity over the former ore body. The other indicated locations (vertical lines of Figure 41a) lie within the Leadville with the exception of those on the north slope of Sheep Mountain which are contained in both formations. At this point it has developed to greater degree within the Leadville, but there is a vertical dike-like body of it which seems to cut both formations and spread out along the bedding planes of the Leadville to a greater extent than in the underlying Dyer. The relations of this 'dike' are obscure because of slump and the great amount of slide rock at the critical location. If the 'dike' is truly present, it has east-west strike in opposition to the strike of all other structures observed on Sheep Mountain.

If the reader will again survey Figures 41, 41a and 42 the following generalizations will be noted:

1) Typical jasperoid textures have been developed in greatest profusion in the zone adjacent to the London fault, i.e. near the immediate crest of the London anticline or between it and the fault.

2) Texture of the typical jasperoid is finest at the north (Sherwood mine) and coarsest at the south.
3) The relative amounts of silica in the form of jasperoid as determined from combined field, megascopic, and microscopic observations increases towards the south within the area considered.

The paragenetic position of jasperoid is early. It formed before barite introduction as is supported by the presence of barite in vugs, and in transecting open veinlets with relatively smooth walls, and by the microscopic relations. There is a suggestion, however, that some of the silica of the jasperoid post-dated the formation of barite (Figure 21b). The relations of this are subtle and consist of corrosion of some but not all of the barite blades, and the apparent localization of barite on the north slope of Sheep Mountain to areas and possibly vein structures of clearer but texturally similar jasperoid silica. This last seems to have formed in overlapping sequence with barite.

The position of jasperoid silica within a single mineralization cycle is herein adopted.

The boundaries of masses of jasperoid apparently are sharp, both within the bedded dolomite which it has replaced and stratigraphically.

Idiomorphic-type silicification.—The idiomorphic type of silicification consists of the type which contains relatively coarse-grained idiomorphic quartz with zonally arranged carbonate in tiny blebs. It has been amply described on pages 114-117 of this paper so a summary will suffice here.
The characteristic type has been observed only in the Dyer formation in the vicinity of the Wagner claims on Sheep Mountain. The Leadville limestone has been eroded at this point so its possible expression in that formation are not known. Megascopically, after slight weathering it resembles sandstone.

Microscopically, it consists of an allotriomorphic intergrowth of variable-sized crystalline quartz. The structure is due to later enlargement of perfect euhehdrons of quartz of various sizes which contain zones of carbonate blebs in crystallographic orientation. The beautiful aspect of one of these crystals is shown in Figure 15.

The initial stages of the formation of this type are demonstrated in the specimens from a locality a few hundred feet southeast of the Wagner claims. (See Figure 41a). Figure 20 shows a skeletal euhehdron of quartz which contains a great abundance of carbonate blebs. The texture of the blebs is identical with that of the surrounding country rock and the manifestation of the silicification is observed under the microscope by the clearer aspect of the carbonate within the skeletal outline. Evidently at this point, the solutions which carried the silica were not concentrated enough in that substance to effect more than a slight silicification of the country rock. In addition they were not of sufficient strength to rearrange the car-
bonate inclusions and in the area of the skeletal euhe dron, did not have the power to dissolve and transport the carbonate. Any explanation which is provided does not satisfactorily explain the solution of impurities from the original dolomite to produce clear carbonate leaving the carbonate behind in the presence of replacing activity by quartz. It may have been that the solutions were so saturated with the carbonate radical that they did not have further solution power on carbonates but to the writer the explanation is inadequate and doubtless complex functions governed such a process.

The presence of the large amount of carbonate within this and other small euhedrons from this locality comprise the evidence for the statement that the included blebs are of country rock derivation. A few of them are present in other euhedral quartz of the locality as shown in Figure 20 (upper right).

The distribution of this type of silicification is indicated in Figure 41a by the horizontal lines.

Paragenetically, the position of the idiomorphic quartz is after the principal barite deposition. Minor amounts of microcrystalline barite are to be observed in later cross-cutting relations however. Figure 16b illustrates the typical aspect of the relations between this type of quartz and the bulk of the barite, with barite
cleavages having controlled the ingress of the siliceous solutions.

As far as the observations on the specimens of this type of silicification have shown, the idiomorphic quartz represents the silicification and the later accretion around the grains takes the place of true vein quartz. In places, as seen in Figure 20, small veinlets of quartz are observed. The relative amount of these is almost nil, and merely represent silica which would have deposited in crystallographic continuity with euhedral quartz had there been an appreciable development of it.

Transitional type.—Certain of the silicified masses reveal textural and structural similarities both to typical fine-grained allotriomorphic jasperoid and to idiomorphic silicification. The distribution of these is indicated in Figure 41a by the inclined lines.

The Sacramento jasperoid presents the clearest relations. The idiomorphic development is subdued and almost lacking but there are abundant carbonate inclusions. Where the euhedral cores have developed, they are small and include poorly arranged inclusions. Except for the carbonate inclusions and the texture this could be related to true jasperoid. Practically the same statements can be made for the locality east of the Mudsill mine (no photograph). The
Sacramento silicification has developed at the expense of the Leadville formation whereas the material near the Mud-sill has been formed in the Dyer formation. The similarity between the two in texture and structure indicates that the development of any type was independent of host rock and did depend on the character of the solutions and the related environment of deposition.

Rounded masses of the silicified material from the Sacramento locality have been transected by later veinlets of clear quartz which bears every similarity to vein quartz at this mine except grain size. In certain places, the amount of later quartz has very nearly obliterated the earlier fine-grained texture. The relation of the later quartz to well-defined veinlet walls indicates epigenetic activity, and the accompanying rounded masses and relicts of the earlier material within the later as shown in Figures 36a and 37b indicate replacement. It is thought that formation of the transecting structures accompanied the introduction of vein quartz although not all the quartz observed was necessarily introduced by these later solutions but may represent reworking of the earlier material and elimination of impurities in the presence of the later siliceous solutions.

Paragenetically, this type is best placed in the early period.
Quartz.--Vein quartz, which is found in greatest relative abundance at the Sherwood and Sacramento mines deserves no special mention. It contains numerous irregular rows of dusty-appearing inclusions. It is usually rather coarse-grained and in places shows pronounced strain effects. Paragenetically, it belongs to the middle period of the mineralizing activity as good evidence indicates that it followed barite in the paragenetic sequence. Minor amounts have been observed as late vug fillings in the ores.

Discussion.--The silicification of the limestones in the area presents one of the salient points of interest especially in view of the different types which have been described in the literature. It was indeed unfortunate that the party was unable to determine the structural affiliations of much of the material because of collapse of former mine workings.

The close paragenetic relation between barite and silicification provides a basis for including the silicification among the manifestations of the principal mineralization epoch. If the silica had been universally earlier than barite, this might not be valid, or if there were no transitional features between allotriomorphic and idiomorphic silicified limestones. The presence of idiomorphic-type silicification younger than barite and suggestions of
grading of this type over towards true jasperoid which is for the most part older than barite, justify the inclusion of all silicification along with barite within a single mineralization epoch.

In the Aspen monograph (21, 217-220), Spurr has described the silicification of the Leadville limestone and says "The first stage of silicification is the appearance of isolated crystals of quartz in the limestone...... initiation of these processes is signalized by the occurrence of isolated, perfect crystals in unaltered rock, and these crystals enlarge or multiply until they join, and thus accomplish a complete replacement. The rock that results from the complete silicification of limestone or dolomite sometimes resembles in the hand specimen a chert, but more often a fine-grained and altered quartzite."

Loughlin describes the Leadville jasperoid (2,172 and 218) and megascopically refers to it as flint. Microscopically, "...a perfect crystal of quartz will be seen embedded in an anhedral grain. This structure shows that the development of perfect quartz crystals is the first step in the process of silicification. As the process continues the limestone around the earlier-formed crystals is itself replaced, and the result is an interlocking aggregate of perfectly bounded quartz crystals embedded in a groundmass
composed of anhedral grains representing the later stages in the replacement of the original limestone." (2, 172).

The replacement of limestone described in the quotation is essentially that which Spurr has noted in the Aspen district, except that at Aspen the jasperoid typically had the appearance of impure quartzite whereas the Leadville jasperoid is more aptly termed flint.

The type of silicification which has been produced at Aspen can evidently be most closely correlated with the idiomorphic type of the present paper. The textures and structures of the Leadville jasperoid do not agree with any specific occurrence in the area but are related to the idiomorphic type by their microscopic features and to the typical jasperoid by their external flinty appearance. All things considered, the description of the Leadville material indicates that it is most similar to the Sacramento jasperoid which has features of both types. It is not possible to compare it exactly with the idiomorphic type as is found at the Wagner, and certainly it is not possible to correlate it with the Sherwood, Mudsill, or Sheep Mountain silicification in which there are no signs of early idiomorphic stages.

The bulk of the silicification in the area (Sherwood, Mudsill, and Sheep Mountain) bears many features in common with that which has been described from Tintic (22,
22a, 154-158). It differs in that the undulous extinction is less prominent, there are no feathery recrystallized aggregates, and the jasperoid neither is banded nor shows signs of rhythmic dispersion of material within it. Lindgren believes that the Tintic jasperoid represents replacement of limestone by colloidal silica with subsequent recrystallization into fibrous and granular quartz. He considers, furthermore, that the siliceous solutions advanced in colloidal form through the country rock and presents evidence indicating that they advanced as a surge or wave of material because there are no fading jasperoid contacts and he found it practically impossible to find a border phase, so sharp were the contacts.

The evidence in the Horseshoe-Sacramento district does not permit of satisfactory explanation by any one of the three discussed processes as it partakes of all in different places. Field relations were not clear enough to allow a definite statement as to the fading or non-fading boundary of the jasperoid proper. It certainly maintains itself within well-bedded contacts and the dike-like body of it on the north slope of Sheep Mountain which the writer suspects is present must have well-defined walls. The idiomorphic type, however, is evidently not characterized by abrupt contacts and is similar in most respects to the Aspen type in which individual centers of recrystallization resulted
and addition of material enlarged and welded them into the resulting aggregate.

The course of events which has resulted in the various textures and structures of silicification were as follows: siliceous solutions were evolved from some deep-seated source and penetrating the brecciated and partially recrystallized country rock dolomites effected replacement. Where the solutions were present in greatest concentration, they deposited their siliceous material rapidly about many centers of crystallization, and being relatively unsaturated with respect to the constituents of the country rock, removed all but a very little which remained as residuary carbonate. It is quite possible that much of this type deposited as exceedingly fine-grained fibrous quartz and with subsequent partial recrystallization presents undulous extinction effects. There are no definite evidences of colloidal origin at the Sherwood mine, which represents the ultimate in this direction, although it cannot be denied that the possibility of colloidal deposition is not remote.

At greater distances from their source, the solutions lost part of the value of their original concentration and at their place of deposition, could not produce as many initial centers of crystallization although continuation of supply of material produced a dense fine-grained jasperoid (north and south sides of Sheep Mountain). This slightly
coarser type is found to the south of the Sherwood mine and observations indicate its average grain size increases with distance from the Sherwood although it is confined to the anticlinal region of the fault.

Identical solutions to these which produced the typical jasperoid, ranged through the country rocks at a distance from the fault. At the Sacramento mine, their concentration was not only less but they had acquired so much carbonate from the dolomitic horizons that it was impossible for them to effect a complete siliceous replacement of the rocks and the resulting 'transitional' jasperoid grains contain an appreciable content of relict carbonate. The silica concentration was great enough, however, to cause a multitude of centers of crystallization only a few of which had opportunity to grow as euhedral grains. Undulatory effects are almost missing.

At greater distances from the source, the solutions were dilute with respect to silica and started to replace the country rock dolomite in small euhedral centers as at Aspen and with continued additions of dilute material, expanded individual grains and added new centers until the textures such as at the Wagner were produced. The carbonate inclusions indicate that the solutions contained an abundance of country rock constituents and the alternating zones indicate that at certain times during the process the solutions were
capable of removing carbonate, while at other times they had only the power to rearrange the country rock constituents about the growing quartz crystals.

The presence of barite in relations indicating that it is younger than most of the jasperoid silica and older than all of the idiomorphic silica must be explained. This is taken up further on.

Vein quartz represents continued introduction of silica under conditions quite different than those which obtained during the silicification of the country rock. It is typical vein quartz in every sense. There is a paucity of vein quartz in the Sheep Mountain area and it is the belief of the writer that the accretion stages of the idiomorphic silicification may well represent a contemporary introduction of vein quartz elsewhere in the area.

It is considered that demonstration herein provides satisfactory evidence that the silicification process was not similar to that which has been described elsewhere and combines some of the features from each of the districts reviewed.

Oxidized Minerals.

All the deposits examined bear traces of oxidation by meteoric waters. The Sherwood mine presents a partial exception in that most of the material which has been examined showed no traces of oxidation products. It appears that
oxidation was related to the Tertiary erosion surface and
the mines whose ores lay close to the unglaciated Tertiary
surface show prominent effects (Kudsill and Sacramento).

Secondary minerals which have been noted in the
area are: limonites, calamine, smithsonite, anglesite,
cerussite, malachite, azurite, aragonite, calcite, and gyp-
sum.

Limonitic material is typical of much of the area
but the relative small amount of pyrite in the Sheep Moun-
tain localities has resulted in but a small production of
it there except at one place.

Calamine and smithsonite are present in very small
amounts in the ores examined and it is probable that the
solutions which contained the zinc leached from sphalerite
migrated very readily without depositing their load.

Pisolitic malachite is found in vugs in the Wagner
ores. In the ores from one of the shafts near the Sherwood
mine, azurite is present in small rounded patches on the
face of country rock fragments and both country rock and
azurite have been transected by narrow veinlets of malachite.
In general, however, there is not much of the secondary
copper material. This can be ascribed to the habit of the
hypogene copper mineral, tennantite, within galena where it
not only has the protection of the enshrouding galena about
it to ward off meteoric attack but also the added protection
of anglesite which in many places has rimmed galena. The
typical but weak oxidation of galena is to anglesite.

The small amounts of gypsum and calcite which have
been noted are present as vug fillings or crusts usually as-
associated with limonitic material. The single noteworthy
occurrence of aragonite is in the material on some of the
Sacramento dumps. It is associated with calcite in coarse
crusty masses with long fibrous crystals radiating from
centers of growth and with the common outer surface of bund-
les of crystals in a band showing poorly developed mammilary
structures.

The characteristic results of oxidation of the ores
has produced limonite and anglesite with accompanying small
amounts of copper carbonates. In the ores examined (except-
ing the Search) there seemed to have been a marked tendency
towards loss of zinc.
WALL ROCK ALTERATION.

The only wall rocks which are in contact with orebodies in this area are dolomites hence the preceding descriptions of mineralization which has affected the country rock are in truth, wall rock alteration processes.

Metasomatic processes in the country rocks adjacent to orebodies are as much a part of the mineralization as is the deposition of the ore minerals. The differences are due to the fact that there is a greater surface exposed to any unit mass of solution in the wall rocks as the fracturing is generally less intense with smaller openings the rule and the composition of the wall rock is markedly different from the bulk composition of the vein. In limestone wall rocks, however, in which the ore minerals have effected bedded replacements, the usual differences between environment within the orebody and within the walls are not so profound and wall-rock alteration usually represents the fading limits of an orebody rather than mineralogic changes in a different direction.

In the Horseshoe-Sacramento district, the metasomatic processes in the country rock can be classified as:

1) Silicification
2) Pyritization
3) Recrystallization
   a) Early
   b) Late
Silicification of the country rocks has been summarized in the preceding section. It is here considered as wall-rock alteration in that its effects are most profound near or remote from the ores, but not actually being a part of them. In the case of the Wagner silicification, however, the quartz is the most abundant of the gangue minerals.

Pyritization takes the form of disseminated pyrite throughout the silicified rocks and in places, in the limestones. For instance, the ring veinlet of pyrite illustrated in Figure 25 may be considered as a manifestation of wall rock metasomatism in that it is not associated with other ore minerals.

The early recrystallization of the dolomitic country rocks evidently bears no direct relations to the mineralization as G. F. Loughlin (written communication) stated that in his wide experience in the general area, masses of recrystallized limestone are as common at distances from centers of mineralization as they are closer to them. It is a fact that many of the ores are found in areas of recrystallized limestones, but this may be due to structural reasons. The writer considers that recrystallization remote from the mineralization did not have relation to ore deposition, but the recrystallization in the proximity of orebodies may or may not have been related to the early dilute phases of the mineralization.
A late type of recrystallization is clearly and beautifully related to sulphide deposition. As illustrated in Figure 26, recrystallization of small amounts of dolomite has been cleared of its dark material in the process. In certain of the Sherwood ores the solutions from which sphalerite deposited effected small amounts of similar recrystallization.

In summary, late recrystallization of dolomite and introduction of pyrite represent minor wall-rock alteration in that they have effected a change in the composition of the country rock. The widespread silicification is the most prominent feature. Orebodies grade into alteration zones due to the nature of their replacement origin.
LOCALIZATION OF THE ORES.

Geologic Structures.

The most favorable structures which localized the orebodies in the area were fissures diverging from the London fault, and with little or no displacement on their walls. The close association of the ore with the fault is realized if it is remembered that the hypothetical center of gravity of production is less than 0.5 miles from the fault in Spring Valley. Furthermore, the largest producer, the Sacramento, is on the east flank of the London anticline, whereas the other two important mines, the Sherwood and Muddsill, are on the steep western anticlinal limb. All the important mineralization is on the north flank of the pitching anticlinal nose on Sheep Mountain (12, 17). This latter generalization is believed by the writer to be susceptible to the qualification that the presence of the anticlinal nose is of no economic significance and that the absence of orebodies is not to be explained on that basis. It is thought that the southern region on the steep south slope of the anticlinal nose was too remote for access of the metallizing solutions in great amounts. There is some barite and galena in the Brown's Pass ore but no tennantite.

In order to ascertain the structural features of the area which have been of importance in localizing the ores,
the following necessary factors of an epigenetic ore must be considered:

1) A source of metalliferous solutions.
2) Evolution of these solutions.
3) Transport of the solutions, via
   a) Collecting channels into
   b) Trunk conduits which lead them to
   c) Dispersing channels in which they may deposit, or
      migrate further into
   d) Microchannels which allow final deposition.

The source and evolution of the metalliferous solutions cannot be disputed as the ore deposits furnish proof of their former existence. Item 3a, collecting channelways, refers to the necessity of means by which the solutions can be led from their immediate source. This would include fractures in the cupola itself. An abundant literature presents evidence of such fractures.

The trunk channelway in the present case would be the zone of the London fault. The restriction of ore deposits along the footwall of the fault in the Alma district has been proven by the Alma authors (11 and 12) and in the Horseshoe-Sacramento district their localization in the hanging wall in an aureole adjacent to the fault is noted on Plate I.

It is not clear whether the principal dispersing channels are cross-faults or the divergent fissures. In the ultimate analysis the ores are localized with respect to divergent fissures both in the Alma district and in this area
to the south but there are possibilities that cross-breaks have produced an additional qualifying factor. At New York Mountain, about one-quarter of a mile north of the London mines, there is a prominent cross-fault. The ores on New York Mountain are bedded replacements of the Leadville with values in silver and lead. On the north brink of Pennsylvania Mountain, there are several east-west breaks of considerable magnitude. Near this point abundant pyrite and quartz are found in the London fault zone far above the apex of the London vein system. A cross-break of uncertain character is undoubtedly present near the Sherwood mine and is trending in the general region of the Sacramento mine. It displaces the anticlinal structure but its relations to the fault are hidden. All things considered, it is not impossible that the cross-breaks act as modifying channel-ways in diverting either upward or lateral flow of the former transporting medium. Their effect on solutions coursing the footwall would serve to divert them through the zone of gouge which usually accompanies the London fault.

The immediate dispersing channels were divergent fissures usually striking north or northeast. The fissures in the region of the Sherwood mine which can be found by surface studies are divergent from the northwest and constitute a unique type. There is no saying, however, that
these are the ones which would be found related to the mineralization if the mine workings were accessible. The Mudsill, Sacramento, Wagner, and various others are all related to principal zones of fissuring which strike northeast, and diverge away from the fault.

The microchannels in reality comprise both minute features and others of grosser nature. In this category would occur breccia zones, brecciated rubble, small fractures in country rock and other early minerals, and allied types. In general the effective opening of one of this type of fractures is small, the amount of solution which could be passes is small and they serve more as loci of replacement and deposition than as paths of flow. Such features are noted in all the ores examined.

It is thus possible to conclude that the emplacement of the orebodies was related to fracturing of the country rocks, and from the relation of the ore zone to the London fault to state that it served as the major unit of structural control within the area.

The fracturing of the rocks was caused by:

1) Stresses which produced the London fold.
2) Stresses which produced the London fault.
3) Other pre-mineral stresses.

The effects of the different periods of stress to which the area has been subjected, most of which took place in the early Tertiary are relatively obscure because of the super-
imposing of one on another. It is not clear whether the brecciation of the rocks was related to the folding, the faulting, later stresses, or combinations of all. It is the belief of the writer that some of the later stresses may have had important effects with regards to the localization of values but the evidence is rather shaky. At the Nelson claim, which shows the strongest barite-galena mineralization in the area, the barite has been highly fractured. The Sacramento barite has also been strongly fractured; this occurred prior to the introduction of vein quartz. It is possible that areas which received strong fracturing after the earliest period of mineralization are the ones which display the strongest mineralization. The Sherwood pyrite is fractured in part. Thus later stresses, which served to reopen channels or to establish new ones, may have played their part in the localization of the ore as well as the major and auxiliary structural features which account for the regional aspect.

The paragenetic position of dolomite and ferruginous dolomite from the different localities, varying as it does, suggests that the solutions were not everywhere controlled by the same set of conditions or fractures which were open at the same time everywhere in the area. There seems to be no doubt that the dolomite has been derived from the country rocks and its relative position in the
sequence of deposition at different places indicates there were minor adjustments in the structural aspects of the region which endured during the activity of the mineralizing solutions.

It is probable that many of the fissures found along the London anticline had their inception during the folding and were accentuated during faulting and perhaps modified further by later readjustment.

In summary, the ores are related to small divergent fissures trending northeast in the hanging wall of the London fault, and they lie on either flank of the London anticline, but nowhere remote from the structural aureole of the fault.

Host Rocks.

The host rocks of the orebodies in the district comprise both the Leadville and Dyer formations. About 80% of the mineral production has come from the Leadville, but the Mudsill mine which lies within the Dyer is reported to have had a larger production than the Sherwood in the Leadville.

Wide experience has indicated that of the two the Leadville is the most favorable, and especially the upper portion (2, 189). There are no ores in the Manitou as are found at Leadville.
The Sherwood and Sacramento mines which have accounted for the bulk of the mineral production lie in the Leadville formation. Other localities are about equally divided between the two formations and it is probable that many of the former ores in the Leadville have been destroyed by erosion as it is lacking over great areas.

Some interesting relations were noted in two prospects west of the Sacramento mine. The attitude of a fissure with respect to the prospects has been indicated in Figure 12b. The lower prospect, in the Dyer, contained but a bare trace of recrystallized limestone whereas, the upper prospect, about the same distance from the only prominent fissure nearby, but in the Leadville, showed prominent recrystallization and evidences of epigenetic action in greater abundance. Presumably this is an indication that other things being equal, the Leadville was the more highly susceptible rock in the presence of solutions.

There is another reason why the Leadville and especially the upper portion has attained greater prominence as an ore carrier. It is usually typically overlain by one to several feet of Weber (?) shales which in turn is overlain by porphyry. These constituted an effective barrier to the rise of solutions and the evidence is noted in the many examples where orebodies have spread out from fissures beneath the basal Weber(?). (Figures and Plates of Reference 2).
The Dyer formation in the area has no impervious beds nor is it typically capped with shale or porphyry so that once solutions started rising they might continue through the formation without impedance.

It is also probable that the physical characters of the two formations exerted some effect. It is thought that the Leadville was the more easily fractured, and hence would present more channels for the solutions to travel in, and from which to replace the surrounding rock.

In summary, it is believed that the Leadville formation was more favorable to replacement because of its physical and chemical nature, and because it is typically capped with Weber(?) shales which constituted an impervious barrier to the further rise of solutions.
ZONING OF THE ORES.

Introduction.

The concept of the zonal arrangement of certain hypogene orebodies with reference to some proven or hypothetical source point has long been recognized. The zonal expression, reduced to simplest terms, takes the form of directional variations of physical or chemical features within the ores. The variations are commonly assigned to a temperature differential with the characteristics of the higher temperatures being assigned to the region closer to the source. Loughlin and Behre have pointed out that the simple concentric arrangement of temperature zones may be upset by complicated structural conditions (6, 254).

The chemical features which are usually called upon to express mineralization zoning are:

1) Mineralogic changes with accompanying variations in chemical elements, most commonly metals.
2) Mineralogic changes without marked variations in the chemical content of the ores.
3) Chemical changes without variation of mineralogic components.

The common physical variations are:

1) Textural changes of any or all components.
2) Change in physical aspect of the orebodies.

It is possible therefore to express mineralization zoning by any one of several means or by all of them together if there are suitable manifestations of variability.

In a discussion of mineralization zoning the burden
of proof lies with the writer in that it must be shown to satisfaction that the ores formed contemporaneously or at least, within a single mineralization epoch and that they are all related to the same source. In the case of regional zoning over wide areas it is not an easy matter to show conclusively that the ores are contemporaneous. In a single orebody or ore zone, however, it is comparatively east to demonstrate if the ore introduction occurred within a single epoch and that variations in properties are related to a given source direction. The present question lies between the two extremes, the ores are in a group of bodies spread out over several square miles and although variations cannot be traced from one unit to the next, the similarity of structural and mineralogic features precludes the possibility of more than one age of mineralization.

Furthermore, there is the question of the validity of the evidence. Marked textural or chemical changes if properly qualified can usually be accepted without question. On the other extreme are slight variations which are accepted in direct proportion to the estimate of the integrity of the observer. Usually, it is found that considerable amounts of laboratory and field evidence which the reader does not have at command have influenced the worker in his conception. The present description of the zonal variations of the
mineralization within the Horseshoe-Sacramento district will show that it lies in the intermediate zone between well-defined variations and poor ones, that some of the characters vary whereas others do not, and that the zoning is really present although subdued. The slightness of most of the variations is due to the fact that the deposits formed under essentially the same environment and at a distance from the source of heat, thereby requiring that all changes be slight inasmuch as they are areal rather than vertical.

General Statement.

With regard to the contemporaneous age of the deposits within the area, it has been shown that the smaller ones are narrow bedded replacements of one of the dolomitic horizons of the region, localized by members of a common fissure system, the northeast divergent group. Two of the larger mines are related to this same system whereas the third, the Sherwood, from surface indications appears localized with respect to a northwest set of fractures. This is not negative evidence as it is recalled that the Sherwood is exceedingly close to the London fault and that the underground work in the London mine has indicated the complex nature of the fracture pattern in the immediate zone of the fault.
It could be argued that relation to a common fissure system is not good evidence especially in view of the fact that this is about the only well-developed system in the area. From the regional basis, however, the argument may be defeated as there has not been found evidence of marked faulting during the mineralization epoch. There are no cross-cutting veins and the whole activity seems to have been confined between the period of auxiliary faulting related to the reverse faulting, and a post-mineral stage.

The best evidence is in the character of the ores themselves. They show a community of mineralization similarities, chemical similarities, textural similarities, and similarities of structural control which additively cannot be disputed. Furthermore, the directional variations of properties of the ores which constitute the manifestations of mineral zoning, are in themselves, good evidence of contemporaneity of deposition. If there were only two occurrences of ore within the area, and these were different, the objection to using variations within the ores themselves would carry weight, but where evidences of gradational variations build up over the area and point in essentially the same general direction, it is possible to utilize them as proof of deposition of the minerals from nearly identical solutions under slightly different environments but at essentially the same time.
It has been shown that the deposits of the outer zone of Leadville which are of the same type as those described herein are areally zoned(6). Ore deposits in the hanging wall of the Cooper Gulch fault in the Alma district vary from gold deposits in the Loveland Mountain area to silver-lead-barite bodies at the south (11, 123-126). The London gold mineralization in the footwall of the London fault is shown to grade areally northwards into silver-lead replacement orebodies at New York Mountain (12, 16).

Evidences of Zonal Distribution.

The evidences for zonal distribution of the mineral deposits in this area are not related to any single feature but are related to cumulative variations of several components of the ores, for the most part chemical, but in certain cases physical. It has not been possible to consider any single feature over the whole district as suitable material is not to be found and moreover certain of the typical constituents are lacking in some of the localities. In the presence of most of the other constituents, however, this omission can be ascribed to minor structural features as an adjacent body may contain the omitted mineral. Sphalerite, for instance, is not found in many of the ores, but its absence can be related to another cause, namely its ease of solution by meteoric waters under oxidizing conditions.
In general, the ores from all the localities show or indicate the former presence of the following constituents: quartz, dolomite, pyrite, sphalerite(?), galena, and tennantite. Manganiferous ankerite, argentite, and chalcopyrite have been observed only in the Sherwood ores whereas the Sherwood mine and adjacent ground definitely does not contain barite whereas the bulk of the remaining localities do. Small amounts of ferruginous ankerite found here and there within the district have no direct significance. The proof of zoning therefore is directed to discussion of the presence of the minerals which are unique to the Sherwood ores, the areal extent of the barite zone, and the chemical and textural variations of the other minerals and metals. In anticipation, it is stated that the directional variations of the features which are considered point to the Sherwood mine as the locus of the most intense thermal characteristics and the Brown's Pass prospect as the opposite extreme.

Figures 41, 41a, 42, 43, 44, 45, and 46 have been prepared so that the reader may visualize the variations over the area, and allow descriptive discussion to be limited.

Figures 41, 41a, and 42 together with the section on silicification show how the textural aspect and amounts of epigenetic silica varies within the region. The
generalizations which may be obtained are as follows:

1) The grain size of the jasperoid or silicified limestone increases southwards from the Sherwood mine in the immediate wall of the London fault, and increases to the east away from the fault at any given point. See Figure 41.

2) Typical fine-grained jasperoid with allotriomorphic intergrowth of component grains, some with undulous extinction, is confined to the immediate wall of the London fault, although there are the modifying textural variations within it noted previously. See Figure 41a.

3) The relative amounts of total epigenetic silica in the ores is estimated to increase to the south away from the Sherwood mine. See Figure 42.

The three greatest concentrations of barite are found in the Sacramento ores, in the northern Sheep Mountain area, and in the ores from the Nelson claim. Generalizations which are obtained from the study of the barite occurrences are as follows:

1) In the northern part of the barite zone, in the region of the Sherwood mine, barite is not found close to the London fault nor in the Sherwood ores.

2) The zone of concentration of barite abuts on the fault at the southern end but its northern termination is not known as it is removed from the fault.
3) The only great concentration of barite in the northern part of the area is at the Sacramento mine which is about three-quarters of a mile east of the London fault. See Figure 43.

Not shown by sketches is the observation that pyrite displays its coarsest texture at the Sherwood mine where it is intergrown with vein quartz.

With regard to the relative amounts of sulphide minerals the following may be stated:
1) Pyrite is most abundant at the Sherwood mine, and decreases in relative amount to the south and to the east away from the Sherwood.

2) The highest observed concentration of sphalerite is at the Sherwood mine, and whereas other observations are not good, small amounts of fresh unoxidized sphalerite in some of the Sheep Mountain localities indicate that its relative amounts was much less there.

3) Galena and tennantite are present in greatest amounts at the Sherwood mine and decrease in relative amounts to the south.

4) The ratio of amount of tennantite to galena is highest in the Sherwood ores and decreases to the south. (Sacramento ratio indeterminate). See Figure 44.

In terms of metals and non-metals the previous generalizations indicate that:
1) More iron (pyrite) has been introduced in the Sherwood ores than elsewhere in the area.

2) More sulphur has been introduced at the Sherwood.

3) More silver and copper (tehmanite) has been introduced into the Sherwood ores than in the ores to the south.

4) The ratio of silver to lead is higher in the Sherwood ores than in the ores on Sheep Mountain.

5) BaSO₄ is abundant in the area removed from the Sherwood mine but was not precipitated along with the other Sherwood ore minerals although found in conjunction with them elsewhere in the area.

As shown in Figure 45, the location of the larger productive mines is in the area in which the ratio of silver to lead is high. They are also found in the area in which there was a relatively stronger mineralization. The amount of epigenetic sulphide minerals is very small in the Sheep Mountain area to the south. Galena is the most persistent of the sulphides and is found in small amounts nearly everywhere. The approximate total amounts of ore minerals in the various localities with reference to the Sherwood mine as the standard may be found by imagining lines connecting the extremities of the relative mineralization lines of Figure 44. The plane area totally enclosed by the present and imaginary lines would closely
approximate the relative intensity of the mineralization at the different localities.

Figure 46 indicates that the only unique minerals in the area, manganiferous ankerite, chalcopyrite, and argentite, are found in the Sherwood ores. Manganiferous ankerite is thought to represent an introduction of manganese similar to the manganosiderite of Leadville, but in the presence of lesser quantities of available iron. Manganosiderite is characteristic of both the 'hotter' and 'intermediate' mesothermal zones of Leadville (6, 225-226) and it is probable that manganiferous ankerite is a still lower temperature equivalent. The 'unique' minerals are observed in negligible amounts.

The color of the sphalerite at the different localities is not diagnostic in itself, but coupled with other data, presents suggestive additional evidence of a zonal arrangement. The Sherwood sphalerite is brownish whereas the Wagner sphalerite is distinctly greenish. Loughlin and Behre note that the sphalerite of the intermediate mesothermal zone at Leadville is dark brown while that found in the cooler mesothermal zone is light resinous to green (6, 223). It is considered that the dark sphalerite of the Sherwood is allied to their dark sphalerite in its zonal position and the Wagner sphalerite to their green sphalerite.
Figure 42

MINES and PROSPECTS
Hanging Wall of
London Fault
Mosquito Range
Colorado

LEGEND
Scale in Miles
0
1

EPIGENETIC SILICA
Relative amounts
Negligible
Small
Moderate
Large

London Fault
Figure 43

Pennsylvania Cr.

London Fault

MINES and PROSPECTS
Hanging Wall of
London Fault
Mosquito Range
Colorado

Big Sacramento Cr.

Little Sacramento Cr.

Four Mile Cr.

Sheep Mt.

LEGEND

Scale in Miles
0 1

BARITE OCCURRENCES

Showing
Quantity
Zone of concentration

London Fault
Supplementary Discussion.

As inferred on a previous page, mineralization zoning need not necessarily be expressed in all the constituents of the ores, nor over the whole area. Instead it may be found in serial variations of several of the properties or constituents, one varying among several places and overlapping variations of another tying in and connecting the complete picture.

It is the writer's belief that if structure of the channelways in which the solutions migrated be momentarily discounted, only certain of the components of the ores need be susceptible to the thermal causes which relate to their observable chemical and physical variations within a mineralized area. Thus the zoning may be noted by either chemical or physical manifestations, and these may be found in either early minerals in the paragenetic sequence or late minerals, or in most favorable circumstances by all minerals.

It would seem as if the earlier minerals which formed, commonly quartz and pyrite, should be found throughout the mineralized area as the expression of the widespread deposition of ferrous sulphide and silica. The textural variations they show indicate variations in the concentrations of the early solutions at different places and the
variations in amount indicate the relative volumes of solutions which arrived at the different localities. Quartz and pyrite are in this category because they have demonstrated so much ability to form under widely different conditions that Lindgren has been prompted to include them among the 'persistent' minerals.

Minerals which tend to have more restricted stability fields (this does not refer to sphalerite or galena) are susceptible to having their component elements appear in different places as different minerals. Thus in this district, the silver is typically contained in tennantite, but under extraordinary environments which prevailed in solutions in the Sherwood locality, the silver took the form not only of tennantite, but of argentite. Similar cases can be made for chalcopyrite and manganiferous ankerite.

In general, elements which readily appear in minerals having wide stability fields usually form in these minerals, and these minerals are susceptible to textural and quantity changes as an expression of mineralization zoning. Elements whose minerals characteristically have restricted stability fields are most susceptible to mineralogic zoning with variations expressed in changes in the mineral species rather than in texture or amount alone.

If a complicated structural pattern is imagined
superimposed over the relatively simple changes noted, with minor readjustments and reopenings of the solutionways occurring at different stages of the mineralization epoch, deviations from the expected pattern can be allowed without discrediting a zonal concept.

In the present case the ores are zoned with reference to geologic structures. There can be no doubt that the mineralization is related to the London fault from the plot of the mineral localities which shows an aureole of mineralization arranged in a rude semi-circle about a portion of the fault. The London fault localized the paths which the solutions took, and where the requisite structural conditions prevailed in the area valuable metallization occurred. This metallization, however, could only occur where the solutions had great enough concentrations of constituents to promote precipitation and replacement. This condition obtained in the small triangular area of the Sherwood, Sacramento, and Mudsill mines. Elsewhere, although the solutions and favorable structures were present, there was not enough valuable constituent present to allow more than a weak mineralization.

The direction of the zoning indications of all types points to the Sherwood mine as having had higher temperatures and more concentrated solutions prevailing during the formation of its ores than were realized at the other
localities. The direct result of this observation is the statement that the Sherwood mine is located closer to the former source of heat and epigenetic material.

The characteristics of the Sherwood ores which contrast with others in the locality, are:

1) Finest-grained jasperoid silica, thought to have resulted from precipitation from more concentrated solutions.

2) Most abundant pyrite and coarsest pyrite, a result of possible slower crystallization under higher temperatures, and certainly the result of a greater introduction of iron sulphide.

3) Greatest amount of sphalerite, galena, and tennantite, indicating the former presence of more abundant solutions.

4) Presence of manganiferous ankerite, chalcocpyrite, and argentite, indicating unique conditions not found elsewhere.

5) Absence of barite which is in the other ores, indicating that barite was not stable in the Sherwood environment if its components had ever been present.

6) Darker sphalerite.

At the other extreme is found the ores of Brown's Pass in which galena, barite, and silica are the only epigenetic minerals noted.

The gradational aspects of the mineralization are thought to decrease in intensity south along the London fault and east from the fault at any given point. This is borne out by a glance at the charts which have been prepared. The eastward gradation is most marked by the appearance of barite in the northern part at a distance from the fault
whereas it is close to the fault at the south; and by the textures of the silicification.

The deposits are at approximately the same elevation, so as in the outermost Leadville area(6), the visible zoning is lateral rather than vertical. From the structural viewpoint, this indicates that solutions emanated from a point beneath or adjacent to the Sherwood ground and found escape in directions to the south and east because of the earlier production of fissures and fractures which served as channels. Structural control by the fractures allowed migration to the south in the broken ground adjacent to the fault and to the east with metallization where the most favorable conditions obtained. During migration, heat was dissipated and material lost by interaction with the rocks traversed so that the mineralization at any distance from the supposed source is relatively weaker than nearer to it.

It follows that the deposits are structurally related to the area adjacent to the London fault and zonally related to the ores of the Sherwood mine as the locus of most intense deposition. The solutions had their dispersive source near the Sherwood ground and made ore in the favorable structural region nearby where they had been present in greatest amounts and in highest concentrations.

The theory that the pitching anticlinal nose on Sheep Mountain has tended to localize deposits on its
gentle north flank (12, 17) is discounted by the writer. Although the deposits are admittedly on the north flank, the concentration of values is related to proximity to source. The absence of valuable deposits on the south slope is due to remoteness from source and not to local structural control.

The absence of deposits north of Little Sacramento Gulch in the presence of favorable host rocks and supposedly favorable structures cannot be explained. There is a slight mineralization on the south slope of Dream Mountain and a group of deposits northeast of the Sherwood mine in which country rock recrystallization has been the principal effect. Structural relations are obscure and a good part of the Leadville formation has been removed by erosion. The Dream Mountain occurrence represents a minor amount of solution which strayed from the usual path and escaped northwards.

Classification.

Loughlin and Behre have shown how certain ores in the Leadville district may be zonally grouped, and divide the mesothermal zone into the 'hotter', 'intermediate', and 'cooler' types (6, 224-225). They are able to trace gradational characters from one distinct type into another.

The mineralogic characteristics which they assign to the intermediate mesothermal zone are: slight amounts
of manganosiderite, jasperoid and quartz, pyrite, marmatite, chalcopyrite, galena, tennantite, bismuth sulphides, argentite, gold, and a little barite and late siderite. These grade into the cooler mesothermal types which show: quartz and jasperoid, pyrite, green sphalerite, galena, argentite, dolomite, and abundant barite. They consider that the intermediate type has sufficiently high thermal affinities to be classed as 'near magmatic source' whereas the cooler type they class as 'distant from source'.

The similar character of the deposits in the Horse-shoe-Sacramento district indicates that they can be classed as belonging to the cooler mesothermal zone and their manifestations of zoning are representative of intra-zone variations. For the most part they contain the diagnostic species of the Leadville zone such as quartz and jasperoid, pyrite, light sphalerite, galena, dolomite, and abundant barite.

The Sherwood mine constitutes the only departure from the general pattern. Inasmuch as the Leadville authors have traced gradations from hotter types through types similar to the Sherwood into the distinctly cooler types, and the directional features noted herein indicate that the Sherwood type represents a type which has cooler representatives in the surrounding area in abundance, it is thought
best to place the complete array within the cooler mesothermal zone. The Sherwood ores have intermediate mesothermal characters as shown by the presence of the manganiferous ankerite, and perhaps represent the upper temperature limit of the cooler mesothermal deposits.

In summary, part of the transitional zone between the intermediate and cooler mesothermal deposits is represented by the ores of the Sherwood mine, whereas the bulk of the mineralization of the district is classified as the cooler mesothermal type. The cooler type diminishes in intensity to the south along the hanging wall of the London fault.
GENESIS OF THE ORES.

That the ores of this type in the central part of Colorado have had a magmatic origin is too well-known to require additional support in this place.

Evidence is to be found in the mineralization zoning which must admit some thermal control that could have been attained either by the normal temperature-depth relation or by relation to a source of magmatic heat. The ores in the area are at about the same elevation and the areal variations when considered in relation to the general structure will not admit an interpretation other than the magmatic source.

Following the major and most of the minor structural adjustments of the region, metallizing solutions were evolved from some unknown igneous body which is still concealed from view. The present surface during this early Tertiary metallogenetetic time is thought to have lain beneath an additional 10,000 feet of covering rocks (2, 41). The source of the solutions was possibly the same or allied body which in the earlier course of its differentiation produced the fractions which were emplaced as porphyritic bodies prior to the major tectonic action.

The earliest solutions may have been exceedingly dilute with respect to epigenetic components and aided or caused some of the widespread recrystallization of the
dolomitic horizons. The recrystallization is so widespread and so remote in certain cases from other evidences of mineralization, it is certain that if such solutions were the cause they were not in every place followed in their channelways by the later mineralizing solutions whose effects are more localized.

With respect to epigenetic constituents, siliceous solutions were the earliest manifestation of the mineralization. They evidently had their origin at depth in the ground near the present Sherwood mine, and spreading upwards and outwards to the south and east in the fractured zone adjacent to the London fault effected silicification. Where the principal conduit lay, near the Sherwood, they coursed with relative rapidity, and being concentrated, deposited their siliceous load about many centers of crystallization in the jasperoid at the Sherwood by replacement of the dolomite. Further to the south, along the hanging wall of the fault, where they were more remote from their source, their concentration became depleted with respect to silica and due to possible admixture with silica-free solutions. Being less concentrated, they deposited their silica by replacement of the dolomite but at a slower rate which resulted in progressively coarser textures as they flowed southwards. The estimated increase in total silica content to the south may be explained by
postulating that the total amount of silica introduced into the rocks was greater to the south although the solutions were less concentrated. This infers that solution flow was less rapid as the distance from their source increased which is a valid theoretical basis. The locus of the channelways by which they emerged from depth is related to unsuspected structural features in the Sherwood area, which however, may be obscurely related to the cross-break there.

During the later stages of the silica replacement, the concentration of barite in the solutions had built up to such a degree that it began to be deposited. In the Sherwood area, which was connected to the source by a more direct conduit, the flow of solutions was comparatively more rapid, and resulted in a more rapid transfer of heat. During the period at which barite concentration was favorable to its deposition, the situation of the Sherwood was too warm for the mineral to deposit. On the other hand, a small quantity of manganiferous ankerite found conditions suitable there at about this stage and deposited. Barite replaced country rocks and earlier-formed silica. It also filled fractures within the jasperoid.

There is no evidence to indicate that the finest-grained jasperoid had colloidial origin. Undulous extinction is present but that in itself may only indicate a later
recrystallization imposed on an earlier still finer-grained siliceous replacement.

Following the barite stage, silica continued to be introduced. In certain of the localities, this silica took the form of jasperoid and replaced part of the just-deposited barite. In the area of the present Wagner claims, siliceous solutions had not arrived until after the barite deposition. They were comparatively weak and evidently had a considerable content of the country rock carbonate as one of their components. In any case, they caused scattered centers of crystallization to form which by later accretion of material, grew in crystallographic continuity with the nuclei. At certain stages, the solutions did not have the power to dissolve the country rock carbonate which the quartz was trying to replace, and re-arranged part of it into zonally arrayed blebs which were subsequently engulfed by later quartz. This type of silicification represents less concentrated solutions and merges into the vein quartz stage.

During the stages previously outlined, the replacement of country rock by silica and barite released quantities of dolomitic constituents into the solutions. In places, some iron was contained in small amounts. These carbonate constituents migrated with the solutions, and where favorable opportunities presented deposited in
replacement masses or in fissure fillings.

Meanwhile, in the ores of the north end of the zone such as the Sacramento, the later silica took the form of vein quartz and replaced earlier barite and dolomite. Probably at the same time, partial recrystallization and clarification of some of the jasperoid occurred, resulting in a type of silica in vein-like structures which is closely related to vein quartz.

In the closing stages of the silica introduction, pyrite began to deposit as fillings, replacements of country rock, and replacements of quartz. It was succeeded by sphalerite which in turn gave way to the period of galena deposition. Both occur as fillings and small replacement masses. Tennantite was deposited during the closing stages of the galena deposition and is everywhere localized within galena masses. The last effects of the mineralization were small amounts of vuggy quartz and carbonate.

Some of the solutions which transported the metallic constituents effected minor amounts of recrystallization in the dolomites which can be directly related to them. As evidences, tiny clarified zones are shown to be related to the introduction of pyrite. The recrystallization merely accomplished the abstraction of impurities from some of the grains of country rock adjacent to the veinlets, but in the process did not completely clarify all of each grain affected.
The solutions which accompanied the introduction of sphalerite caused some recrystallization along minute fractures.

The absence of great amounts of recrystallization in the dolomites, where considerable amounts of sulphides have been deposited some of which caused slight recrystallization effects, is to the writer, evidence that the minute paths followed by the solutions were influenced by structure. It constitutes an evidence against diffusion as one would think that in an area of easily replaceable dolomites which were subject to mineralization to varying degrees, diffusion effects would be prolific.

The generalized paragenetic tabulation is shown in Table III.
### Generalized Paragenetic Relations

<table>
<thead>
<tr>
<th>MINERALS</th>
<th>Early</th>
<th>Relative time</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brecciation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recrystallization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silicification</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vein quartz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn ankerite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dolomite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe dolomite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyrite</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Sphalerite</td>
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<td></td>
<td></td>
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<tr>
<td>Galena</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Tennantite</td>
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<td></td>
<td></td>
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<tr>
<td>Chalcopyrite</td>
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<td></td>
<td></td>
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<tr>
<td>Argentite</td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STAGES.</th>
<th>Mineralization (continued)</th>
<th>Metallization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction of silica</td>
<td>Solution of country rock</td>
<td>Introduction of Fe and S</td>
</tr>
<tr>
<td>(continued)</td>
<td>(continued)</td>
<td>Introduction of other metals, removal of Fe and S</td>
</tr>
</tbody>
</table>
REGIONAL RELATIONS OF ORES.

Of more than passing interest is the possible relations which the ores in this area have to the London gold mineralization to the north. There the ores lie in the footwall fractures of the fault, and a structural trap has been provided by the east-dipping London fault upon which the Weber(?) shales abut on the upturned east limb of the syncline. It is tacitly assumed though not proven that the fault has east dip in the present area though steeper than in the London country.

Furthermore, the Alma authors infer that the ores in the east wall of the London fault to the south of the London mines originated from solutions trapped in the footwall which leaked through the fault gouge at some favorable structural locality and made their way into the rocks of the hanging wall (12, 17).

It is certain that the solutions which caused the London ores were localized for the effective part of their migration in the footwall of the fault. There is no evidence which indicates that the solutions which caused the ores in the hanging wall of the fault in the Horsehoe-Sacramento area ever had a footwall course. The only suspected relation is that at the Sherwood mine which appears to represent the most intense thermal conditions, there is some kind of a cross-break which may have served to guide
the solutions from the west to the east wall if they ever were exclusively in the west wall. The most reasonable interpretation possible at this time is that the great disturbed zone adjacent to the fault tapped the solutions near their source and guided them to higher regions without specification as to which wall guided the solutions in their travels.

The observations along the ore zone of the London fault are as follows:

1) The northernmost locality of principal mineralization is on New York Mountain, one-quarter mile north of the North London mine. Values were in silver and lead, and the ores were in the form of replacement deposits at the top of the Leadville formation.

2) The London mines, including the North London, South London, London Extension, American, and Lonion Butte workings, stretch out along the fault for two miles. The ores are principally gold-quartz veins with porphyry walls.

3) Items 1 and 2 pertain to the footwall ore zone; the southern extent has not been determined. The ore zone pitches 12° to 15° to the southeast and the lowermost and southernmost workings are those of the London-Butte.
4) Three miles south of the London-Butte mine is the next important mineralization, the Sherwood. This is in the hanging wall and the more highly mineralized zone has only a mile of extent along the trend of the fault, or to the neighborhood of the Nedsall mine.

In referring to changes in the character of the footwall ores, the Alma authors state (ll, 117),

"It is to be expected that southeast of London Mountain, toward the margin of the mineralized area, there will be a change in metal content analogous to the one toward the northwest (New York); but, owing to the tendency of the ore-forming solutions to travel northwestward up the pitch of the fold, the changes towards the southeast may be more abrupt than those towards the northwest."

If the Sherwood mineralization represents a distant facies of the London gold mineralization, the previous quotation is not strictly correct as the changes are not abrupt from the Sherwood south and would not need to be abrupt at depth north of the Sherwood except in the presence of marked structural irregularities. On the other hand, the London mineralization may be completely confined to the footwall and change character abruptly there south of the London-Butte mine, in which case the Sherwood would represent a separate center.
It is seen that if relation between the Sherwood mineralization (including that of the area to the east and south) and the London gold mineralization could be established, it would be of tremendous importance in encouraging exploration work in the footwall to the south of Pennsylvania Mountain.

The present work, in summary, indicates the following:

1) There is no sign of valuable metallization of the London gold type south of the London-Butte mine.

2) There is no apparent relation between the London footwall mineralization of gold and the Horseshoe-Sacramento hanging wall mineralization of silver-lead.

3) There is no evidence that the solutions which caused the silver-lead mineralization in the hanging wall were necessarily confined to the footwall and broke through into the hanging wall at some favorable structural locus.

4) There is evidence that the Sherwood ores have the highest thermal affinities of any in the hanging wall, and, to the south and east, mineralization had lower thermal characters.

5) There is evidence that to the south and east of the Sherwood the zoning of the deposits is also expressed by a diminishing amount of valuable metallization although the
thermal characters changed but slightly within the zone removed from the Sherwood.

6) There is evidence that the small area containing valuable deposits is located closest to the effective source and that although all the mineralization is intimately related to structure, only that portion which combined favorable structure and proximity to source has been abundantly metallized.

The following are the writer's personal opinions:

1) The London gold type of metallization is likely to be found for some distance south of the present workings of the London-Butte mine.

2) There is a relation between the Horseshoe-Sacramento ores and the London ores; the silver-lead ores represent a facies of the London gold ores which formed at a greater distance from the magmatic source.

3) The solutions which caused the London ores were confined to the broken zone in the footwall of the fault. The solutions which caused the Horseshoe-Sacramento ores had their local dispersive source in the ground beneath the region of the Sherwood mine and as their only evidences of activity are to be found in the hanging wall, it cannot be shown that they broke through the footwall.

4) Although the local source of the Horseshoe-Sacramento
metalliferous solutions is below or adjacent to the Sherwood ground, it is felt that the source was the same as for the solutions which effected the London mineralization. The close relationship of both kinds of ore to the structurally disturbed ground in the walls of the fault is evidence of considerable weight.

5) The earliest manifestation of epigenetic activity was silicification of country rock dolomite and breccias. This effected wide areas to greater or lesser degree but, to the writer's knowledge, no valuable ores of any type in the London zone have been found where some silicification, at least, has not occurred. The silicification was related to the early solutions and channels; metallization was localized by later solutions, channelways, and distance from source.

6) In the Horseshoe-Sacramento district, there are suggestions that pronounced brecciation following the introduction of barite allowed ingress of more of the later metallizing solutions than where it did not occur. This is borne out by the marked barite brecciation at the Sacramento mine, which was in the area favorable to receiving comparatively large amounts of lead and silver, whereas in the Nelson ores, containing highly fractured barite, there is abundance of later galena but this
locality was too remote from the source to receive a silver metallization.

7) It follows from (6) that the condition of channelways and of smaller fractures intimately governed the inflow, dispersion, and precipitation of the valuable metals. Therefore local structural adjustments during the period of mineralization activity was of prime importance in localizing ores within the favorable area nearest the source. The factors necessary were: (a) Nearness to source of solutions, (b) fractures permitting solution flow, (c) intra-mineralization brecciation allowing large surfaces to be replaced.
FUTURE OUTLOOK.

Economic.

Any future gold production of the area will be related to southward extension of the footwall fissure veins of the London type. The distance south of the London-Butte mine to which the favorable conditions are likely to obtain is a matter of conjecture only.

Lead-silver orebodies may be present in the footwall beyond the southern extreme of the gold mineralization. One might suppose that footwall structural conditions would be as favorable as those in the hanging wall for this type of replacement body. If search is to be made for such, another likely place to prospect is in the Leadville formation in the Sherwood area.

Three areas in the hanging wall contain possibly favorable ground for exploration. The triangular area bounded by London fault between the Sherwood and Mudsill mines and apexed at the Sacramento contains unexplored ground. There is some ground between the Sacramento mine and the 'Top of cliffs' prospect which is underlain by the Leadville. Most favorable in this area perhaps, is the buried west limb of the anticline between the fault and the anticlinal axis. Volumes of the Leadville formation are to be found in this ground in the presence of favorable structural conditions. The presence of ore will relate to whether or not suitable
channelways were available for solution travel at the proper time during the mineralizing epoch. This latter locality has been thoroughly prospected at the surface but the conditions at depth are not known.

The area northeast of the Sherwood mine on the opposite side of the stream presents attractive but dubious possibilities. The Leadville formation is poorly exposed and a considerable thickness of Weber(?) rocks lie between the westernmost Leadville outcrop and the supposed position of the London fault. Therefore a large amount of concealed Leadville is in the proper structural position. The question here relates to whether any amounts of solution penetrated the ground northeast of the Sherwood as there are no surface indications.

The third and least favorable area is that on Sheep Mountain. It is favorable structurally but unfavorable mineralogically as it was too remote from the source to receive great amounts of the valuable constituents. The rock on the crest of Sheep Mountain is White porphyry. The porphyry overlies a thin stratum of the basal Weber(?) beds which in turn overlies the Leadville formation. The Leadville has been traced around three sides of the peak but of course cannot be seen where it is bent downwards towards the fault beneath the porphyry except on the gulch wall at the north. The whole area is characterized by barite and silicification.
There is a possibility of ore in this area beneath the peak but if present, it will be lower in silver than the ores to the north and would probably consist of small galena bodies like that of the Nelson claim.

Prospecting in the district will entail expensive methods and the geologic promise for additional silver-lead orebodies is slight.

Geologic.

Unanswered problems have arisen during the course of the work and there is no likelihood of a solution to many of them. Some, however, which are to be outlined, are susceptible to conclusive results.

An attempt should be made to gather enough material from the different metallized localities to handpick the ores for galena assay. The galena-tennantite association insures that the results would demonstrate ratios of lead, copper, and silver.

Oriented specimens of recrystallized dolomite should be taken in order to ascertain if the recrystallization occurred under directed stress. It is felt that the whole question of recrystallization deserves further study.

Silicification types in the area are distinct and in the opinion of the writer, of varying character which reflects conditions of formation. A greatly increased number of specimens should be collected and studied, not only from
the Horseshoe-Sacramento district, but from Alma and Leadville. A regional pattern of more precise nature might result.

The significance of barite should be further investigated.

The source of the placer gold on Pennsylvania Mountain is a problem for which the truth may be found at some future time.

The structural relations are so complex and so important to the finding of ore that they deserve intense study. Unfortunately, complete solution will never be attained but any future underground operations in the Horseshoe-Sacramento area should be examined in order to gain as much as possible of the detailed structures.
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