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THE GEOLOGY OF THE LAKE ALBION REGION
BOULDER COUNTY, COLORADO

By Ernest Eugene Wahlstrom, B.A.,
(University of Colorado, 1931)

A Thesis submitted to the Faculty of the Graduate School of the University of Colorado in partial fulfillment of the requirements for the Degree M.A.

Department of Geology

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This Thesis for the M.A. degree, by

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Department of

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by

R. D. George

R. D. Crawford

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226274
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CONTENTS

Manuscript
Page

Introduction

Geography and Physiography

Structure

Petrography

226274
378.788B
W127a

CONTENTS

Manuscript
Page

Introduction

Geography and Physiography

Structure

Petrography

Manuscript
Page

Petrography (Continued)

Mineralogy

Procedure

Economic Geology

ILLUSTRATIONS

THE GEOLOGY OF THE LAKE ALBION REGION
BOULDER COUNTY, COLORADO

INTRODUCTION

Purpose of the Work

An effort has been made in this thesis to present the features of the geology, petrography, and ore deposits that were observed during the progress of the field work at Lake Albion and in the subsequent laboratory investigations.

The field work consisted of mapping and collection of rock and mineral specimens. The laboratory work included the analysis of minerals, and the examination of both thin sections and polished sections of the rocks and ores of the region.

It is the purpose of this paper to give information to persons interested in the mines or prospects who do not care for or understand technical descriptions, as well as to those interested in the more theoretical considerations.

Methods of Surveying

A plane table and telescopic alidade were used in the work. Frequently the Brunton compass-pace method was used in making minor traverses, and in the survey of mine workings. The Brunton compass was used exclusively in the measurement of strikes and dips. Large rock monuments erected on the points of a triangulation net established by Mann and Heentz in 1912 were used as primary triangulation points in the Albion survey. The Mann and Heentz triangulation net was established during the survey of the City of Boulder water shed. A base line of calculated length was taken from the map of the water shed.

Acknowledgments

The writer is indebted to Mr. Frank Bateman for his excellent assistance as an instrument man. A particular debt is owed to Professors R. D. Crawford and R. D. George at whose suggestion the work was undertaken, and under whose supervision it was completed. Thanks are also due Mr. J. Terry Duce, Mr. R. J. Watson, and Mr. Fred White for their kindly assistance and interest in the work.

GEOGRAPHY AND PHYSIOGRAPHY

Location.

The area discussed in this report covers approximately $2\frac{1}{2}$ square miles, and is included in sections 17, 18, 19, and 20 of Township 1 North, Range 73 West, and sections 13 and 24 of Township 1 North, Range 74 West, and lies almost entirely in Albion Valley, which is located in the extreme west-central part of Boulder County, Colorado.

Emphasis is placed in particular upon the geology and

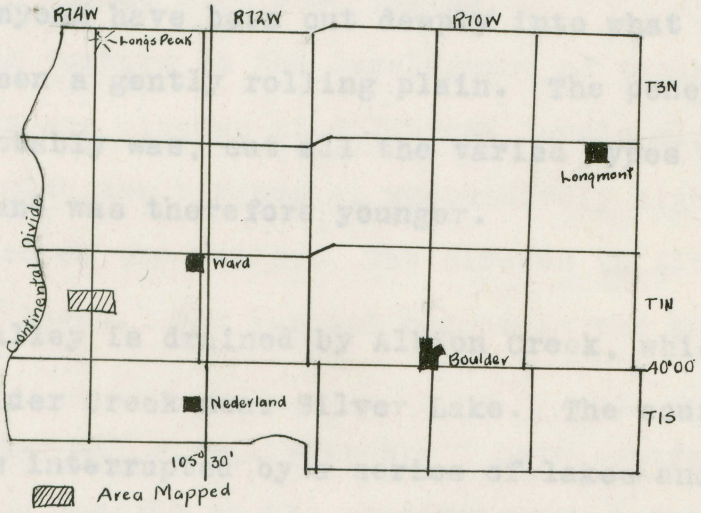

Figure 1. Outline Map of Boulder County Showing Area Mapped.

ore deposits of the area around the now abandoned mining camp at Camp Albion, Colorado.

Relief.

Albion Valley, in which Camp Albion lies, is in one of the ruggedest portions of the Colorado Rockies. To the southwest are North and South Arapahoe Peaks with elevations of 13,605 feet and 13,300 feet respectively. In the area of the map are Albion and Kiowa peaks with elevations of 12,596 feet and 13,101 feet. Just to the west are rugged Arikaree and Navajo peaks.

The difference in elevation between the floor of Albion Valley and the adjacent ridges averages from about 2,000 to 2,500 feet. The lowest point in the area mapped is at about 10,500 feet elevation.

From the tops of the ridges it can be seen that the valleys and canyons have been cut deeply into what appears to have once been a gently rolling plain. The peneplane, for such it probably was, cut all the varied types of rocks in the region and was therefore younger.

Drainage.

Albion Valley is drained by Albion Creek, which flows into North Boulder Creek near Silver Lake. The course of Albion Creek is interrupted by a series of lakes and waterfalls of glacial origin. Albion Lake, which is just west of Camp Albion, is the largest and easternmost of these lakes.

Dams have been built at Lake Albion and at Green Lakes Numbers 1 and 2 to retain the water and increase the capacity. The water is used for drinking and irrigation.

Vegetation.

Most of Albion Valley is above timberline. The eastern end, however, is below timberline and is heavily wooded. The edge of the timber is close to the mines and mine timber would have to be hauled only a short distance.

Glaciation.

The most effective agent of erosion in this area, without question, has been ice, in the form of valley glaciers. East of the mouth of Albion Valley a great pile of morainal and outwash material has been deposited irregularly to a depth of many feet and forms typical glacial topography. At the junction of the valleys of Albion Creek and North Boulder Creek a typical medial moraine can be seen. Albion Valley is a typical U shaped glaciated valley.

A striking feature is the development of tandem cirques. Tandem cirques are cirques at different levels along a glaciated valley with the cirques at successively higher levels toward the head of the valley. The cirques in Albion Valley are marked by lakes. The largest cirque is the one at Green Lake No. 3.

C. A. Morey* and W. D. Thornbury** have separately presented evidence leading to the conclusion that there have been two distinct periods of glaciation in this region. In their evidence they have considered such features as degree of weathering, different levels of morainal deposition, tandem cirques, hanging cirques, and benches. Their researches appear accurate, and because of their efforts, the glacial effects will not be considered further in this work.

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*C.A. Morey,"Glaciation in the Arapahoe and Albion valleys, Colorado", Master's Thesis, University of Colorado, 1927.

**W.D. Thornbury, "Glaciation on the east side of the Colorado Front Range between James Peak and Long's Peak", Master's Thesis, University of Colorado, 1928.

Climate.

Snow banks exist the year around in Albion Valley and the surrounding region. Most of the ground is covered by snow as late as June. There are very few nights that do not have temperatures very close to or below freezing.

During the summer months showers or snow flurries are very frequent. The wind blows most of the time, both in the summer and winter, and sometimes reaches a high velocity.

At Silver Lake the mean annual precipitation measured over a period of 13 years was 38.84 inches. The elevation of Silver Lake is 10,190 feet. A recording station near Long's Peak, to the north of Camp Albion, showed a mean annual precipitation of 21.38 inches, and a mean annual temperature of 37,5 degrees Farenheit. These records were made at an elevation of 8,956 feet.

The climate has been a strong factor in the prevention of the development of the mines at Camp Albion. Because of the rigorous weather the camp is snowbound a large part of the year. The heavy precipitation also makes the mines very wet, thus hindering the deep development of the veins.

Culture

Camp Albion may be reached by travelling approximately 4½ miles over a very poor road extending west from University Camp, which is situated about 5 miles north of Nederland, the nearest town of any importance. Another very poor wagon road connects Camp Albion with Silver Lake. The road from Nederland to University Camp is well graded and excellently maintained.

Nederland is a mining town of about 200 people. The inhabitants are supported mainly by the surrounding gold and tungsten mines, and, to a certain extent, by summer tourists. Daily stages connect Nederland with Boulder, the county seat of Boulder County.

Ward is a small town located 7 miles northeast of Camp Albion. The population is about 100. The main industry is mining. The mines around Ward have produced both gold and silver ores. A daily stage connects Ward with Boulder.

STRUCTURE

Intrusions

Intrusions in this region are of two different ages. The older intrusions are represented by three fairly large gneissoid igneous dikes and several smaller granitic and pegmatitic dikes striking generally northeast and occurring lit-par-lit in the older gneisses and schists. Two of these large dikes outcrop at the east end of the ridge separating Albion and North Boulder Creek valleys. These dikes can be traced to the southeast of the ridge where they cross North Boulder Creek Valley at Goose Lake. Northeast of the ridge the dikes are buried under alluvium and cannot be seen. The dikes are approximately 1000 feet wide.

The third large dike occurs along the precipitous northern face of Mount Kiowa, and also forms the cliff west of Green Lake number three. It can be traced eastward along the north side of Albion Valley where it is intersected at Green Lake number one by an intrusion of monzonite. This dike is about 1500 feet wide.

The younger intrusion is in the form of a stock which cuts across both the granite dike and the metamorphic rocks. Only the southern contact of this stock was mapped.

An outcrop of the monzonite was observed at Long Lake, about 2 miles north of Lake Albion. At this outcrop the monzonite is very coarse grained, indicating that it is part of a large intrusion. The mapped width of the southern boundary of the monzonite is approximately two miles. It is seen, then, that the monzonite has a surface area of at least four square miles and probably more. The monzonite bears no relation to the planes of schistosity of the metamorphic rocks and apparently has steeply inclined walls. (The above observations are given in justification of the term "stock".)

Small porphyry dikes have been intruded along some of the faults and fractures; however, their relation to the large intrusions or to each other is not known.

Faulting

Faults are numerous and, in general, are of small displacement. The faults are of different ages, and in some cases movement has taken place along a single fault plane at more than one time.

The most important fault in the area covered by the map is the fault located in the floor of Albion Valley near Camp Albion. The fault cuts both intrusives and the metamorphic gneisses and schists. In the metamorphic rocks the fault is confined to a zone about 6 feet wide. In the monzonite and syenite the fault zone widens and is sometimes as much as 30 feet wide where it has produced a breccia of striking appearance. It is in or near this breccia that most of the mineralization has taken place.

The displacement is not great. The dip is about 60 degrees to the north.

Another important fault extends from the northwestern edge of Lake Albion westward along the floor of Albion Valley and crosses the high mountain to the west of Green Lake number 4. (This mountain is not named on the U. S. Geological Survey map of the topography but has been called "Smith's Peak" on the map of the Boulder City water shed.) This fault has not cut the monzonite east of Albion Dam, so it is assumed that the fault plane abuts against the contact of the schist with the monzonite. The displacement along this fault could not be measured, but it is probably small. The fault plane is almost vertical. Just west of Green Lake number 3 the fault plane has been intruded by a small felsite porphyry dike. (Not shown on the map)

A third important fault cuts off the top of the granite dike west of Green Lake number 3 and extends eastward along the north side of Albion Valley.

Other smaller faults have been mapped, but no attempt was made to locate every small dislocation of the rocks. Many of these small faults are marked by small dikes or irregularly shaped felsite porphyry intrusions. It is the post-intrusion shattering of some of these dikes that indicates more than one period of movement along the faults. Another evidence of different periods of faulting is the intersection and offset of a small fault south of Lake Albion by the large fault first described.

PETROGRAPHY

Pre-Cambrian Metamorphic Rocks

Most of the exposed rocks in this region are gneisses and schists. East of Albion Valley exposures are not found because of the thick cover of glacial material. In Albion, North Boulder Creek, and James Creek valleys metamorphic rocks are the main type. The metamorphic rocks extend west to the continental divide and for miles beyond. The lamination of the rocks is emphasized by the lit-par-lit intrusions of pegmatitic and granitic material.

In Albion Valley the schists have a rather uniform dip and strike, and in places on the valley floor look very much like upturned resistant sedimentary beds. The strike averages about North 60 degrees East, and the dip is about 50 degrees to the northwest. From the character of the metamorphic rocks it is judged that they were originally sedimentary and consisted probably of shales and shaly sandstones.

Biotite sillimanite schist and gneiss predominate. Cordierite-sillimanite schists are also found. Some of the schists and gneisses contain much magnetite or garnets or both. The magnetite and garnets may have been formed by contact metamorphism as a result of monzonite intrusion.

Pre-Cambrian Igneous Rocks

A few specimens and thin sections of the pre-Cambrian rocks were studied in order to classify the various rock types in a general way. The following descriptions are not complete and may have to be revised upon further study.

There are two types of igneous rocks of probable pre-Cambrian age intruded into the gneisses and schists, both types forming prominent dikes paralleling the planes of schistosity of the metamorphic rocks. The two dikes at the eastern end of the ridge between Albion and North Boulder Creek valleys are quartz monzonite, and the dike outcropping along the north face of Mt. Kiowa and west of Green Lake number 3 is biotite granite.

Gneissoid Quartz Monzonite

The quartz monzonite varies from a light gray to a dark gray in color. The structure is mainly gneissoid, but some outcrops are distinctly massive. In general the strike of the gneissic structure is parallel to the strike of the dike. Because the quartz monzonite is not uniformly gneissoid, and because of the parallel orientation of the gneissoid structure and the dike, it seems probable that the structure is due to flow.

The quartz monzonite is coarse-grained and porphyritic in texture, but the size and number of phenocrysts are not constant. Near the lower part of the outcrop of the dike the quartz monzonite has numerous feldspar phenocrysts with a maximum length of an inch which forms about 50 per cent of the rock. The rock at this place should be called porphyritic quartz monzonite; however, it is not representative of the whole dike. Toward the middle and top of the dike the rock is more uniform in grain, and has only a few phenocrysts.

Black flakes of biotite, glassy looking quartz, and light gray feldspar can be recognized in the hand specimen.

The rock is badly weathered in places and appears as a mixture of chlorite, quartz, and kaolin.

The minerals, as determined under the microscope, are titanite, black iron ore, biotite,plagioclase, orthoclase, and quartz.

Titanite and black iron ore are accessory minerals. The titanite occurs in wedgelike crystals with a very high birefringence and a pronounced dispersion. The black iron ore occurs as small anhedrons with the biotite. The biotite occurs as highly pleochroic grains between the grains of feldspar and quartz. It forms about 15 per cent of the rock.

The plagioclase was determined by the Michel-Levy method. It varies in composition from labradorite to andesine. Many of the plagioclase grains are zonally banded, with labradorite in the center and andesine at the edges. Many plagioclase grains show crystal boundaries. Many orthoclase grains contain poikilitic inclusions of plagioclase and biotite, particularly the phenocrystic orthoclase. Small irregular patches of plagioclase and quartz appear to have replaced parts of the orthoclase grains. This is probably a deuteric effect. (The term "deuteric"classifies phenomena that are a result of late magmatic solutions acting on early formed crystals from the same parent magma). The quartz shows undulatory extinction and was the last mineral to form.

In the thin section the texture varies from equigranular to porphyritic. In the porphyritic varieties the ground mass is coarse grained and hypautomorphic. In the equigranular varieties the texture is hypautomorphic granular.

The percentage composition by volume of the different minerals varies somewhat. The plagioclase and orthoclase occur in nearly equal amounts, and the quartz forms from about 5 to 15 per cent of the rock.

The feldspars are all somewhat kaolinized, the plagioclase more than the orthoclase.

Biotite Granite

The biotite granite is a medium gray rock varying from coarse to medium to fine in texture. It is mainly massive, but some outcrops show a decided gneissoid structure. As in the quartz monzonite the gneissoid structure may be due to flow. Most specimens show a few scattered phenocrysts of feldspar.

The minerals that can be recognized with the naked eye or with the aid of a lens are biotite, muscovite, quartz, and feldspar. The biotite occurs as black, shiny flakes with a perfect cleavage. The biotite and muscovite make up about 10 per cent of the rock. The quartz has no cleavage and forms about 15 per cent of the rock. The feldspar shows excellent cleavage and is light gray. It occupies about 75 per cent of the rock by volume. The granite has not been weathered very much. A few of the feldspar grains appear to be slightly altered to kaolin.

The minerals determined under the microscope are black iron ore, muscovite, and biotite, plagioclase, orthoclase, and quartz.

The black iron ore occurs in small, scattered, opaque anhedrons. The biotite and muscovite occur either in parallel intergrowth or as separate grains. The biotite is unusual in that it appears to have formed mainly after the orthoclase. It occurs in small clusters of highly pleochroic grains in the interstices between the quartz and feldspar. It is possible that the biotite was originally precipitated in the normal order, but was dissolved and reprecipitated at a later stage. It forms about 5 per cent of the volume of the rock. The muscovite appears in some cases to have replaced the orthoclase, indicating that it, too, was one of the last minerals to form in the granite. It is an accessory mineral.

The plagioclase was determined by the Michel- Levy method to be calcic oligoclase. Some of the grains show partial crystal outline. The oligoclase froms about 5 per cent of the rock. The plagioclase show much alteration. The other minerals appear fresh in thin section.

The orthoclase forms about 55 per cent of the rock and, like the quartz, occurs in irregular grains. The quartz shows undulatory extinction. It occupies about 35 per cent of the volume of the rock. The texture is even grained and hypautomorphic.

The normal coarse grained granite, just described, grades in patches into a finer-grained, somewhat gneissoid rock that approaches quartz monzonite in composition. The plagioclase is andesine and is present in variable amounts and occupies a maximum of 20 per cent of the rock by volume. The other features of the rock, except for the finer grain, correspond with those of the normal biotite granite.

Pegmatite

Pegmatites occur lit-par-lit in the schists and gneisses and are particularly abundant near the large dikes above described, and are probably associated with these dikes. The dikes vary in width from a few inches to 10 or 15 feet. The pegmatites are very coarse grained and contain variable amounts of quartz and gray feldspar.

Under the microscope the quartz shows undulatory extinction. Both plagioclase and orthoclase are present. The plagioclase is generally calcic albite. None of the minerals show crystal boundaries and all occur in large grains. Alteration is not pronounced. The texture of the rock is pegmatitic and xenomorphic-granular.

Tertiary(?) Intrusions

The southern portion of the stock as it outcrops in Albion Valley is composed of monzonite and rocks differentiated from a monzonitic magma of slightly later age. The differentiates form dikes cutting across the monzonite and each other. The earlier differentiate is syenite and forms dikes up to 500 feet in width. The later differentiate is basic syenite and occurs in dikes up to 4 feet in width and cuts across both the monzonite and syenite.

Monzonite

Megascopic Description

The monzonite is a light to medium gray phanerocrystalline igneous rock. The hand specimens show a massive structure. In the outcrops of the monzonite the rock shows a cubical jointing which causes the rock to weather into blocks up to 2 or 3 feet in width. The texture of the monzonite is variable. Near the contact with the schist or granite the rock is medium-fine grained. Away from the contact it becomes much coarser and in places is almost as coarse grained as pegmatite.

Some of the finer grained monzonite is slightly porphyritic and shows a few small, scattered feldspar phenocrysts. An average specimen shows grains of fairly uniform size with the larger grains having a diameter up to ½ of an inch. The larger grains are gray feldspar and poikilitically enclose numerous small grains of a glossy black mineral and in a few cases a light brownish yellow mineral. The feldspar in the hand specimen is recognized by its light gray color and excellent cleavage. Some of the feldspar grains show two very good cleavages intersecting at right angles. The feldspar forms about 80 per cent of the rock by volume.

Besides the feldspar, there are two other conspicuous minerals. One of these is a black mineral which shows good intersecting cleavages and has a glossy luster. This mineral is either hornblende or pyroxene. The other mineral is titanite. It occurs as flat light brownish yellow crystals up to three-sixteenths of an inch in length. The black mineral forms about 20 per cent of the rock and the titanite 1 or 2 per cent by volume.

The monzonite has been only slightly altered. In the field the monzonite often has a thin coat of light grayish brown color which has probably been formed by the weathering of the hornblende or pyroxene and the staining of the rock by hydrous iron oxides.

Microscopic Description

The minerals that were determined in thin sections of several specimens from the monzonite stock are apatite, titanite, black iron ore, pyroxene, hornblende, plagioclase, orthoclase, and quartz. The apatite, titanite, black iron ore, and quartz are accessory minerals.

The apatite occurs in small, narrow prisms with a negative elongation. Cross sections of these prisms are frequently seen and form small hexagons. The mineral is colorless and has a low birefringence.

The titanite, as in the hand specimen, is a conspicuous mineral in the thin section. It forms large wedges, with a high relief and a very high birefringence. A few of the titanite crystals are twinned with the twinning plane parallel to the b axis of the crystals. An interference figure of the titanite shows marked dispersion $(\rho > v)$ and a positive optical character.

The black iron ore is titaniferous magnetite. Some of the monzonite was powdered, and the magnetite was easily separated from the powder with a magnet. The mineral was tested and gave a positive reaction for titanium. Because the mineral is very magnetic, it was believed to be magnetite and not ilmenite.

The pyroxene is somewhat variable in composition. It occurs either in very pale green grains, or in light green to yellowish green grains, or in crystals showing gradations between the two. In the crystals showing both, the darker green variety is always at the outer aprt of the grain. By volume the ratio of green to very pale green pyroxene is about 4 to 1.

The thickness of some sections could be determined by observing the maximum interference, color in quartz grains, and referring to a table of birefringences. In these sections the pale green pyroxene was found to have a birefringence of about .025 and the green pyroxene a birefringence of about .019. The grains showing maximum interference colors have extinction angles measure from the trace of the prismatic cleavage to the Z axis varying from a maximum of 42 degrees for the pale green grains to a maximum of 50 degrees for the green. The green mineral is somewhat pleochroic; the color varies from green in the direction of the X axis to yellowish green in the direction of the Z axis. Sections cut at right angles to the prismatic cleavages show two sets of cleavages intersecting at nearly right angles. By means of these data the pyroxene was determined to be pale green diopside containing a large per cent of iron and grading into almost pure, green hedenbergite.

The hornblende is strongly pleochroic. In the position of least absorption (X), the color is yellowish green, and changes through grass green to deep green in the position of greatest absorption (Z). The highest angle, measured from the trace of prismatic cleavage, is 32 degrees ($Z \wedge c$). The high extinction angle is characteristic of the mineral pargasite, which is a variety of hornblende. The grains of hornblende are elongate, and show good prismatic cleavage intersecting at angles of about 55 and 125 degrees. Some grains show intergrown hornblende and pyroxene, but in most instances the two minerals occur separately.

The plagioclase occurs poikilitically in the orthoclase as small crystals and as grains in contact with the orthoclase and other minerals. It is sometimes zonally banded and, in such cases, varies from andesine in the center of the grains to calcic oligoclase on the rim. The feldspars are twinned after both the Carlsbad and albite laws and could be determined by the Michel-Levy method.

Many orthoclase grains have and unusual appearance. Almost every slide shows stringers or irregular patches of a more highly birefringent mineral, which is probably albite. The albite appears to be a deutric replacement of the orthoclase, and, following the nomenclature proposed by H. L. Alling* the orthoclase and albite form "deuteric perthite". "Deuteric perthite" is that variety of perthite which is produced by the irregular replacement of an early formed feldspar by a later one, both feldspars crystallizing out from the same magma but at different times.

In the thin section the replacing albite generally appears in elongate, often wormlike, patches and in irregular blebs. It is probable that the irregular blebs correspond to cross sections of the elongate patches. In an individual grain of orthoclase all the patches extinguish at the same position. The long direction of the replacing albite makes a maximum angle of about 15 degrees with the trace of basal cleavage of the orthoclase.

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* H. L. Alling, "Perthites", The American Mineralogist, Volume 17, Number 2, pps. 46 - 65, 1932.

Evidence that the perthite is due to deuteric replacement is found in the following facts:

1. The blebs are large and have irregular outlines. This precludes the possibility of the perthite being formed by exsolution or unmixing if the constituents of the orthoclase as the magma cooled. Exsolution perthite** is characterized by thin, stringlike blebs that have formed in shrinkage cracks. Further evidence that the perthite is not due to unmixing is presented by the fact that the orthoclase does not bear a constant ratio by volume to the replacing albite. Exsolution perthite probably would show a constant ratio between the volumes of orthoclase and unmixed albite.

2. The orthoclase is the only mineral affected, and the albitization is the only process that acted to change the character of the orthoclase. If solutions had acted on the feldspar in the last stages of consolidation of the magma, it seems likely that kaolinization would be evident. It does not seem probable, then, that pneumatolytic or hydrothermal replacement has been active.

3. Small, irregular patches of albite have been deposited on the rims and between the grains of some of the orthoclase. This suggests that albite is one of the very last constituents of the magma to crystal-

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**H. L. Alling, "Perthites", <u>The American Mineralogist</u>, Volume 17, Number 2, pps. 46 - 65, 1932.

lize.

From the above statements it is seen that the perthite probably was formed in a late stage of the consolidation of the magma, and that solutions original to the magma, and rich in the albite molecule, attacked and partially replaced the earlier crystallized orthoclase. Such replacement is defined as "deuteric" and fits the meaning of the word as recently defined by Alling*.

Thin sections of the monzonite show that the texture is poikilitic and hypautomorphic.

Quartz occurs in small interstitial grains. It was seen in only a few of the slides that were examined.

Estimation of the mineral composition of the rock in per cent of the total volume gave the following: orthoclase, 45 per cent; plagioclase, 40 per cent; mafic minerals, 12 per cent; and accessory minerals, 3 per cent.

Normal Syenite

The syenite is a light gray, medium grained, massive rock occurring as dikes cutting the monzonite or as bodies grading into monzonite. It is found in the monzonite only and in believed to be a differentiation product of part of the monzonitic magma.

Examination of the hand specimen shows a great predominance of feldspar and very little ferromagnesian minerals. The feldspar is light gray and shows good cleavage. In addition to the feldspar a black shiny mineral with good

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*H. L. Alling, "Perthites" Loc. cit.

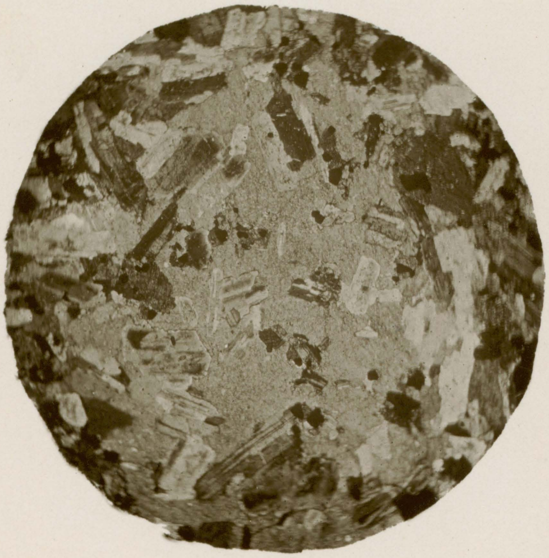

Figure 2. Photomicrograph of monzonite showing poikilitic inclusion of plagioclase by orthoclase. Magnification 10X.

cleavage can be seen. This is probably either hornblende or pyroxene. This mineral constitutes less than one per cent of the rock and occurs only in small scattered grains.

Examination of the thin section shows the following minerals: garnet, titanite, hornblende, plagioclase, and orthoclase. The garnet is isotropic and euhedral. It has a brownish color and probably is the variety melanite. The crystals are small and few in number. The titanite occurs in small wedges, with high relief and a high birefringence, giving white of a higher order as an interference color.

The hornblende is dark green and has the same features shown in the hornblende found in the monzonite. It occurs sparsely and in small grains.

Plagioclase forms about 5 per cent of the rock. Most of the grains show distinct zonal banding and vary from oligoclase in the centers of the grains to albite on the edges. The plagioclase is twinned polysynthetically after the albite law, and the twinned lamellae are generally very closely spaced.

The orthoclase has an unusual appearance. It is replaced by a more highly birefringent mineral from a few per cent to 75 by volume. The replacing mineral is probably albite and occurs as irregular patches or stringers in the orthoclase, giving it a microperthitic appearance. As in the monzonite the replacement is probably due to deuteric action of albite rich solutions, which, in the late stages of the consolidation of the

Figure 3. Photomicrograph of syenite showing deuteric replacement of orthoclase (gray) by albite (white). Magnification 35X.

rock attacked the already crystallized orthoclase. The orthoclase forms approximately 90 per cent of the rock by volume.

Thin sections show that the texture is xenomorphic-granular. The mineral grains are fairly uniform in size.

The rock does not show much alteration that can be attributed to outside agencies. The deuteric replacement is considered magmatic in origin.

Basic Syenite

This rock occurs as narrow dikes cutting across both normal syenite and monzonite. It is a dark gray, fine-grained, massive rock showing two minerals in the hand specimen: one, a black cleavable mineral which is either pyroxene or hornblende, and the other a light gray mineral with a good cleavage which is probably feldspar. The relative proportions of these minerals are difficult to determined because of the small size of the individual grains.

The minerals, as determined under the microscope, are apatite, titanite, hornblende, pyroxene, plagioclase, and orthoclase. The minerals, except pyroxene, are identical with those of the monzonite. The ratio of hedenbergite to ferriferous diopside is here approximately 10 to 1.

Estimation of the percentage composition gave the following results: orthoclase, about 60 per cent; plagioclase, about 15 per cent; and mafic minerals, including hornblende and pyroxene, about 25 per cent.

The texture is hypautomorphic and poikilitic. The mafic minerals very often occur as small crystals in the larger orthoclase grains. The grains of orthoclase and plagioclase are interlocking and are uniform in size.

Quaternary Deposits

Alluvium

The youngest formations are the deposits of glacial material and the large talus slopes that are very common.

In the valleys streams have eroded away most of the glacial material and only occasional remnants are seen. However, the streams have not been able to move the great piles of angular talus rock that have formed at the bases of the cliff-like walls of the valley.

The tops of the ridges north and south of Albion Valley are covered by a thin layer of sharply angular rock that has probably been formed by frost action. The character of the angular fock conforms to that of the underlying rock and seems to confirm the view that the fragments are formed by the action of frost.

Vein Breccia

Most of the mines at Camp Albion are located on a fault trending generally east-west and cutting schist, monzonite, syenite, and quartz monzonite. This faulting, aided by subsequent mineralization, has produced in the monzonite and syenite a breccia of striking appearance. The brecciated zone is in places as wide as 30 feet and consists of angular to rounded fragments of syenite and monzonite embedded in a grayish to brownish matrix. The individual fragments vary in size from about a quarter of an inch to 6 inches in diameter. The fragments are often rounded and probably have been shaped by the grinding together of the brecciated fragments by movement along the fault in which the breccia occurs. The fragments along the greater part of brecciated zone are monzonite. However, at one place the fault has cut across syenite and has produced a very conspicuous breccia. This breccia has been worked for its mineral content at the Albion shaft.

The fragments in the syenite breccia are light gray and the matrix is dark gray. The minerals that can be recognized in the hand specimen in the matrix are quartz, light gray asbestos, greenish to gray pyroxene, feldspar, chalcopyrite, pyrite, and galena. The pyroxene is by far the most abundant mineral in the matrix. The brecciated fragments are mainly light gray feldspar.

Where the fault has cut the monzonite, the brecciated fragments are medium gray and do not contrast with the color of the matrix as sharply as the syenite.

The minerals in the matrix do not appear to have been deposited simultaneously. The order of deposition, not considering the metallic minerals, is first, pyroxene, then asbestos, and finally quartz. The minerals appear in a banded arrangement in some of the seams in the breccia and in such cases the pyroxene forms bands on the walls of the seams, and the quartz forms lenticular shaped masses in the center. The asbestos, where it is seen, occurs between the quartz and pyroxene or in bunches between the pyroxene grains. Another evidence that quartz is formed last is that it seems to be replacing the pyroxene. The quartz occupies the central parts of many pyroxene crystals and has shreds of pyroxene suspended in it, giving the appearance of irregular corrosion of the earlier formed pyroxene. The quartz has a grayish color due to the suspended shreds of pyroxene.

Microscopic examination of thin sections of the breccia shows the following minerals: in the syenite fragments, orthoclase and plagioclase feldspar; and in the matrix, pyroxene, asbestos, quartz, carbonate, and sulphide ores.

The syenite closely resembles the normal syenite described above except that the feldspars are partly kaolinized, and the accessory minerals are altered or not present.

The pyroxene of the matrix was determined by optical and chemical means to be diopsidic aegirite. The pyroxene lines the walls of the seams in the breccia and first formed enhedral monoclinic crystals with a dark green color. These crystals appear to be compact and homogeneous. Deposited in a band around some of the crystals and in parallel arrangement is a second generation of diopsidic aegirite.

This second generation of pyroxene is fibrous and less compact than the first generation and in general is a more yellowish green than the first formed pyroxene. However, its extinction angles and other optical properties coincide with those of the early pyroxene.

The diopsidic aegirite shows well developed pyroxene cleavage. Two sets of good cleavages intersecting at approximately right angles can be seen in sections cut at right angles to the c axis. Some of the grains of pyroxene show a well developed parting that might be mistaken for cleavage. The direction of the plane of parting could not be definitely determined, but it is not basal. A section of the mineral cut parallel to the clinopinacoid did not show any traces of the parting. The maximum extinction angle of the diopsidic aegirite, as measured in the oriented section just mentioned, is 17 degrees ($X \wedge c$). The mineral is biaxial and positive in character.

The asbestos occurs in fibrous masses between the grains of pyroxene. Only a few patches were observed. The highest extinction angle measured was 37 degrees.

The quartz was one of the last minerals to crystallize. It has attacked some of the pyroxene grains and has partly or almost completely replaced them. The fibrous pyroxene has been attacked more than the compact variety. Some sharp crystal outlines remain in the compact pyroxene indicating very little corrosion by the quartz; however, some of the compact pyroxene grains have been replaced at the center by the quartz.

The carbonate occurs in small, irregular patches and probably is an alteration product resulting from the alteration and replacement of the pyroxene. The carbonate shows good rhombohedral cleavage and has a very high birefringence.

The sulphides are pyrite, galena, and chalcopyrite, and occur in irregular grains in the matrix of the breccia.

MINERALOGY

The ores at Camp Albion show an unusual association of gangue and ore minerals. A detailed study of two of the gangue minerals was made in order to determine their optical properties and chemical compositions. For purposes of description the minerals are classified as gangue and ore minerals. The ore minerals include the metallic sulphides. The gangue minerals include all other minerals found in the veins.

Gangue Minerals

Diopsidic Aegirite

This mineral occurs in all the veins of the district. It is medium gray to greenish gray to black. In the veins the color is generally gray, but where the mineral is found in crystals in seams, it is glossy black. The powder is gray.

The mineral crystallizes in the monoclinic system and shows the following forms: unit prism, positive orthodome, and in a few crystals, a small clinopinacoid. The orthodome was distinguished from a basal pinacoid by measuring the angle between the trace of the prismatic cleavage and the face in question in a thin section of a crystal cut parallel to the clinopinacoid. The angle was determined to be 74 degrees. This agrees with the angle between the orthopinacoid(100) and orthodome($\bar{1}01$) given in Dana's "System of Mineralogy" for the pyroxenes.

Dana, J. D. and Dana E. S., "System of Mineralogy", Sixth Ed., John Wiley and Sons, New York, 1911.

The cleavage is prismatic and is well developed. The structure is fibrous to massive. The hardness is 6, and the specific gravity about 3.3. The fusibility is 4. The following data were noted in thin section: extinction angle, 17 degrees ($X \wedge c$, in the acute angle beta); high relief; biaxial positive; pleochroic, X - green, Z - yellowish green. The index was determined to be greater than 1.70 in oils.

The results of the analysis are as follows:

	Per cent	Molecular Ratio
SiO_2	57.00	0.946
Al_2O_3	4.05	0.039
Fe_2O_3	15.87	0.099
FeO	2.57	0.035
MgO	4.64	0.114
CaO	8.38	0.149
Na_2O	6.35	0.106 (Na_2O plus K_2O)
K_2O	0.39	
H_2O (above 110)	0.25	
TiO_2	1.03	0.012
	100.53	

Following the methods outlined by Washington and Merwin* in their study of the acmitic pyroxenes, the following molecular composition was determined:

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*H. S. Washington and H. E. Merwin, "The acmitic pyroxenes" The American Mineralogist, Volume 12, Number 6, pps. 223-251, 1927.

	Per cent
$(Na,K)_2O.Fe_2O_3.4SiO_2$	45.10
$(Na,K)\ O.Al_2O_3.4SiO_2$	2.65
$CaO.MgO.2SiO_2$	25.37
$CaO.FeO.2SiO_2$	8.07
$Al_2O_3.3SiO_2$	9.17
SiO_2	8.59
TiO_2	1.04
	99.93

Some of the powder analyzed was examined under a microscope and was found to contain a few grains of quartz. This explains the large excess of uncombined silica reported in the molecular percentage column.

Disregarding the quartz and considering only the combined molecules, the mineral is classified as diopsidic aegirite. According to Washington and Merwin* the mineral should be named "diopsidic acmite", but because the physical properties of the mineral above described agree with those of aegirite as it is defined in common usage, the term "aegirite" is used here.

Asbestos

Asbestos occurs in all the veins, but in variable amounts. It is found either in irregular bunches between grains of pyroxene or in thin bands in the center of a vein. In the bands the long direction of the fibers is parallel to the walls of the veins and not crosswise as

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*Loc.cit.

is the case in many occurences of asbestiform minerals. The fibers in the irregular bunches do not have any constant orientation. Single fibers were measured that had a length of 2½ inches.

The asbestos is light grey. It is easily fusible at about 3 and colors the flame a brilliant yellow due to the high sodium content. If the flame is observed through a blue glass, a violet coloration, due to potassium, can be seen. The hardness and specific gravity were not determined because of the finely fibrous character of the mineral.

The following optical properties were determined from immersions of the asbestos in oils. The highest extinction angle measured from the trace of the prismatic cleavage to the X axis is 39 degrees. The mean index of refraction is about 1.630. The mineral is slightly pleochroic and shows pale yellows and pale yellowish greens. The angle of intersection of the cleavages could not be determined, but from the chemical composition it seems likely that the mineral is an amphibole, or is related to the amphibole group. The asbestiform structure is common in the amphibole minerals.

In the analysis of the mineral all results were checked by a parallel analysis except the alkalies. In the alkali determination great difficulty was experienced in obtaining a proper fusion and extraction. The results of the most successful fusion were taken, and, from the total summation appear accurate. However, the percentages of the alkalies are to be regarded with some doubt until verified.

The analysis is as follows:

	Per cent	Molecular Ratio
SiO_2	56.48	0.952
Al_2O_3	1.22	0.012
Fe_2O_3	8.38	0.053
FeO	2.67	0.037
CaO	2.70	0.048
MgO	17.40	0.437
Na_2O	8.09	0.132
K_2O	1.82	0.019
H_2O (above 110°)	0.87	
TiO_2	0.30	
	99.93	

Calculations, using this analysis, give the following formula for the asbestos:

$25(Na,K)_2O.8CaO.72MgO.6Fe_2O_3.2Al_2O_3.157\ SiO_2$

This formula does not correspond to that of any mineral that could be found in the literature available to the *writer. Further study is needed to prove that it is a* new mineral.

Quartz

The quartz is milky white and occurs either in crystal form or granular. Crystals were formed in open cavities in the veins.

Professor A. B. Sperry kindly loaned the writer a specimen of green quartz that he found in a prospect pit at Camp Albion. The specimen shows a mixture of grayish green quartz and colorless quartz. A thin section shows the presence of a great many small, elongate crystals in the green quartz. Some of these crystals have a very low birefringence and are apatite. Wet tests showed the presence of phosphate in the quartz. The other crystals gave a maximum extinction angle of 36 degrees measured from the long direction of the crystals. End sections of the crystals appear to have amphibole outline. Both the apatite and amphibole(?) are faintly green in the thin section, and it is probable that the green color of the quartz is due to their presence.

Feldspar

Feldspar occurs in most of the veins as scattered light gray grains showing good cleavage and having a hardness of 6. It is probably soda-bearing orthoclase.

It is biaxial positive and has the following indices, as determined in oils: alpha, 1.518; and gamma, 1.525 From these figures the birefringence is about .007. The maximum extinction angle measured from the trace of the basal cleavage is 8 degrees.

Calcite

Calcite occurs in small white to grayish masses showing a perfect rhombohedral cleavage. It is easily scratched with a knife blade. It is found only in the veins.

Barite

According to Professor R. D. George small amounts of barite have been found in the tunnel of the Snowy Range mine.

Ore Minerals

Pyrite

Pyrite occurs in the veins. It is massive and contains a small amount of copper. It has a hardness of 6.

Chalcopyrite

The chalcopyrite is massive. It is brass yellow and has a hardness of 4. It is often coated with an iridescent film of sulphide. It occurs in the veins and as replacements in the vein walls.

Galena

The galena found in the veins with the diopsidic aegirite and asbestos shows well developed octahedral cleavage. The galena replacing the wall rock of the veins shows both cubic and octahedral cleavage.

Alteration

The veins at Camp Albion have undergone only slight alteration due to secondary processes. The only noticeable change in the ores is the local oxidation of the iron ores to limonite.

Procedure

Separation of the Minerals for Analysis

In the selection of material for analysis only the freshest was used.

Because of the difficulty of separating the minerals to be analyzed from the minerals with which they were associated, it was found necessary to use means other than sorting with a lens and tweezers to obtain pure materials.

In the case of the diopsidic aegirite it was found necessary to remove galena and quartz. Most of the quartz was removed by mixing the powdered mineral with bromoform in a separating funnel. The diopsidic aegirite sank and was drawn off. The powder was caught on a filter paper and thoroughly washed with alcohol and then dried at a gentle heat (about 110° C). It was then boiled in concentrated nitric acid for 10 minutes in order to oxidize the galena to $PbSO_4$. The HNO_3 was removed by washing the powder with water, and the $PbSO_4$ was removed by boiling the powder in ammonium acetate solution. The powder was again caught on a filter paper and thoroughly washed with warm water. The powder was then dried and bottled for analysis.

In preparing the asbestos for analysis it was found necessary to remove only the calcite that was intimately mixed with it. The calcite was removed with warm dilute HCl. The HCl was removed by washing with water. The asbestos was then dried for two hours at a gentle heat (about 110°C) and placed in a bottle for analysis.

Methods of Analysis

Methods of chemical analysis outlined in the textbook "Chemical Analysis of Rocks" by H. S. Washington* were used in the chemical analysis of the two minerals above described. Occasional reference was made to the book by Hillebrand and Lundell** "Applied Inorganic Analysis".

In order to assure accuracy in the results of the analysis, every precaution was observed. In order to correct for impurities in the reagents, a blank analysis was made, using the same amounts of fluxes and reagents as used in the mineral analysis.

Analyses of each mineral were made in duplicate, and sometimes a third analysis was made in order to be reasonably sure of the results. If two results checked closely, they were taken to be accurate. If they varied, the third analysis was made, and if it checked one of the first two results, the two checking results were accepted. The average of the two results is reported.

In the determination of the alkalies, it was found necessary to vary the customary procedure of the J. Lawrence Smith method. One requisite of this method

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* H. S. Washington "Chemical analysis of rocks", Third edition, John Wiley and Sons, New York, 1919.

** W. F. Hillebrand and G. E. F. Lundell "Applied inorganic analysis", John Wiley and Sons, New York, 1929 is that the substance to be analyzed be ground to an impalpable powder in order that it may be mixed very intimately with the fluxes used in making a fusion. It was found impracticable to powder the asbestos.

The fluxing agents used in the J. Lawrence Smith method are $CaCl_2$ and CaO. These two substances are obtained by heating a mixture of $CaCO_3$ and NH_4Cl. The reactions are as follows:

$$CaCO_3 + 2NH_4Cl = CaCl_2 + 2NH_3 + CO_2 + H_2O \text{ and}$$

$$CaCO_3 + \text{Heat} = CaO + CO_2$$

The CaO and $CaCl_2$ attack the substances being analyzed, and form compounds of calcium with ironoxides, alumina, silica, et al, insoluble in water, and also chlorides and oxides of sodium, potassium, and calcium which are very soluble in water. These soluble compounds are then separated from the fusion by leaching with water.

In the case of the asbestos it was found practicable to dissolve the NH_4Cl in water and add this to the mineral in a platinum dish. The narrow end of a platinum spatula was employed to fray the fibers of asbestos and allow the NH_4Cl solution to moisten as much of the material as possible. Then finely ground $CaCO_3$ was added and intimately mixed with the asbestos and NH_4Cl solution. This paste was transferred to a platinum crucible which had about an eighth of an inch of $CaCO_3$ in the bottom to prevent sticking of the fusion. The platinum crucible was placed in a drying oven and the paste dried.

After the paste was dry, the crucible was removed from the oven and placed in a hole cut in an asbestos board which allowed about ½ of the crucible to protrude through. A beaker of water was placed on the lid of the crucible to keep the upper part of the crucible cold and prevent the volitization of the chlorides of Potassium and Sodium. The flame from a bunsen burner was gradually applied until the bottom of the crucible became a dull red. This temperature was maintained for two hours when the flame was removed, and the crucible was allowed to cool. The chlorides were then removed by leaching, and the further steps were the same as those of the general procedure in the ordinary method.

This method does not have a general application and should be used only where the ordinary method is impractible.

ECONOMIC GEOLOGY

The Mines

Only one mine has produced ore in notable quantities. The Snowy Range mine and mill were worked during the summer of 1909 and produced 482 tons of lead concentrate, which, according to Mr. E. E. Miller, M. E., carried the following average values per ton: gold, .07 ounces; silver, 27 ounces; and lead, 41 per cent. Zinc was also reported but in variable amounts.

The mill in which the ores were concentrated has been dismantled, and little is left but the foundations. The mill, when operating, had a daily capacity of 50 tons.

The Snowy Range tunnel is about 700 feet long and is located in a mineralized fault and breccia zone. The ore minerals are galena, sphalerite, copper-bearing pyrite, and chalcopyrite. These minerals occur in a gangue consisting of diopsidic aegirite, asbestos, quartz, feldspar, and calcite.

The Eureka tunnel is about 260 feet long and has been driven into the Eureka vein, which is about 18 inches wide and consists of banded pyroxene and quartz with disseminated sulphide, asbestos, and calcite.

The Eureka vein branches off from the Snowy Range vein. The intersection is on the Snowy Range property. The Eureka vein is north of the Snowy Range vein.

Shafts have been sunk on the Albion and Monarch claims but have produced little ore. Most of the other claims have shallow shafts or short tunnels. None of these has produced any good ore.

The ground between the several claims has been patented as a placer. This placer claim is called the Minnie S. and has not yet been a commercial producer. It is doubtful that the gravels contain enough gold for profitable placering.

The Ores

The ore deposits at Camp Albion are probably high-to-medium-temperature deposits. The banding in the veins with the pyroxene next to the wall rock and the quartz in the middle of the vein suggests a variation of conditions during the formation of the vein. The pyroxene probably was deposited at a temperature of about 500 degrees C. The quartz has the apperrance of pegmatitic quartz and probably was deposited at a temperature of about 400 degrees C. or lower.* The banding, then, is explained by a progressive cooling of the ore bearing solutions as they passed through a faulted and fractured zone in the solidified monzonite and syenite.

Another factor influencing the deposition of the ores was the nature of the wall rock. The gneiss and schist have not been mineralized as have the monzonite and syenite, and the difference in deposition is probably due to the chemical composition of the metamorphic rocks

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* Waldemar Lindgren, "Minerl deposits", McGraw-Hill Book Co., New York, Third edition, pps. 718-724, 1928.

which is often unfavorable for the precipitation of ore minerals.

A brief examination of polished sections of the ores indicated the following probable order of deposition of the sulphide minerals: pyrite, sphalerite, chalcopyrite, and galena. The sulphides appear to have replaced the gangue minerals in the veins and the later sulphides the earlier. In some of the veins the wall rock has been replaced by sulphides. This replacement has generally extended only a few inches beyond the limits of the vein proper.

Future of the District

Anyone interested in successfully developing the properties at Camp Albion must take into consideration the following factors: the rigorous climate, the great amount of ground water, and the distance from the mines to a smelter. Another factor that must be considered is the method of milling the ores. The presence of the tough, fibrous asbestos might complicate the milling process.

The ore bodies are well marked and continuous. The veins vary from less than an inch to 8 or 10 feet in width. The sulphide content of the veins is variable along their length and in cross section.

It may be said with a fair degree of certainty that the mineralization does not extend beyond the limits of the monzonite and that development of veins in the metamorphic rocks is likely to be unprofitable.

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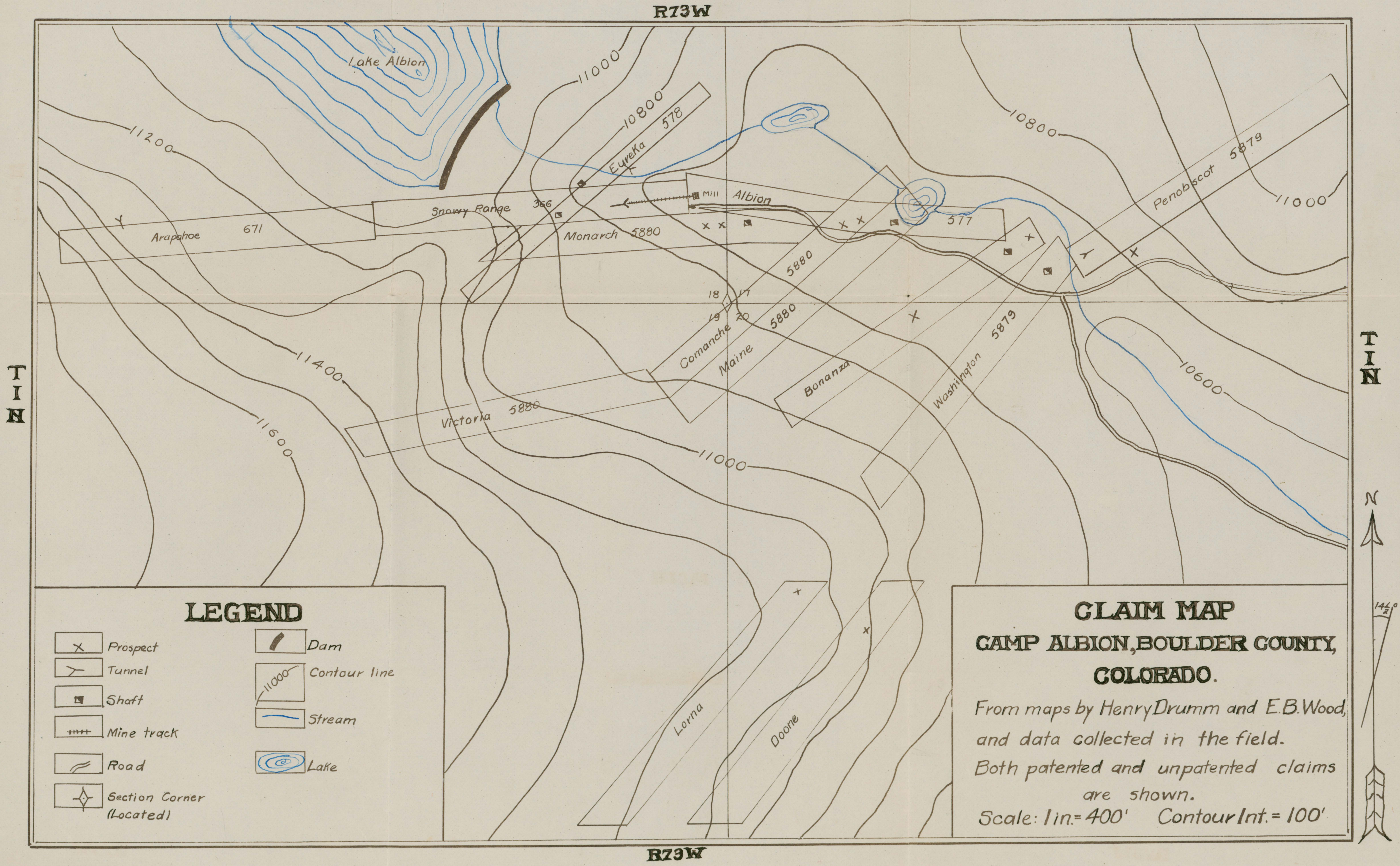


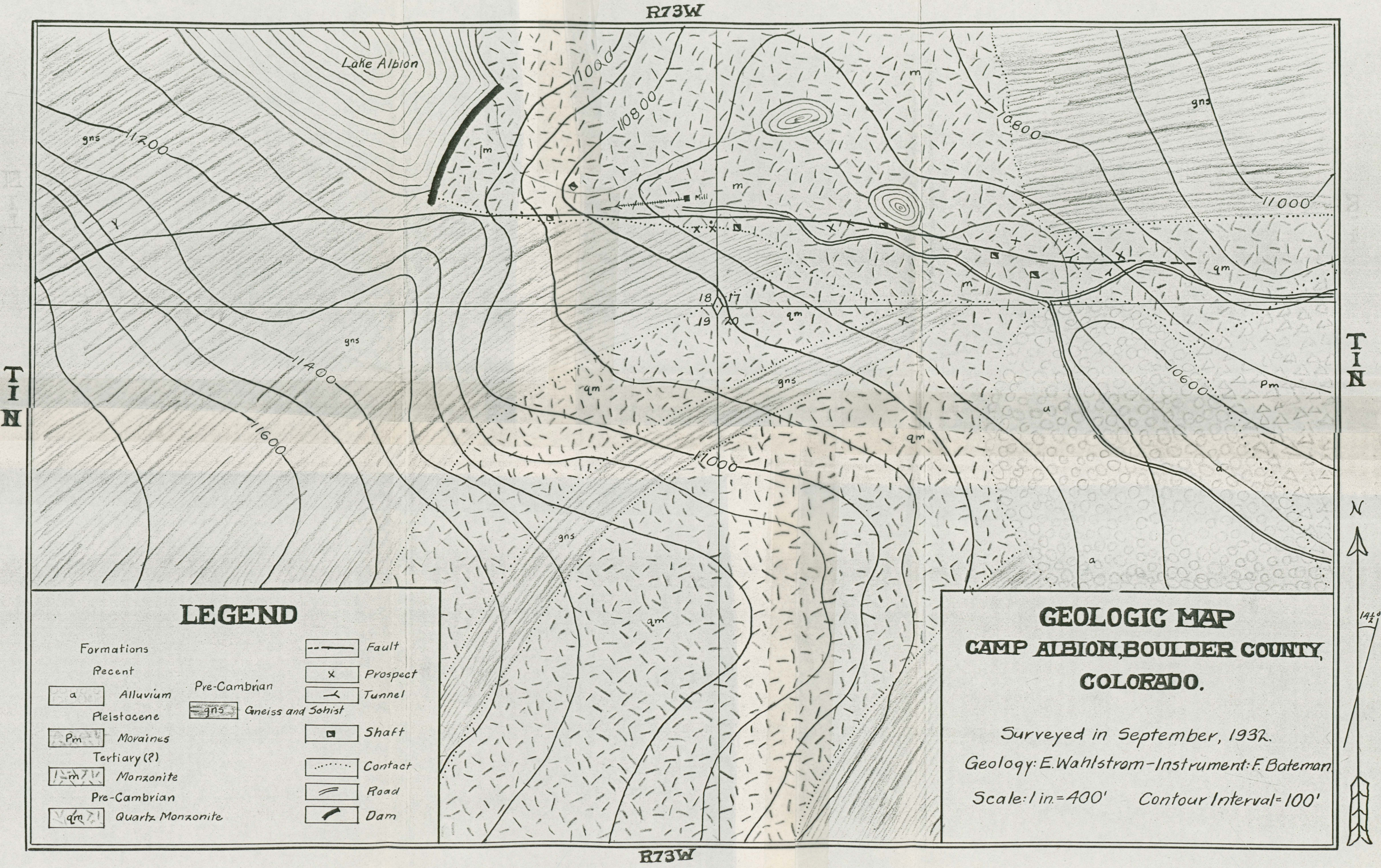
CLAIM MAP

CAMP ALBION, BOULDER COUNTY, COLORADO.

From maps by Henry Drumm and E.B. Wood, and data collected in the field.

Both patented and unpatented claims are shown.

Scale: 1 in. = 400' Contour Int. = 100'



GEOLOGIC MAP
CAMP ALBION, BOULDER COUNTY, COLORADO.

Surveyed in September, 1932.

Geology: E. Wahlstrom - Instrument: F. Bateman.

Scale: 1 in. = 400'   Contour Interval = 100'

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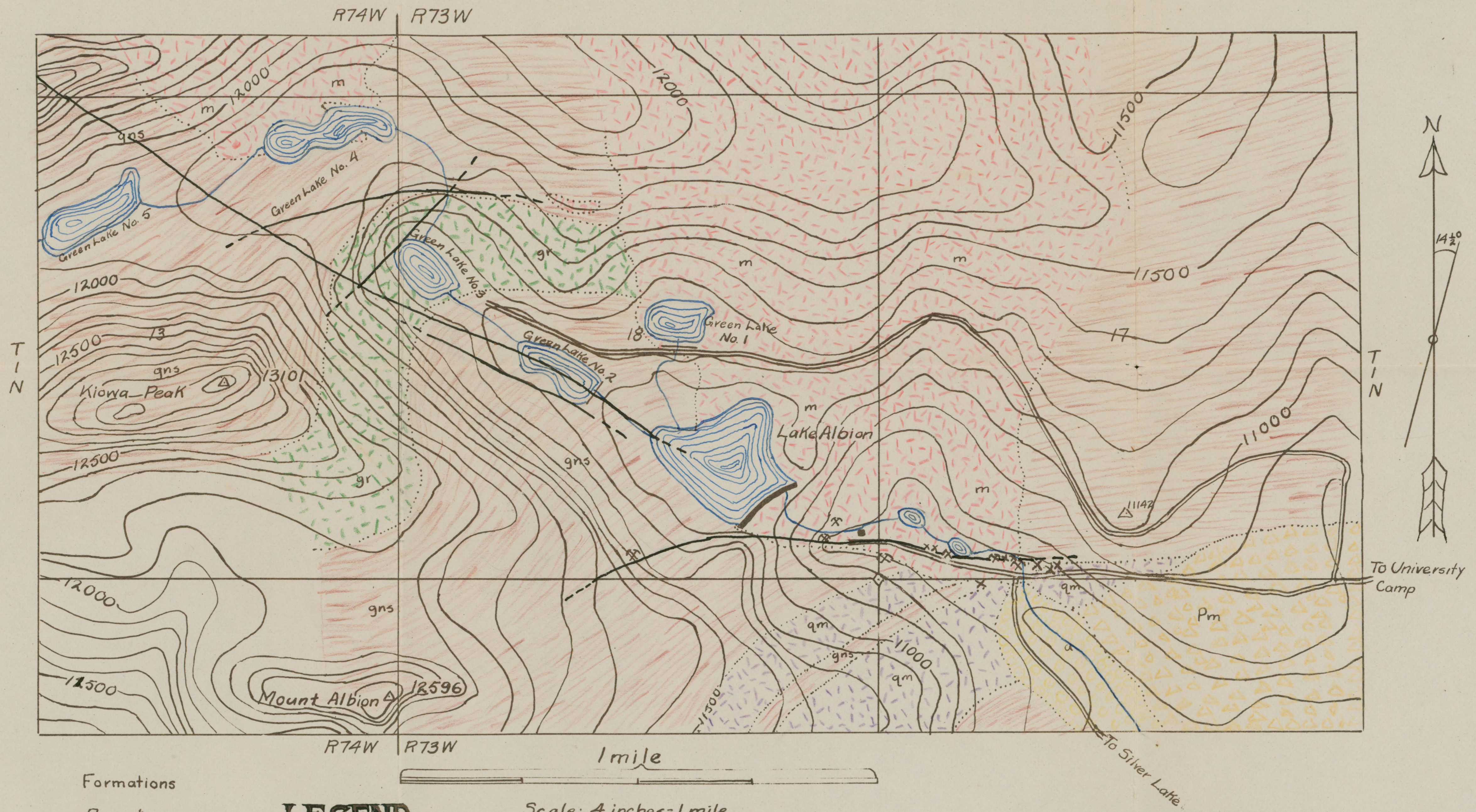

LEGEND

Formations

Recent

a Alluvium

Pleistocene

Pm Moraines

Tertiary(?)

m Monzonite

Pre-Cambrian

gr Gneissoid granite

qm Gneissoid quartz monzonite

gns Gneiss and schist

Scale: 4 inches = 1 mile

Contour Interval = 100 feet

┈ Contact (Mapped)

— · — Fault

× Prospect

⚒ Mine

═ Road

/ Dam

~ Stream

◎ Lake

△ Triangulation point

⟡ Section corner (Located)

GEOLOGICAL MAP
LAKE ALBION REGION
BOULDER COUNTY, COLORADO

Topography from U.S. Geological Survey map of Rocky Mountain National Park. Edition of 1919.

Geology surveyed in Sept., 1932