[Read before the Society, March 29, 1931]

PRELIMINARY REPORT ON THE GEOLOGY OF MOUNT LINCOLN AND THE RUSSIA MINE, PARK COUNTY, COLO.[1]

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and
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INTRODUCTION

Since the summer of 1928 a detailed study of the geology and ore deposits on the east side of the Mosquito Range near Alma, Park County, Colorado, has been a part of the cooperative program of the Colorado Metal Mining Fund, the State of Colorado, and the United States Geological Survey. In order to make some of the results of this study immediately available to those engaged in developing or prospecting in the area, a preliminary report[4] was published that covered part of the district.

The present report serves the same purpose for another part of the district and gives some information regarding the geology of the Russia mine that may be of general use in prospecting in the district. Of the several silver-lead mines whose ore bodies occur as replacement deposits in the upper part of the Leadville ("Blue") limestone, the Russia mine was the only one in the district accessible for study.

The location of the Mount Lincoln area is shown in Figure 1.

During the summers of 1928 and 1930 the writers, ably assisted by Robert D. Butler, mapped the areal geology of this region. In 1928 the writers made two visits under-

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[1] Published by permission of the Director of the United States Geological Survey.
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[4] Singewald, Q. D., and Butler, B. S., Preliminary geologic map of the Alma mining district, Colorado: Colo. Sci. Soc. Proc., Vol. 12, No. 9, pp. 295-308, 1930.

ground in the Russia mine, and in 1930 the mine was mapped by Singewald in co-operation with Robert E. Landon and Robert D. Butler, assisted by Waldo Butler.

The relative certainty with which sedimentary or igneous contacts and fissures could be determined in the field is indicated on the geologic maps that accompany this paper. Contacts and faults actually seen are shown by solid lines; those not seen but inferred with considerable assurance are shown by broken lines; those whose existence or position is doubtful are shown by broken lines with question marks. It is probable that faults and small igneous masses not shown on the areal geologic map exist at places where the bedrock is covered by soil or talus.

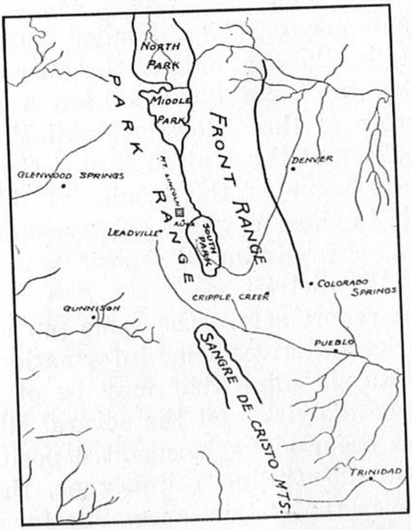

Fig 1. Index Map of central Colorado Showing Location of Mt. Lincoln Area

The writers are grateful to Mr. James N. Redman, of Denver, for his many courtesies and for the large amount of information on the Russia mine that he furnished. They are also indebted to Mr. Sydney H. Ball, of New York City, for information obtained by him in 1928 during a geologic examination of the area for private interests, and to Mr.

M. N. Short, of the United States Geological Survey, for a study of the polished sections of specimens from the Russia mine.

The geography and general geology of the Mt. Lincoln and nearby areas have been described in several previous reports.[5]

ROCK FORMATIONS

PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks of the area consist of injection gneiss, pegmatite, granite gneiss, quartz-mica schist, and granite. These are cut by numerous Tertiary (?) igneous dikes. The pre-Cambrian and the Tertiary dikes are not differentiated on the acompanying geologic map. Their distribution has been mapped in detail by John Vanderwilt and Robert E. Landon, whose work will be included in the final report on the Alma district.

PALEOZOIC SEDIMENTARY ROCKS

The areal distribution of the sedimentary rocks is shown on the accompanying geologic map (Plate I). What may be considered a type section of the sedimentary rocks for the Mount Lincoln area, measured on the cliffs at the head of Lincoln Amphitheater, is shown in columnar form in Figure 2. No discordance in dip was observed within this series. Detailed descriptions of the lithologic units into which the formations are divided are omitted here because of the similarity to the descriptions already published[6] for similar sections elsewhere in the Alma district. However, there are a few special features of the stratigraphy that deserve mention.

All zones of the two members of the Sawatch formation found in the Alma district as a whole occur in the Mount Lincoln area, and all except the lower quartzite zone maintain nearly constant thickness. The lower quartzite zone

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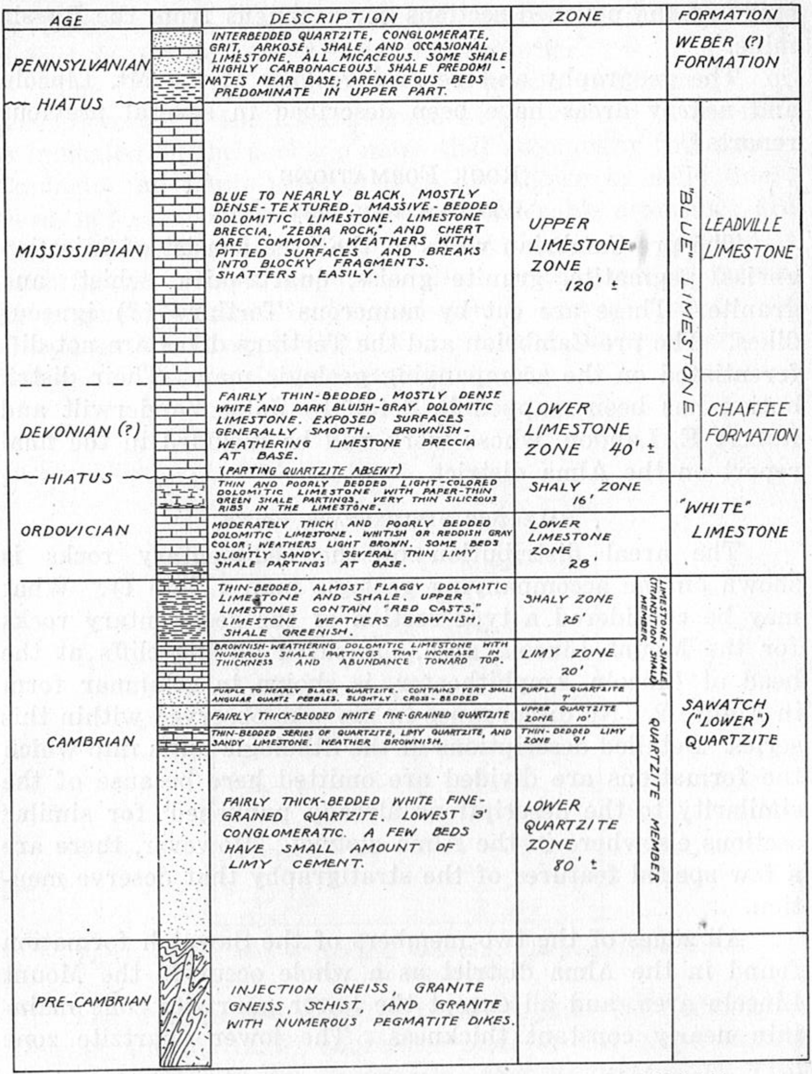
[5] Emmons, S. F., Geology and mining industry of Leadville: U. S. Geol. Survey Mon. 12, 1886. Patton, H. B., Hoskin, A. J., and Butler, G. M., Geology and ore deposits of the Alma mining district, Park County, Colorado: Colorado State Geol. Survey Bull. 3, 1912. Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geol. Survey Prof. Paper 148, 1927.

[6] Singewald, Q. D., and Butler, B. S., op. cit., pp. 296-303.



AGE	DESCRIPTION	ZONE		FORMATION
PENNSYLVANIAN	INTERBEDDED QUARTZITE, CONGLOMERATE, GRIT, ARKOSE, SHALE, AND OCCASIONAL LIMESTONE. ALL MICACEOUS. SOME SHALE HIGHLY CARBONACEOUS. SHALE PREDOMINATES NEAR BASE; ARENACEOUS BEDS PREDOMINATE IN UPPER PART.			WEBER (?) FORMATION
HIATUS				
MISSISSIPPIAN	BLUE TO NEARLY BLACK, MOSTLY DENSE-TEXTURED, MASSIVE-BEDDED DOLOMITIC LIMESTONE. LIMESTONE BRECCIA, "ZEBRA ROCK," AND CHERT ARE COMMON. WEATHERS WITH PITTED SURFACES AND BREAKS INTO BLOCKY FRAGMENTS. SHATTERS EASILY.	UPPER LIMESTONE ZONE 120' ±	"BLUE" LIMESTONE	LEADVILLE LIMESTONE
DEVONIAN (?)	FAIRLY THIN-BEDDED, MOSTLY DENSE WHITE AND DARK BLUISH-GRAY DOLOMITIC LIMESTONE. EXPOSED SURFACES GENERALLY SMOOTH. BROWNISH-WEATHERING LIMESTONE BRECCIA AT BASE. (PARTING QUARTZITE ABSENT)	LOWER LIMESTONE ZONE 40' ±		CHAFFEE FORMATION
HIATUS				
ORDOVICIAN	THIN AND POORLY BEDDED LIGHT-COLORED DOLOMITIC LIMESTONE WITH PAPER-THIN GREEN SHALE PARTINGS. VERY THIN SILICEOUS RIBS IN THE LIMESTONE.	SHALY ZONE 16'		"WHITE" LIMESTONE
	MODERATELY THICK AND POORLY BEDDED DOLOMITIC LIMESTONE. WHITISH OR REDDISH GRAY COLOR; WEATHERS LIGHT BROWN. SOME BEDS SLIGHTLY SANDY. SEVERAL THIN LIMY SHALE PARTINGS AT BASE.	LOWER LIMESTONE ZONE 28'		
CAMBRIAN	THIN-BEDDED, ALMOST FLAGGY DOLOMITIC LIMESTONE AND SHALE. UPPER LIMESTONES CONTAIN "RED CASTS." LIMESTONE WEATHERS BROWNISH. SHALE GREENISH.	SHALY ZONE 25'	LIMESTONE-SHALE (TRANSITION SHALE) MEMBER.	SAWATCH ("LOWER") QUARTZITE
	BROWNISH-WEATHERING DOLOMITIC LIMESTONE WITH NUMEROUS SHALE PARTINGS THAT INCREASE IN THICKNESS AND ABUNDANCE TOWARD TOP.	LIMY ZONE 20'		
	PURPLE TO NEARLY BLACK QUARTZITE. CONTAINS VERY SMALL ANGULAR QUARTZ PEBBLES. SLIGHTLY CROSS-BEDDED	PURPLE QUARTZITE 7'	QUARTZITE MEMBER	
	FAIRLY THICK-BEDDED WHITE FINE-GRAINED QUARTZITE	UPPER QUARTZITE ZONE 10'		
	THIN-BEDDED SERIES OF QUARTZITE, LIMY QUARTZITE, AND SANDY LIMESTONE. WEATHER BROWNISH.	THIN-BEDDED LIMY ZONE 9'		
	FAIRLY THICK-BEDDED WHITE FINE-GRAINED QUARTZITE. LOWEST 3' CONGLOMERATIC. A FEW BEDS HAVE SMALL AMOUNT OF LIMY CEMENT.	LOWER QUARTZITE ZONE 80' ±		
PRE-CAMBRIAN	INJECTION GNEISS, GRANITE GNEISS, SCHIST, AND GRANITE WITH NUMEROUS PEGMATITE DIKES.			

STRATIGRAPHIC COLUMN FOR MT. LINCOLN

Fig. 2

thins from east to west from a maximum of about 90 feet to a mimimum of about 50 feet. This probably indicates slower subsidence in the west than in the east.

The "White" limestone, owing to the absence of the upper limestone, is much thinner here than throughout most of the rest of the Alma district. This is attributed to erosion before deposition of the overlying Parting quartzite of nearby areas. Evidence has been presented in another paper[7] that, in the entire Alma district, emergence and erosion occurred after deposition of the "White" limestone, that the Mount Lincoln area was a low island while the Parting quartzite was deposited in surrounding areas, and that resubmergence occurred later there than elsewhere.

Two features of the "Blue" limestone are of interest—it rests on the "White" limestone, and a bed of limestone breccia, averaging about 5 feet in thickness, occurs at the base of the formation. The breccia, which serves as a useful horizon marker in locating the contact of the "Blue" and "White" limestone, is found in the Alma district only in and very near the area where the Parting quartzite was not deposited. Because it weathers dark brown and forms a small but distinct ledge it may often be recognized at a distance. The breccia consists of unsorted angular fragments of dolomite, nowhere exceeding 4 inches in length, inclosed in a dolomite matrix. Fragments and matrix are creamy white where freshly broken, but the fragments weather to a darker brown than the matrix.

The Weber (?) formation is the youngest sedimentary formation in the area. Less than 150 feet of its lowest beds remain on Mount Lincoln. The base at some places is a yellow shale, locally called "cap rock," but at other places is a fine-grained quartzite.

TERTIARY (?) INTRUSIVES

Intrusive igneous rocks of late Cretaceous or early Tertiary age, forming part of the belt[8] of Tertiary (?) intrusives

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[7] Singewald, Q. D., Depositional features of the parting quartzite near Alma, Colorado: Amer. Jour. Sci., in press.

[8] Spurr, J. E., and Garrey, G. H., Economic geology of the Georgetown quadrangle (together with the Empire district), Colorado, with general geology by S. H. Ball: U. S. Geol. Survey Prof. Paper 63, pp. 67-71, 1908.

of central Colorado extending southwestward from Boulder County, occur extensively as sills and dikes and in a few places as pluglike or irregular-shaped masses. The mass forming the peak of Mount Lincoln appears to be a laccolithic sill. As at Leadville, these rocks are divided into a gray porphyry group and a white porphyry group. Each group is further subdivided. On the geologic map (Plate I) their distribution within the sedimentary rocks is shown in detail, but their distribution within the pre-Cambrian rocks is not shown.

GRAY PORPHYRY GROUP

General features—Rocks of the gray porphyry group are darker and almost everywhere contain more phenocrysts than those of the white porphyry group. Lithologically they may be divided into three main classes, which Patton[9] designated diorite-porphyrite, quartz monzonite porphyry, and Lincoln porphyry. The last two names have been retained. As the term porphyrite usually implies pre-Tertiary age, the name diorite-porphyrite is here changed to monzonitic diorite porphyry; these rocks are near monzonite in composition, but the term diorite is retained because of its firm establishment in local usage.

Evidence that all the gray porphyries were derived from the same magma reservoir and that they are of nearly the same age will be presented in the final report on the Alma district.

Monzonitic diorite porphyry—The rocks classed as monzonitic diorite porphyry are a little more salic in composition in the Mount Lincoln area than at the type locality on Loveland Mountain,[10] but their appearance is nearly the same at both places. They may be distinguished by their dark color and by the abundance of hornblende and scarcity of quartz as phenocrysts. Usually they have a fresh appearance, but in places they are somewhat altered. Numerous small to me-

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[9] Patton, H. B., Hoskin, A. J., and Butler, G. M., op. cit., pp. 74-92.

[10] Singewald, Q. D., Alteration as an end phase of igneous intrusion in sills on Loveland Mountain, Park County, Colo. (Paper read at meeting of the Geological Society of America, Dec. 31, 1930.)

MT. LINCOLN AND VICINITY

MOSQUITO RANGE, PARK COUNTY, COLORADO

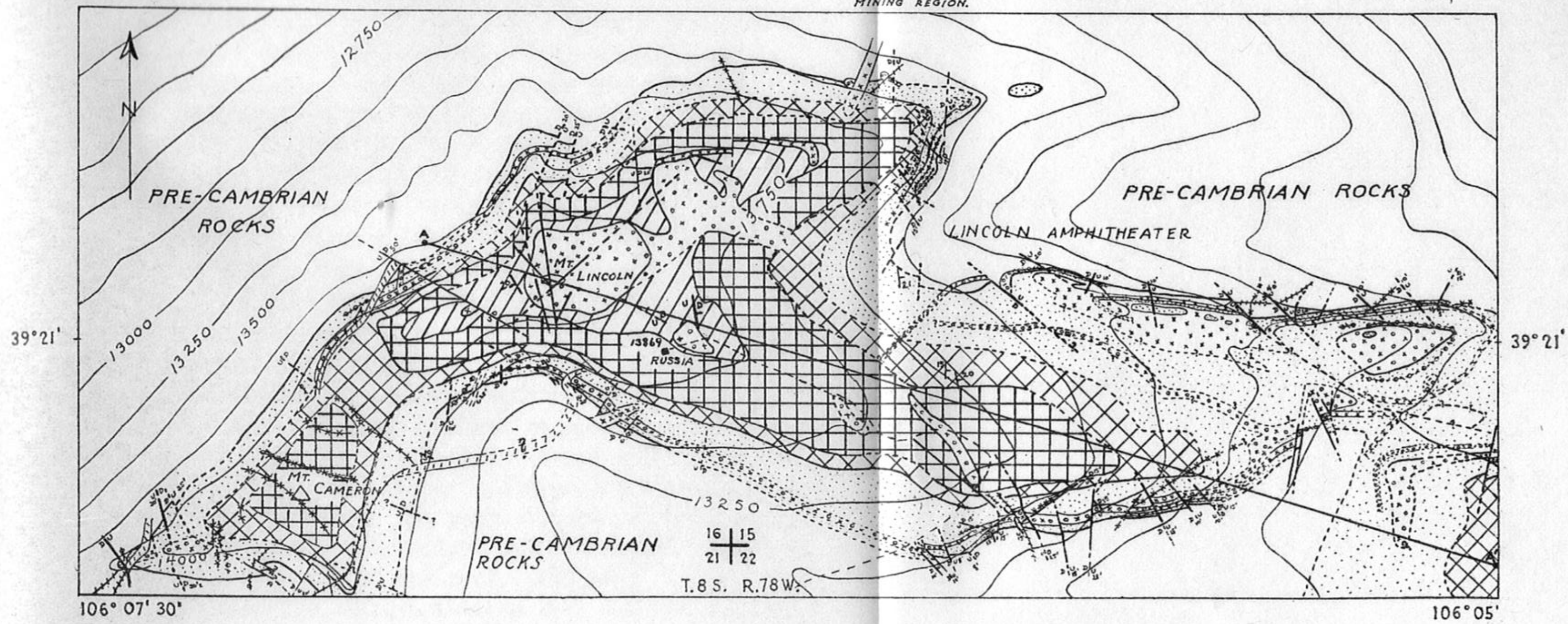
SCALE

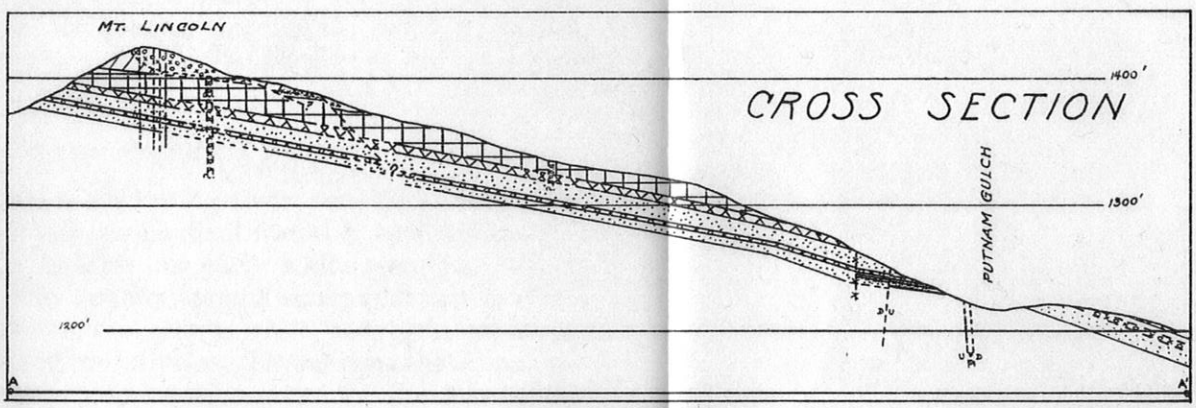
5000 FEET

GEOLOGY BY B.S. BUTLER AND Q.D. SINGEWALD.
PUBLISHED BY PERMISSION OF THE DIRECTOR OF THE UNITED STATES GEOLOGICAL SURVEY, THE COLORADO METAL MINING FUND, AND THE STATE OF COLORADO.

CONTOUR INTERVAL ~ 250'
DATUM IS MEAN SEA LEVEL

BASE FROM U.S.G.S. TOPOGRAPHIC MAP OF THE MOSQUITO RANGE, MINING REGION.





EXPLANATION

SEDIMENTARY

PENNSYLVANIAN	{ Weber (?) Formation		▨
MISSISSIPPIAN	{ Leadville limestone	} "Blue" Limestone	▦
DEVONIAN	{ Chaffee Formation		▦
ORDOVICIAN	{ "White" limestone		▩
CAMBRIAN	{ Sawatch ("Lower") Quartzite		░
Undifferentiated pre-Cambrian with Tertiary (?) intrusives			☐

Strike & Dip

TERTIARY (?) INTRUSIVES

- Late white porphyry
- Lincoln porphyry
- Quartz monzonite porphyry
- Monzonitic Diorite porphyry
- Early white porphyry
- Fissures

Faults

dium-sized grains of plagioclase, hornblende, biotite, and quartz are inclosed in a very dark greenish-gray groundmass.

Quartz monzonite porphyry—The quartz monzonite porphyries are a little lighter in color, have more quartz and less hornblende as phenocrysts, and usually are more altered than the monzonitic diorite porphyries; they lack the large pink orthoclase crystals found in the Lincoln porphyry. Their color, which depends largely on the extent and nature of their alteration, is green, brown, red, or rarely white. Where not intensely altered, small to medium-sized grains of plagioclase, altered biotite and hornblende, and quartz are inclosed in a medium greenish-gray groundmass.

Lincoln porphyry—The typical Lincoln porphyry has conspicuous, fairly well formed crystals of pink orthoclase, ranging from less than 1 inch to more than 4 inches in length, scattered through a rock that in other respects resembles the quartz monzonite porphyry. However, many sills and dikes of Lincoln porphyry have a marginal facies, not exceeding 12 feet in thickness, in which the pink orthoclase crystals are absent and quartz is less abundant and all phenocrysts are smaller than in the rest of the rock. Although the zone of gradation between the marginal facies and the typical Lincoln porphyry is fairly thin, nowhere is there a definite contact between them. In general the Lincoln porphyry is less altered than the quartz monzonite porphyry, but at a few places it is intensely altered.

WHITE PORPHYRY GROUP

General features—Owing to their very light color, the white porphyries often can be identified at a considerable distance. The group includes an early white porphyry, which is older than the gray porphyries and equivalent to the white porphyry at Leadville, and a late white porphyry, which is younger than the gray porphyries. Throughout the Alma district feldspar phenocrysts usually occur in the late white porphyry but do not occur in the early white porphyry; yet this is not universally true. The two white porphyries can be distinguished with certainty only where their age relations can be established.

Early white porphyry—The only occurrence of early white porphyry is a sill, about 3 feet thick, in the Sawatch formation in the northeastern part of the area. Rock from this sill contains a very few small to medium-sized muscovite flakes and quartz grains scattered through a whitish-gray soft groundmass that appears homogeneous to the naked eye. Along joints and on exposed surfaces the rock has a rusty brown color that is darker than its characteristic color elsewhere in the Alma district.

Late white porphyry—The late white porphyry is whitish gray and at many places has sheeted structure. Its groundmass is like that of the early white porphyry. Small to medium-sized phenocrysts of feldspar, muscovite, and quartz are fairly numerous in some varieties but exceedingly sparse in others. The feldspars are usually white and considerably altered. Muscovite appears to be an alteration product of former biotite.

A dike, known locally as the "St. Louis dike," that crops out on the cliffs in the south-central part of the area differs from the other late white porphyries in having, in addition to quartz, phenocrysts of rather fresh biotite and coarse pink orthoclase. The coarse pink orthoclase crystals suggest a genetic connection between this rock and the Lincoln porphyry.

STRUCTURE

On Mount Cameron the average strike of the sedimentary strata is N. 20° E., whereas on Mount Lincoln it is a little west of north, showing a distinct bend. As a similar bend in strike is observed in the strata on the lower slope of Mount Bross, to the south, it is probable that the axis of a slight anticlinal nose extended N. 35° W. through the saddle between Mount Lincoln and Mount Cameron. The average dip of the strata, which is toward the east, ranges from a minimum of 8° in the western part of the area to a maximum of 18° in the eastern part. Hence, Mount Lincoln must be situated structurally on the north flank of an anticlinal nose which flattens considerably to the northwest. In addition to the regional variations, there are numerous local variations in strike and dip. A cross section through Mount Lincoln accompanies the geological map (Plate I).

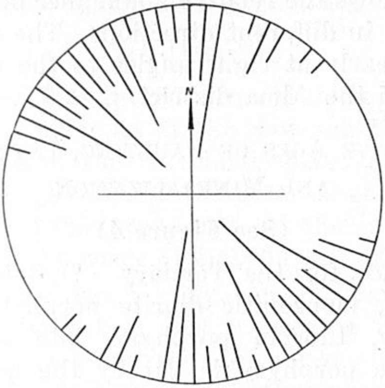
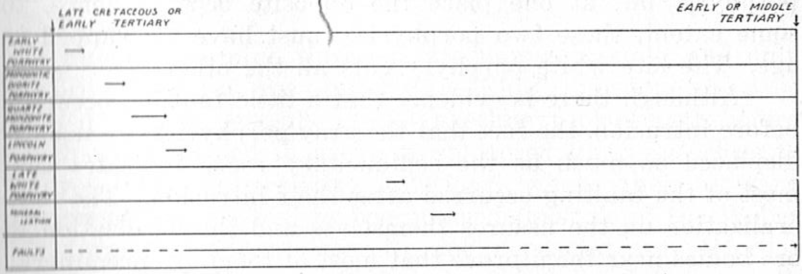


Figure 3—Chart showing trend and relative intensity of fissuring in the Mount Lincoln area.

Although in the Alma district as a whole the faults have been classified into two main groups[11]—"major thrust" faults and "minor" faults—in the Mount Lincoln area all the numerous faults belong to the second group. Most of them are of premineral age and many are mineralized, but some are postmineral. Steeply dipping normal faults that die out within short distances both horizontally and vertically pre-



RELATIVE AGES OF FAULTING, INTRUSION, AND MINERALIZATION
LENGTH AND POSITION OF ARROWS INDICATE RELATIVE TIME

Fig. 4

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[11] Singewald, Q. D., and Butler, B. S., op. cit., p. 307.

dominate. The maximum displacement of the faults rarely exceeds 50 feet, and slickensides on some of them show that at least the latest movement had a large horizontal component.

Figure 3 shows the relative abundance of faults and mineralized fissures in different directions. The prevailing trend is northwest, nearly at right angles to the prevailing trend farther south in the Alma district.

RELATIVE AGES OF FAULTING, INTRUSION AND MINERALIZATION

(See Figure 4)

The sequence for the Tertiary (?) intrusives is early white porphyry, monzonitic diorite porphyry, quartz monzonite porphyry, Lincoln porphyry, late white porphyry. The early white porphyry is cut by the quartz monzonite porphyry but nowhere is in contact with monzonitic diorite porphyry. However, it is correlated with the white porphyry at Leadville, where its relative age is established.[12] Several lines of indirect evidence presented in another paper[13] indicate that the monzonitic diorite porphyry is older than the quartz monzonite porphyry. The Lincoln porphyry at many places in the Alma district cuts the quartz monzonite porphyry, but at one place the opposite occurs; hence, to some extent, these two porphyries must have overlapped in age. The late white porphyry cuts all the others.

Although there is evidence that a little faulting occurred before intrusion, the fact that the gray porphyries are usually displaced as much as the sedimentary rocks indicates that most of the faulting occurred after their intrusion. The mineralization on the fissures themselves and the localization of ore bodies near them prove that most of them are premineral. However, there is evidence throughout the Alma district of considerable postmineral faulting. Moreover, both premin-

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[12] Emmons, S. F., Irving, J. D., and Loughlin, G. F., op. cit., p. 43.

[13] Singewald, Q. D., Alteration as an end phase of igneous intrustion in sills on Loveland Mountain, Park County, Colo.: (paper read at meeting of Geological Society of America, Dec. 31, 1930).

eral and postmineral movements took place on some of the same faults.

The late white porphyry is not displaced by premineral faults, but is mineralized at some places. Its age, therefore, is regarded as immediately before mineralization.

ORE DEPOSITS

It is reported that in 1865 some oxidized gold ores were discovered in the quartzite of the Sawatch formation on the cliffs not far east of the "St. Louis dike." The first silver-lead ore body was discovered in 1871. There is no authentic record as to the total production of the area, but various estimates place it between $1,500,000 and $5,000,000.

The many abandoned mine workings and pits indicate widespread mineralization whose greater intensity in the vicinity of Mount Lincoln than in surrounding areas probably is the result of the regional structure—proximity to a slight anticlinal nose whose pitch flattens toward the northwest. Individual ore bodies are localized along fissures and in the wall rock near fissures. The mineralization was most extensive at the top of the "Blue" limestone, but occurred to some extent at lower horizons, especially in the "White" limestone. No evidence of economically important mineralization has been found in the pre-Cambrian rocks or in the Weber (?) formation.

Few of the mine workings are now accessible, and only the ore deposits at the top of the "Blue" limestone could be studied. These deposits are blanketlike replacement bodies which were formed in areas of shattered limestone close to fissures. The mineralizing solutions, where their upward movement was checked by the impervious shale of the Weber (?) formation spread laterally and deposited argentiferous and to some extent auriferous base-metal sulphides, with ankerite, barite, and quartz as gangue minerals. At many places comparatively recent but presumably preglacial sulphide enrichment and oxidation have formed new minerals that considerably enriched the original ore.

RUSSIA MINE

INTRODUCTION

The Russia mine is about 1,000 feet southeast of the peak of Mount Lincoln and has an elevation of 13,870 feet. It is 9 miles by road from Alma Junction, the nearest shipping point for ore. From the mine to Quartzville, a distance of 2¾ miles, the road has steep grades and is in poor repair; in order to be suitable for truck haulage, it would have to be almost entirely rebuilt, and even then keeping it open during the winter would be difficult. The road from Quartzville to the junction with the main State road, a distance of 2½ miles, needs considerable repair but could be kept open for truck haulage without much difficulty. The remainder of the distance to Alma Junction is covered by a State road that is kept in good condition.

The mine was discovered and located in 1872. It has produced considerably more than half of all the ore from the Mount Lincoln area and is one of the three largest silver-lead mines in the Alma district. The early work and most of the production have been confined to three adits—the Shuck Tunnel, the Pogue Tunnel, and the Redman Tunnel, located northwest of the present portal. The older workings are a maze of irregular-shaped, but nearly horizontal stopes, many of which are filled with waste rock.

GENERAL GEOLOGY

ROCKS

The underground geology is shown on Plate II. The mine workings are almost entirely in the Leadville ("Blue") limestone and the basal part of the Weber (?) formation, but in addition they cut quartz monzonite porphyry and Lincoln porphyry. The porphyries are intensely altered. Some masses are so permeated with iron stain that they have a deep-red color. At or close to the base of the Weber (?) formation is a bed of altered yellow shale that locally is called "cap rock."

STRUCTURE

The average dip of the sedimentary rocks is about 12° nearly due east. Slight variations in strike and dip occur locally.

Sinuous fissures, most of which are small faults, are abundant throughout the mine, but, as many of the stopes are filled, it was feasible to map only the more prominent ones in the older workings. With few exceptions the fissures belong to one of two principal sets. One set strikes north to N. 35° W., and the other N. 55° W. to N. 80° W. The breccia zones on the fissures, which are composed of angular limestone fragments and contain variable but small amounts of clay gouge, vary in width from less than an inch to more than a foot.

There are two main faults that have fairly large displacements. One of these was cut 300 feet from the portal of the Upper Hoosier Tunnel, and followed for more than 400 feet. It is a normal fault with an average strike of N. 66° W. and a dip of 70° NE. and has a displacement of about 30 feet. The so-called "gold vein" occurs along this fault. The other, known as the "Staircase fault," is about 500 feet from the portals of the Pogue and Redman tunnels. It is a normal fault with a strike N. 17° W. and a dip of 50° NE. and has a displacement of about 40 feet. This fault may connect with one that strikes slightly west of north and dips 40°-45° NE., on the Shuck level, 240 feet from the portal. The fault on the Shuck level has a wide breccia zone, but the amount of displacement on it could not be determined.

The absence of evidence that any of the faults are postmineral and the conclusive evidence that many of them are premineral, lead to the inference that all or nearly all are premineral. One of the two main faults contains unbrecciated ore, the "gold vein". This vein was probably the feeder to the replacement ore bodies on the stope level 25 feet above the Upper Hoosier Tunnel. The other main fault, the "Staircase fault," is probably premineral, but this has not been definitely proved. No drag ore was observed along it, and the configuration of the stopes on opposite sides of it does not suggest that once they were continuous. The alinement of the stopes along many of the other faults indicates that they are premineral.

Over large areas in the vicinity of fissures the "Blue" limestone is intensely shattered. In many of these areas the limestone fragments are coated with a thin film of iron-stained clay that was probably formed by the oxidation of substances deposited there during original mineralization.

ORES

OCCURRENCE

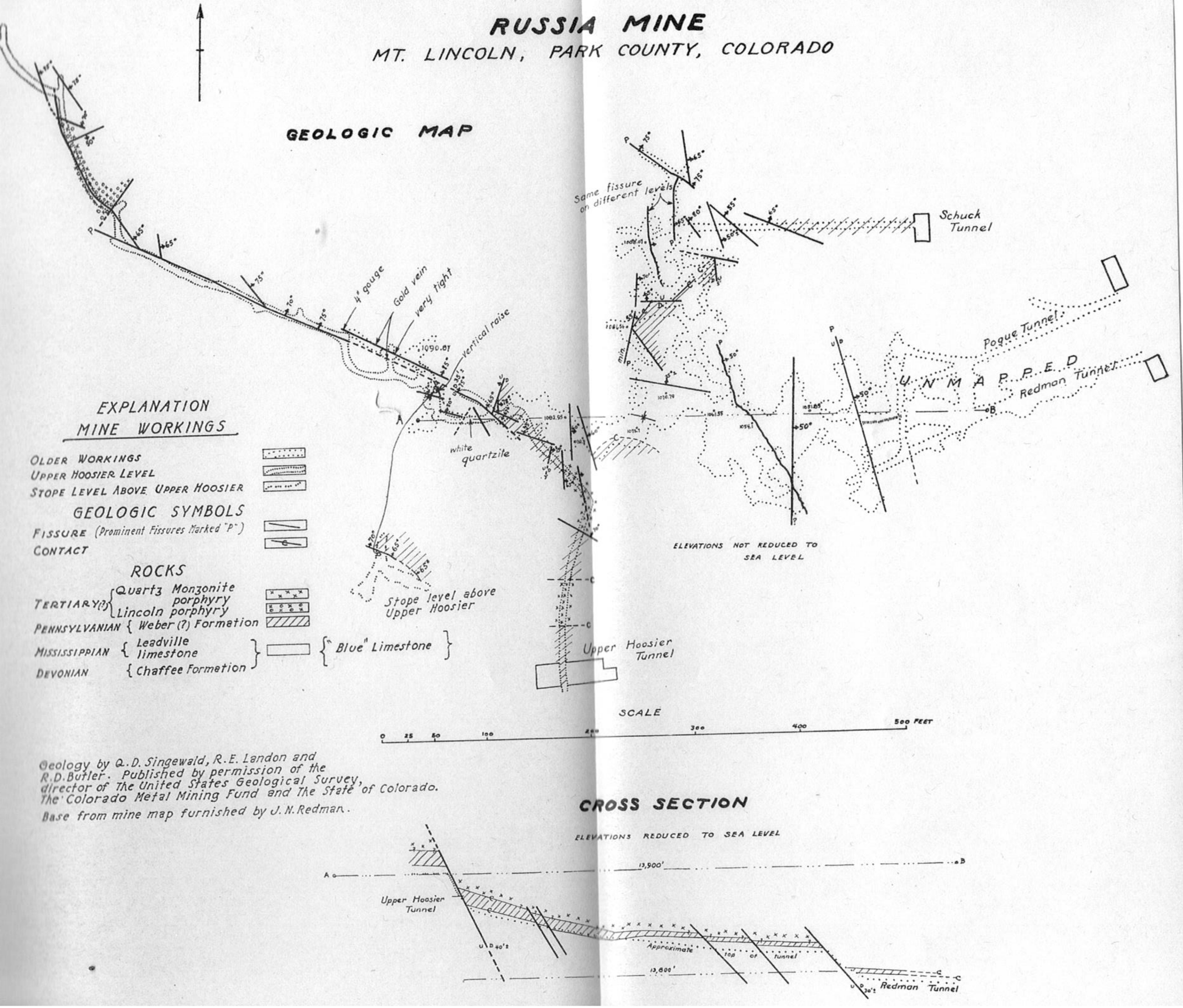
Except for one vein, the ore bodies were irregular-shaped bed replacement deposits in the upper part of the "Blue" limestone. As almost no ore may be seen in place, its occurrence had to be inferred from an examination of the worked-out stopes, many of which are not shown on the mine map. The stopes range in length from a few feet to several hundred feet. As many adjoining ones are connected, the mine is a maze of larger stopes and small connecting passageways. Most of the stopes are very close to the top of the "Blue" limestone, but some are as much as 50 feet below the top. At many places there is an alinement of stopes along a prominent fissure; usually they are on the west side, up the dip from the fissure. The "Blue" limestone surrounding the stopes is intensely shattered.

The "gold vein" is a tabular ore body formed by filling along a fault fissure and replacement of the wall rock to a distance not exceeding 15 feet from the fissure. Its exact vertical range could not be determined, but ore extends more than 50 feet below the top of the "Blue" limestone, and mineralization continues deeper. Horizontally, ore has been mined for only about 100 feet along the fault.

MINERALOGY

The mineralogy of the ores is inferred from a study of the "gold vein", of small masses of lean ore found here and there in the mine, and of a few specimens furnished by Mr. Redman. It seems almost certain that the ore bodies were

PLATE II



RUSSIA MINE

MT. LINCOLN, PARK COUNTY, COLORADO

GEOLOGIC MAP

CROSS SECTION

Geology by Q.D. Singewald, R.E. Landon and R.D. Butler. Published by permission of the director of The United States Geological Survey, The Colorado Metal Mining Fund and The State of Colorado.

Base from mine map furnished by J.N. Redman.

partly oxidized sulphide deposits. The partial oxidation was preceded by the deposition of supergene sulphides, and these two processes must have enriched the original hypogene minerals.

In their usual order of abundance the sulphide minerals in the specimens studied are sphalerite, galena, pyrite, chalcopyrite, freibergite, tetrahedrite, covellite, and chalcocite. Freibergite is the most abundant sulphide mineral ~~In~~ in one specimen which assayed 776 ounces in silver. Short[14] determined through microchemical tests that tetrahedrite containing almost no silver occurs in two specimens in which freibergite is absent. The amount of pyrite varies considerably, and locally galena is more abundant than sphalerite. The sulphide minerals are intimately intergrown in small clusters, never exceeding 1 inch in diameter, that are abundantly scattered through a gangue consisting predominantly of carbonate and barite. Quartz, although not an abundant constituent of the ore, is very abundant on the surface at several places near the mine where large masses of "Blue" limestone are completely silicified. Short observed insignificant amounts of native silver, of supergene origin, in two specimens. Limonite, azurite, malachite, cerusite (or anglesite?), clay minerals, and gypsum were identified as products of oxidation. It is likely that at places other minerals existed.

Regarding the paragenesis of the hypogene sulphide minerals, Short states: "pyrite is always earliest; the sequence pyrite, sphalerite, freibergite, chalcopyrite, and galena in the order named is demonstrated in all sections, but reversals of the above order are occasionally found." Apparently some of the pyrite grains served as neuclei around which later sulphides were deposited, whereas others, now seen as isolated grains, did not. Those that served as nuclei were considerably replaced by the later sulphides, especially freibergite. The sulphide minerals that are later than pyrite but earlier than galena formed principally by replacement of limestone but to some extent by replacement of earlier sulphides. Galena, which commonly occurs as kernels in the sul-

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[14] Short, M. N., of the U. S. Geol. Survey. Written communication.

phide aggregates, appears to have formed principally by replacement of earlier sulphides.

The sequence for the hypogene gangue minerals was (1) slightly cloudy coarse-grained quartz, (2) coarse-grained barite, (3) microcrystalline barite, slightly cloudy microcrystalline quartz (with barite outlasting quartz), and a little ankerite, (4) ankerite and clear quartz, (5) ankerite, and (6) calcite. The slight cloudiness of some of the quartz is due to numerous minute inclusions. Much of the microcrystalline quartz grades into the coarse-grained quartz and appears to have formed by slight granulation, solution, and reprecipitation of the coarse-grained quartz without addition of much more silica. The deposition of ankerite, which is an iron-bearing dolomite, was long continued; it began at the same time as barite, but most of it followed barite. The latest ankerite forms druses in cavities. The presence of subordinate amounts of calcite in some specimens was determined by Short.

The precise age relations between the hypogene ore and gangue minerals could not be established. Where the "Blue" limestone is completely silicified the brecciated structure of the limestone is preserved but the rock is nearly impervious. This fact and the relatively small amount of quartz associated with the ore seem to imply that quartz was formed earlier than any of the sulphides, and that intensely silicified areas were unfavorable to ore deposition. However, some quartz continued to form until after sphalerite. Some barite and a small amount of ankerite formed just before galena, but much of the barite and most of the ankerite are later than galena.

Limonite and covellite, of supergene origin, in all specimens occur in exceedingly narrow veinlets that cut the hypogene sulphide minerals; covellite is especially abundant in freibergite and chalcopyrite, and limonite in chalcopyrite. Many of these veinlets border earlier veinlets of the gangue minerals. A subordinate amount of chalcocite and a slight amount of native silver, both of supergene origin, in two specimens were identified by Short.

In the considerably oxidized specimens limonite is abundantly distributed, and other minerals are present. Grains consisting of aggregates of clay minerals are pseudomorphous after barite. Gypsum occurs in druses, and around sulphide grains it forms collofirm structures with limonite, malachite, and azurite, but is in places cut by malachite-azurite veinlets.

The silver content of the Russia ore bodies varied greatly and was independent of the lead content. Occasional samples assayed more than 700 ounces per ton, but most of the ore probably ran somewhat less than 100 ounces per ton. Microchemical tests by Short showed the silver content of freibergite to be high but of galena to be very low, and Short concludes that the silver content of the little-oxidized high grade ore "is represented entirely or nearly so by freibergite." The gold content was low, being less than 0.5 oz. per ton even in the "gold vein". Except for its higher gold content the ore of the "gold vein" differs very little from that of the bed replacement ores.

Genesis of the Ores

The origin of the ores is very similar to that of many of the ore bodies at Leadville[15]. The hypogene solutions were derived at depth from the same magma reservoir as the Tertiary (?) igneous rocks. Where the upward movement of the solutions along fissures was checked by the impervious shale of the Weber (?) formation, they spread laterally and thoroughly permeated and replaced parts of the "Blue" limestone. The brittle "Blue" limestone is intensely shattered adjacent to fissures, and this feature, together with the chemical composition of the rock, was favorable to replacement. However, some ore was deposited in the fissures themselves. The ore zones of the Russia mine, considered as a whole, trend northeastward, approximately at right angles to the trend of the individual ore bodies. This suggests that at depth the solutions ascended along a northeastward trending fissure or set of fissures that are not now apparent at the ore horizon but may be represented by a zone of brecciation. The

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[15] Emmons, S. F., Irving, J. D., and Loughlin, G. F., op. cit., pp. 209-272.

ore bodies extended out along cross fissures that still further brecciated the limestone.

The composition of the solutions changed as mineralization progressed. Apparently the earliest solutions deposited silica abundantly. As the content of silica decreased, the content of sulphur, barium, iron, zinc, copper, silver, antimony, arsenic(?), and lead increased progressively, and these elements were deposited. The latest solutions probably contained little except iron, which, added to dolomite dissolved from the "Blue" limestone, formed ankerite.

With erosion of the land surface the hypogene deposits were attacked and enriched by downward moving solutions. All except an insignificant amount of this oxidation and enrichment occurred before the region was glaciated.[16]

CONCLUSIONS

The extensive mineralization in the Mount Lincoln area probably is the result of the influence of regional structure upon ore deposition. The richness of some of the individual replacement ore bodies, particularly those of the Russia mine, is due to especially intense hypogene mineralization and to enrichment by supergene solutions. The understanding of the occurrence of ore in Mount Lincoln may be applied to the search for similar ore bodies elsewhere in the Alma district where the Leadville ("Blue") limestone is covered by the Weber (?) formation. As stated in a previous paper[17], the most favorable localities for prospecting within Weber (?) areas should be (1) in the downward projection of mineralized fissures into the "Blue" limestone, even though they may not be rich enough to work within the overlying Weber (?) formation, and (2) on the upward projections of zones that have been strongly mineralized in the lower formations to their intersection of the "Blue" limestone. Ore bodies in the "Blue" limestone at such localities may be especially rich if they are located on structural terraces and if they are partly oxidized. Oxidized bodies are not likely to be present more than a few hundred feet below the preglacial land surface.

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[16] Emmons, S. F., Irving, J. D., and Loughlin, G. F., op. cit., p. 272.
[17] Singewald, Q. D., and Butler, B. S., op. cit., p. 308.