MICROCLINE IN THE NATIVE COPPER DEPOSITS OF MICHIGAN

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INTRODUCTION

Despite decades of intensive mining activity in the copper country of Michigan, and detailed study of the native copper deposits during this period, the fact that a certain feldspar abundant in several of the ore bodies is a very unusual variety of microcline, has not been appreciated. In this paper its distribution, nature and paragenesis are discussed. This information the writer believes will contribute to our knowledge of the native copper deposits and of that important mineral group—the potash feldspars.

SOME PREVIOUS OBSERVATIONS ON THE FELDSPARS OF THE NATIVE COPPER DEPOSITS

In the middle of the last century Foster and Whitney[1] were surprised at the "anomalous occurrence" in the newly discovered native copper deposits of Keweenaw peninsula of a "peculiar reddish variety of orthoclase" which they considered an "undoubted aqueous product" forming after both copper and calcite. Whitney[2] supplemented this with a complete analysis[3] and further remarks on the feldspar's widespread development in small amounts "in all the mines from Keweenaw Point to Ontonagon" in association with analcite, as the "last formed of all the vein minerals." These early mines exploited vertical vein-like ore bodies, known locally as "fissures," which transect nearly perpendicularly the lavas underlying the region. With the opening of mines in the "lodes," as the mineralized vesicular and flow-brecciated tops of the basaltic flows and interbedded felsite conglomerates are called, a red feldspar quite different in appearance from the "orthoclase" found by the afore-quoted workers became conspicuous as a gangue mineral. Pumpelly[4] noticed that some amygdules contained a "red feldspar" intimately associated with prehnite. Julien[5] described brick-red "orthoclase" lining calcite-filled vugs in amygdaloidal basalt at the outcrop of the ore body

[1] Foster, J. W. and Whitney, J. D., Report on the geology of the Lake Superior Land District: *Exec. Doc.*, No. **4,** Pt. 2, 102 (1851).

[2] Whitney, J. D., Notice of new localities, and interesting varieties of minerals in the Lake Superior region . . . : *Am. Jour. Sci.*, **28,** 16–19 (1859).

[3] SiO_2 65.45, Al_2O_3 18.26, Fe_2O_3 0.57, K_2O 15.21, Na_2O 0.65 %.

[4] Pumpelly, R., The paragenesis and derivation of copper and its associates in Lake Superior: *Am. Jour. Sci.*, 252 (1871).

[5] Julien, A. A., Note on a feldspar from the Calumet Copper mine: *Annals N. Y. Acad. Sci.*, **12,** 650–654 (1900).

on which the Calumet Mine was sunk, pointing out its adularia-like habit and ferruginous nature.

In more recent times Palache and Wandke investigated the regional mineralogy. Their observations were incorporated in an exhaustive geologic study of the district.[6] They explained that "orthoclase" occurs here in two forms—as a "red feldspar" which was one of the earliest minerals of the ore forming period and is abundant in several of the lodes, and as "adularia" which was a relatively late mineral and occurs in small amounts in lodes and fissures. Broderick,[7] in an important contribution to the literature on the native copper deposits, considered "adularia" a characteristic mineral of the shallow and intermediate depth zones of these ore deposits. However, the term "adularia" was not used here for the late feldspar as in *Professional Paper* **144**, but referred to the early red feldspar,[8] which as will be demonstrated is microcline.

Although native copper deposits associated with basic extrusives are of world-wide distribution, the writer is aware of only two such localities outside of Michigan from which secondary feldspar is reported. A "pink feldspar" occurs in amygdules in the epidotized, schistose pre-Cambrian basaltic lavas in which the native copper deposits of the South Atlantic states are found,[9] and "red feldspar" filling vesicles is associated with native copper in the traps of the Coppermine River region, Northwest Territory, Canada.[10]

The Distribution of Microcline in the Native Copper Deposits

In the Lake Superior region this variety of microcline is confined to metallized portions of the Keweenaw series. In the southern part of the "Copper Range" microcline is a prominent gangue mineral in the lodes opened in the workings of the Mass, the Adventure, and the Michigan mines. About 60 miles northeast, the Arcadian and Superior lodes carry this mineral in abundance, and in the Pewabic lode and parts of the Isle Royale lode, but sparsely. Farther north microcline is characteristic of the mineralization in the Osceola lode and most of the Kearsarge lode, and is present but not abundant in the Calumet and Hecla conglomerate.

[6] Butler, B. S., Burbank, W. S., et al, The copper deposits of Michigan: *U.S.G.S. Prof. Paper* **144,** 59–60 (1929).

[7] Broderick, T. M., Zoning in Michigan copper deposits and its significance, Pt. 2: *Econ. Geol.*, **24,** 311–326 (1929).

[8] Personal communication, T. M. Broderick, January 1938.

[9] Watson, T. L., The native copper deposits of the South Atlantic States compared with those of Michigan: *Econ. Geol.* **18,** 743 (1923).

[10] Gilbert, G., Copper in the Coppermine River, N.W.T.: *Econ. Geol.*, **18,** 743 (1923)

The Baltic and the Isle Royale lodes which lie north and south, respectively, of the smaller and much less productive Superior lode are characterized by the abundant development of sericite and the complete, or almost complete, absence of microcline. In the Superior and Arcadian lodes both microcline and sericite are important gangue minerals.

Broderick[11] demonstrated that in the Kearsarge lode, which has been mined for miles along the strike and thousands of feet down the dip and hence was very suitable for detection of zoning, with increasing depth the mineralization changed progressively from a microcline ("adularia")—bearing type to a sericitic type. The relation observed by the writer between the microcline and sericite which occur in close association in the Arcadian and Superior lodes is significant because of the light it sheds on the process of ore deposition. In these ores sericite follows microcline in the paragenetic sequence. It is generally assumed that in hypogene ore deposits minerals are successively formed at gradually decreasing temperatures. This generalization is not wholly satisfying in view of the evidence for superposition of the mineralization characteristic of the deeper (and presumably hotter) zone on that of the shallower as indicated by the order of formation of sericite and microcline. The writer believes that during the period of mineralization leading up to the formation of sericite the succeeding minerals were deposited at increasing temperatures. Later minerals were probably precipitated from cooling solutions. There are also indications that there was a waxing and waning in the intensity of mineralization corresponding to the thermal variation.

The Nature and Paragenesis of the Microcline of the Native Copper Deposits

The initial process in the formation of the ore deposits was the introduction of potash-rich solutions (source?) into the northwestward-tilted Keweenaw series. The hot alkaline solutions ascended for thousands of feet along the vesicular and flow-brecciated ferruginous lava tops leaching lime, soda and ferric oxide from the wall-rock and depositing microcline in vesicles, as irregular replacements, or as crusts on the walls of vugs formed where solution exceeded deposition.

The calcic plagioclase was especially amenable to attack. The opaque ferruginous groundmass was also replaced by microcline, but the abundant ferric oxide was not entirely removed, a share of it undergoing redistribution as finely divided hematite which imparts to the feldspar a bright brick-red color. The omnipresence of the inclusions of ferric oxide in the microcline wherever the latter is developed, whether replac-

[11] *Op. cit.*

ing minerals of little or no iron content, or filling voids, points to actual precipitation of hematite from solution contemporaneously with the feldspar.

Augite demonstrated a pronounced resistance to replacement by microcline. Its stability during this early stage in the mineralization is evinced by microscopically observable instances of the preservation of the ophitic texture whereby microcline pseudomorphous after labradorite came to lie enclosed in unaltered augite.

Wherever the microcline was deposited in open spaces it formed small (generally less than a few millimeters in size), usually singly-terminated, short-prismatic crystals with a small but significant variation in habit. The dominant forms of the earliest formed microcline are $m\{110\}$, $M\{1\bar{1}0\}$, and $x\{\bar{1}01\}$. As crystallization proceeded $c\{001\}$ and $b\{010\}$ became conspicuous. In most crystals c and x are equally developed, which gives them an orthorhombic aspect. It is of utmost interest that the morphogenetic classification of the potash feldspars presented by Kalb[12] permits of direct comparison. The earliest crystals are similar to his rhombohedral-like low temperature hydrothermal form (such as occurs in epithermal gold deposits of the North American Cordilleran region), and the latest to his moderate temperature form (as exemplified by the adularia of the Alpine clefts). Thus it appears that even during the comparatively small part of the period of mineralization represented by the time in which microcline was deposited, the effect of rising temperature expresses itself by the variation in the morphology of the microcline. Whenever the side-pinacoid is present a clear inclusion-free zone paralleling the prism faces is conspicuous.

The complex twinning divulged when the apparently simple crystals are viewed between crossed nicols is the distinctive feature of this feldspar and one which distinguishes it from ordinary microcline of granites and associated pegmatites. Sections of crystals transecting the prism zone at steep angles to the c-axis demonstrate between crossed nicols a division into four sectors roughly delineated by the diagonals of the rhombus outlined by the traces of the prism faces. The diagonally opposite sectors extinguish simultaneously when the short diagonal or trace of the b cleavage is inclined at an angle of about 17° to the plane of vibration of the polarizer or analyzer. The central portion is an irregular interpenetration of the two phases. In many crystals the front- and side-pinacoids are composition planes near the vertices.

If the interpenetration type of twinning were subdued and the com-

[12] Kalb, G., Die Kristalltracht des Kalifeldspates in minerogenetischer Betrachtung: *Centr. Min.*, 454 (**1924**).

position planes better developed it would be similar to the intercrossing twins ("Durchkreuzungszwillinge") according to the albite law as first described by Rose[13] for albite from Roc Tourné in Savoy and later by Lacroix[14] for albite from the Pyrenees. In fact some of the microcline crystals approach this state very closely, but they are preponderantly a combination of intercrossing ("durchkreuzung") and interpenetration twins according to the albite law.

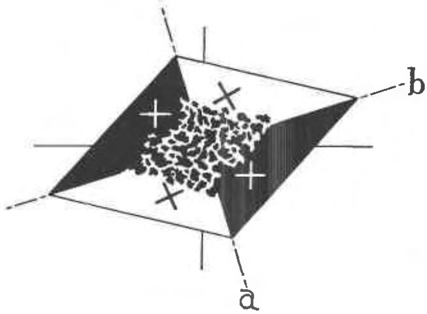

Fig. 1. Diagrammatic sketch showing the twinning of the microcline.

The irregular interpenetration twinning demonstrated by the microcline of the copper deposits has been described as characteristic of the perthitic microcline from miarolitic cavities in the Riesengebirge and Striegau granites in Silesia,[15] and the Waldstein granite of Fichtelgebirge.[16] The writer has found microcline from a vug in a pegmatite at Pala, California, showing similar twinning, and is inclined to believe that further study may show pneumatogenic and hydrogenic microcline to be commonly of this nature.

A quantitative chemical analysis for potash and soda of a sample of microcline from the Michigan mine, Rockland, Ontonagon County, made by Dr. R. B. Ellestad of the Rock Analysis Laboratory of the University of Minnesota showed a K_2O content of 14.98% and a Na_2O content of 0.17%. Insofar as the writer is aware this extraordinary freedom from soda is not attained in any other potash feldspar, the analysis of which is presented in the literature, although data for orthoclase from

[13] Rose, G., Ueber die Krystallform des Albits von dem Roc Tourné und Bonhomme in Savoyen—: *Pogg. Ann. Phys. Chem.*, **125,** 459 (1865).

[14] Lacroix, A., Notes sur quelques mineraux francais. 1. Albite de Pouzac (Haut Pyrenées): *Bull. Soc. franc. Min.*, **11,** 70–71 (1888).

[15] Beutell, A., Beitrage zur Kenntniss der schlesischen Kalinatronfeldspate: *Zeits. Krist.*, **8,** 352 and Fig. 1, Plate 6 (1884).

[16] Durrfeld, V., Die Drusenmineralen des Waldsteingranits im Fichtelgebirge: *Zeits. Krist.*, **46,** 569 and Fig. 1*b*, Plate 12 (1909).

epithermal precious metal deposits and from the iron ores of Michigan[17] approach it closely.

Pumpellyite, epidote, and perhaps chlorite overlapped slightly in period of deposition with the microcline. However, the bulk of these minerals was formed later than the feldspar, as is also the case for prehnite, sericite, quartz, calcite, datolite and copper.

In the North Kearsarge amygdaloid minute sharply twinned albite crystals occur implanted on microcline lining vesicles, or in some cases where the potash feldspar is totally deficient, albite, either clear or rendered cloudy by iron oxide inclusions, appears to be the earliest mineral of the ore-forming period and is engulfed and embayed by the later minerals, such as quartz, calcite and chlorite.

At the stage where $KAlSi_3O_8$ and Fe_2O_3 ceased to be precipitatated the initial loci of mineralization (fractures in the lava top) had been broadened into small irregular vugs crusted with ferruginous microcline, or into drusy veinlets of the same substance. Wall rock alteration was insignificant, being confined to narrow zones of incipient replacement of the labradorite and ferruginous groundmass adjacent to the veinlets and nests of microcline. In the succeeding stage of mineralization the microcline-lined openings provided conduits for the chemically active ore-bearing solutions. The destruction of hematite inclusions, contrasted with its earlier deposition, was a dominant process. The microcline crystals were corroded and the hematite inclusions leached therefrom. At the same time precipitation of saturated phases in the voids and widespread metasomatic alteration of the wall rock prevailed. Pumpellyitization, epidotization, chloritization and silicification often extended far beyond the narrow confines of the feldspathization, and in such cases only vestiges of this phase of the mineralization persisted. In other portions of the lodes this stage of the mineralization was milder, being confined to filling and replacement within the feldspathized areas.

At the close of the period of calcite and copper deposition almost all the primary and secondary cavities in the intensively mineralized areas were tightly filled, but locally vugs lined with calcite or quartz crystals, or more rarely, with sheafs of prehnite, were still open in the now highly altered wall rock. In certain areas where the main part of the ore-forming period manifested itself least emphatically, vesicles lined with microcline persisted in but slightly altered basalt. The comparative weakness of the post-copper mineralization is attested by the almost complete restriction of mineral formation to the deposition of saponite, analcite and orthoclase along the walls of the relatively few open spaces which remained.

[17] Classon, E., Mineralogical Notes: *Am. Jour. Sci.*, **23,** 67 (1882).

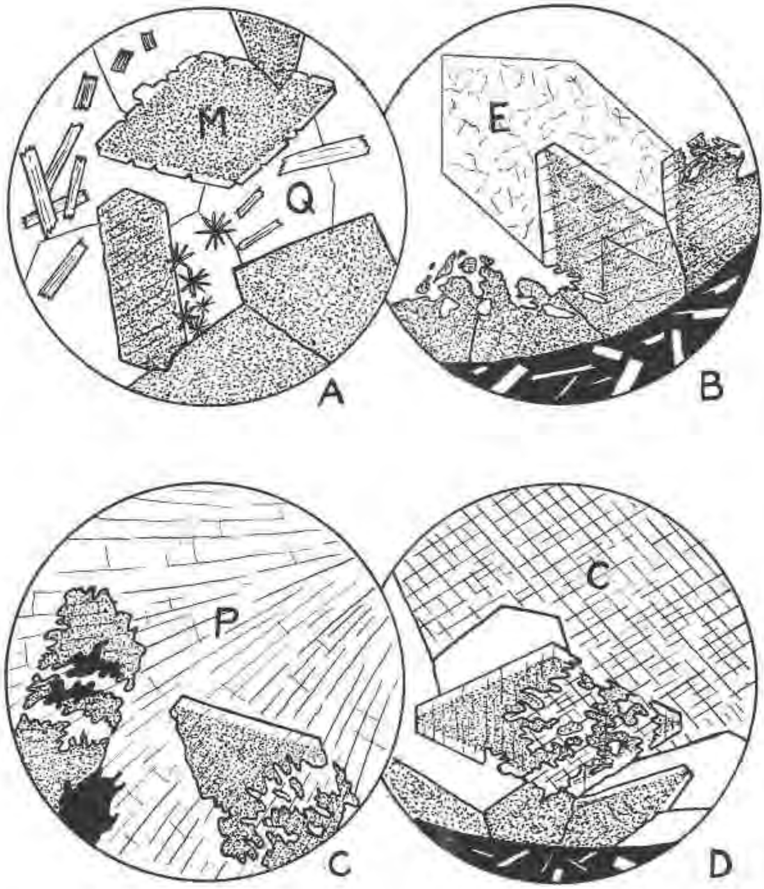

FIG. 2. Some features of the paragenesis seen in thin sections.
Magnification about 25×

A. Microcline (*M*) cloudy with hematite inclusions (stippled) engulfed by quartz (*Q*) and pumpellyite in groups of radiating acicular crystals and stouter prismatic individuals. Mass mine, Ontonagon County.

B. Portion of an amygdule showing the following order of mineral deposition: microcline and hematite, epidote (*E*), and quartz. Inclusion-free zone parallels the prism faces of the microcline. Mass mine, Ontonagon County

C. Microcline embayed by prehnite (*P*), and both replaced by native copper (black). Sometimes prehnite is incipiently or entirely replaced by sericite with good preservation of the sheaf-like structure. Superior mine, Houghton County.

D. Portion of an amygdule showing the following order of mineral deposition: microcline and hematite, quartz, and calcite (*C*). Superior mine, Houghton County.

The orthoclase, in minute crystals of rhombohedral-like habit ($m\{110\}$ and $x\{\bar{1}01\}$), behaves very erratically in polarized light, showing wavy extinction and division into irregular sectors. Orthoclase from the gold telluride ore of Cripple Creek[18] is reported to act similarly. The writer believes these phenomena are due to imperfect crystallization such as would result from compounding by subparallel growths. From veins at Rawhide, Nevada, Rogers[19] described "valencianite" (vein orthoclase) displaying interesting optical anomalies which are suggestive of the twinning of the microcline of the copper deposits. He notes that some of the crystals in polarized light are divided into four sectors, which extinguish in diagonally opposite pairs, with extinction angles measured from the trace of the side-pinacoid of from 5 to 7°.

Conclusion

The "red feldspar" of the native copper deposits of Michigan is an unusual variety of microcline of low, or moderate temperature hydrothermal origin characterized by an adularia-like habit, intercrossed and interpenetrant twinning on the albite-law, and a very low soda content.

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[18] Lindgren, W., and Ransome, F. L., Geology and gold deposits of the Cripple Creek district: *U.S.G.S. Prof. Paper* **54,** 127 and 187 (1906).

[19] Rogers, A. F., Orthoclase-bearing veins from Rawhide, Nevada, and Weehawken, New Jersey: *Econ. Geol.*, **6,** 794 (1911).