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GEOLOGY OF THE MOUNT EMMONS MOLYBDENUM DEPOSIT, CRESTED BUTTE, COLORADO

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INTRODUCTION

The Mount Emmons molybdenum deposit is located beneath the upper south slope of Mount Emmons, approximately 6 km northwest of the town of Crested Butte, Colorado (fig. 1). Mount Emmons lies in the Ruby Range, which is a part of the West Elk Mountains. The Elk Mountains are situated a short distance to the north and northeast.

Mining of precious metals, base metals, and coal in the Crested Butte area has been nearly continuous since the 1870's. Molybdenum was first reported to occur in the region at Paradise Pass and at "Treasury Mountain" (now Treasure Mountain) by Worcester (1919). Extensive regional exploration for molybdenum has occurred primarily in the past 20 years.

PREVIOUS WORK

Molybdenite was first discovered beneath Redwell Basin on the north side of Mount Emmons in 1970 (Sharp, 1978). AMAX Exploration optioned both the prospect area and an adjacent block of claims on the upper south side of the mountain in 1974.

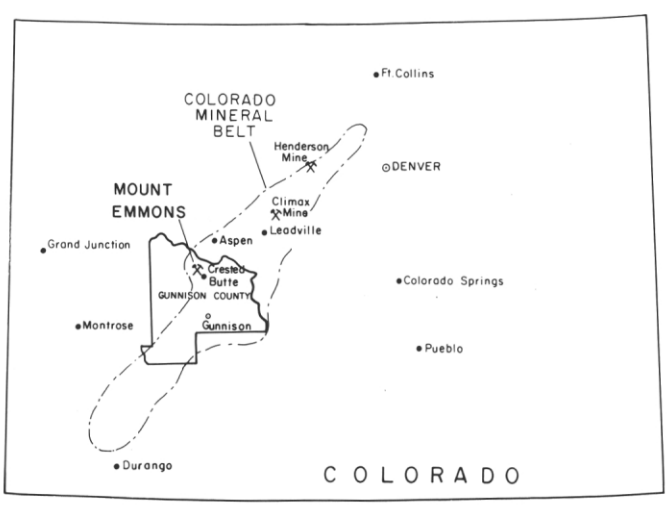

Figure 1. Location map of the Mount Emmons deposit

Drill hole RW 16, drilled in Red Lady Basin on the south side of Mount Emmons in 1976, intercepted the fringe of the Mount Emmons molybdenite deposit. Major geological credit for the Mount Emmons discovery is attributed to John A. Thomas and John T. Galey, Jr. of AMAX Exploration.

The subsequent drilling program initiated in January, 1977 defined the orebody with great accuracy. The geologic reserves at Mount Emmons are 155 million tons having an average grade of 0.44 percent MoS, using a 0.2 percent MoS, cutoff (Ganster and others, 1981).

REGIONAL GEOLOGY

The Elk and West Mountains of west-central Colorado consist mainly of Paleozoic, Mesozoic, and Cenozoic sedimentary rocks intruded by abundant Tertiary igneous rocks of quartz monzonite to granodiorite composition (fig. 2). The northwest-trending Elk Mountains contain a series of stocks (White-Rock, Snowmass, and Sopris) that intrude tightly folded, westward-thrusted Paleozoic sedimentary rocks (Tweto and Sims, 1963). Some igneous rocks have been dated as Laramide age in the Aspen area, but most stocks in the range are mid-Tertiary in age, ranging from 29 to 34 m.y. (Obradovich and others, 1969).

Farther to the southwest, the West Elk Mountains consist of numerous laccoliths, a cluster of small stocks, and a large volcanic center, all of which were emplaced in a thick sequence of gently dipping Cretaceous and early Tertiary sedimentary rocks (Gaskill and others, 1977). Igneous activity began in the mid-Tertiary (29 to 34 m.y.) with (1) sill and laccolithic intrusion in the northern West Elk Mountains, (2) emplacement of stocks and dikes with associated mineralization in the Ruby Range area, and (3) development of an andesitic strato-volcano and volcano field in the southern West Elk Moutains.

Late Tertiary igneous activity was relatively minor compared to the mid-Tertiary events, but has great economic significance. Four

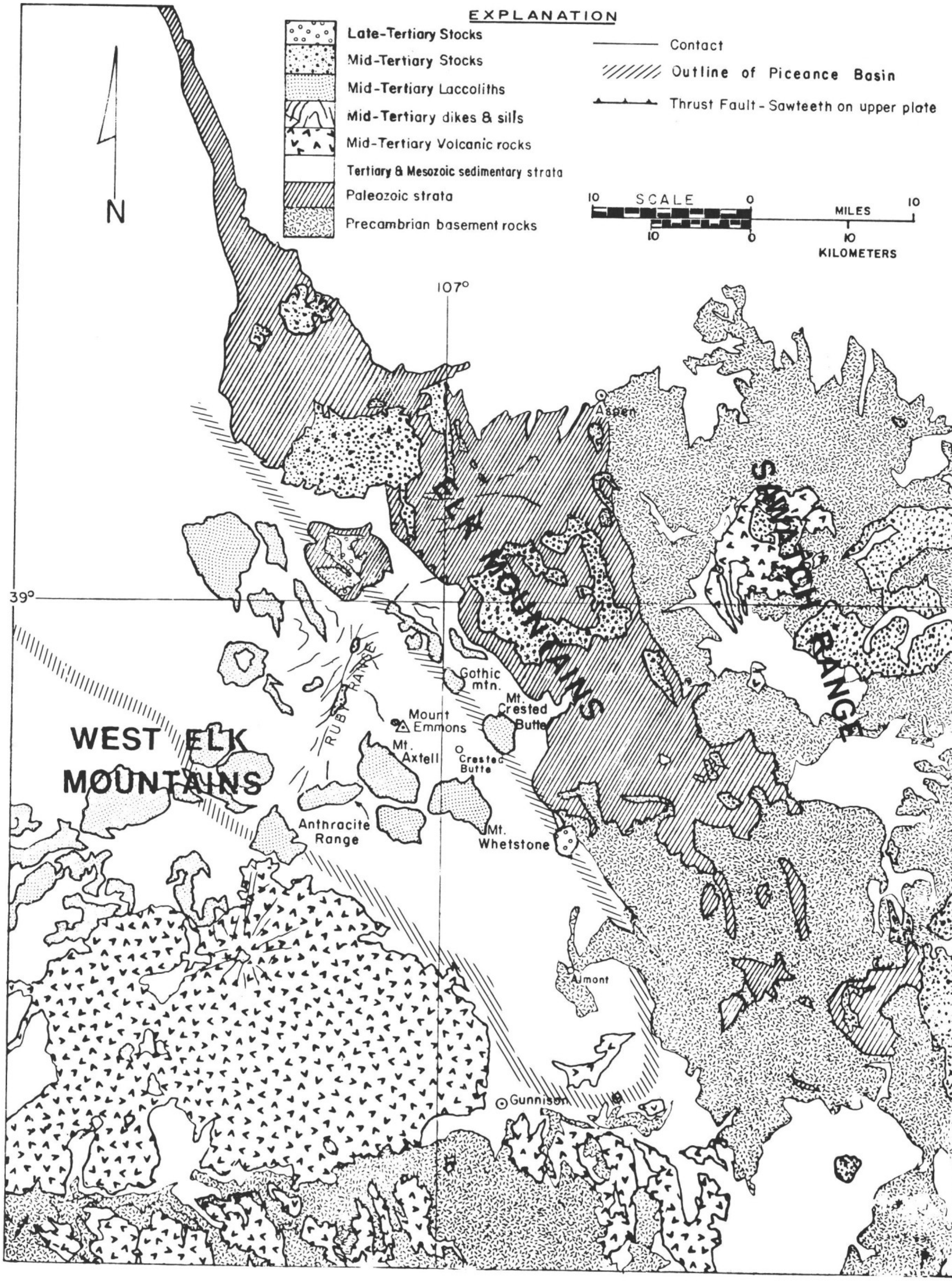

Figure 2. Regional geologic map of west-central Colorado

stocks or plugs, known to be approximately 12 to 17 m.y. old, are: (1) the granite of Treasure Mountain dome (Obradovich and others, 1969), (2) the mineralized felsite-breccia plug and underlying granite porphyry of Redwell Basin (Sharp, 1978; Thomas and Galey, 1978), (3) the mineralized subsurface granite porphyry stock beneath Mount Emmons and Red Lady Basin (Thomas and Galey, 1978; Ganster and others, 1981), and (4) the barren "rhyolite porphyry" of Round Mountain (Cunningham and others, 1977).

The Mount Emmons molybdenum deposit is located in the extreme south-central portion of the Oh-Be-Joyful quadrangle (Gaskill and others, 1967). In general, sedimentary rocks throughout the area dip gently to the south and southwest. The Mount Emmons deposit is located near the south end of the southeast-plunging Oh-Be-Joyful anticline and on the western side of the southwest-plunging Coal Creek syncline (fig. 3). Both structures are assumed to be late Laramide in age, contemporaneous with development of the Piceance Basin syncline.

GEOLOGY OF THE MOLYBDENUM DEPOSIT

Sedimentary Rocks

The sedimentary sequence in the Mount Emmons area spans from late Cretaceous to early Tertiary time. The oldest formation is the Mancos, a 1200-m thick sequence of shales with some interbedded limestones and siltstones (fig. 4). The Mancos Formation is not exposed on Mount Emmons, but may be seen in valley bottoms a few kilometers to the north, south, and east. The overlying Mesaverde Formation, also of late Cretaceous age, consists of a sequence of alternating sandstones, siltstones, shales, and minor coals. On Mount Emmons the Mesaverde Formation varies from 330 to 500 m thick.The upper surface of the Mesaverde Formation was the site of varying amounts of erosion and channel formation. The Ohio Creek Formation, dominantly a coarse sandstone with local chert pebble conglomerate and well-defined shale and siltstone beds, overlies the Mesaverde Formation. The Ohio Creek Formation is of early Tertiary (Paleocene) age and remains fairly consistent at 120 m in thickness on Mount Emmons. Capping Mount Emmons is the Wasatch Formation, also of early Tertiary (Paleocene to Eocene) age. On a more regional scale, within the Ruby Range the Wasatch Formation may reach 500 m in thickness. However, on Mount Emmons specifically, all but the basal 200 m has been eroded. The Wasatch Formation is composed of immature shales, siltstones, arkosic sandstones, and volcanic pebble conglomerates. The Mount Emmons stock has intruded the Mancos and Mesaverde sediments, strongly metamorphosing both formations up to 450 m outward from the igneous contact. Hydrothermal alteration overprints much of the metamorphic hornfels and is recognizable upward through the Wasatch Formation.

Igneous Rocks

Two stages of igneous activity are recognized in the Mount Emmons area during the mid- and late Tertiary. The rocks formed during these two episodes are described below.

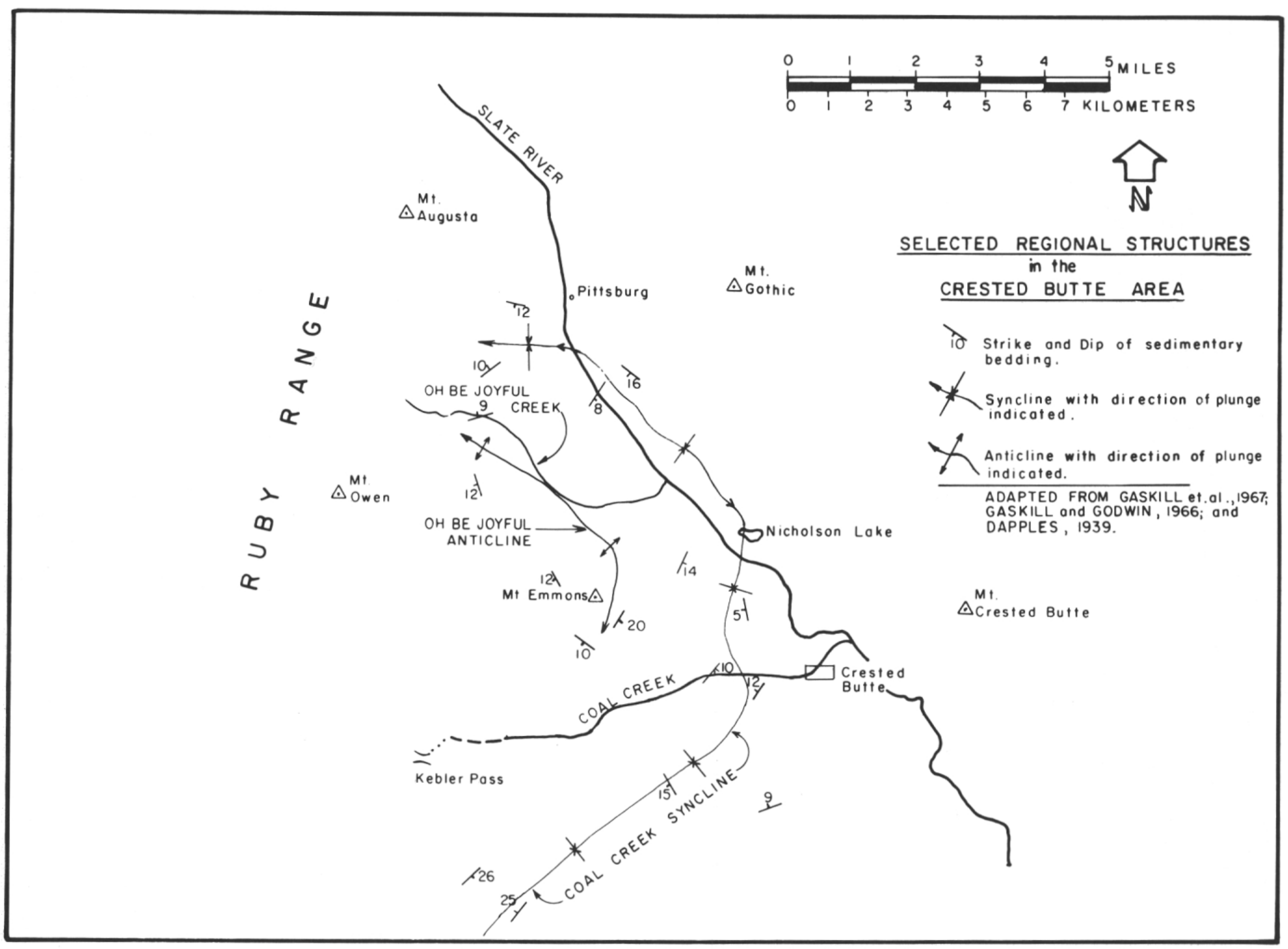

Figure 3. Structural geology of the Mount Emmons area

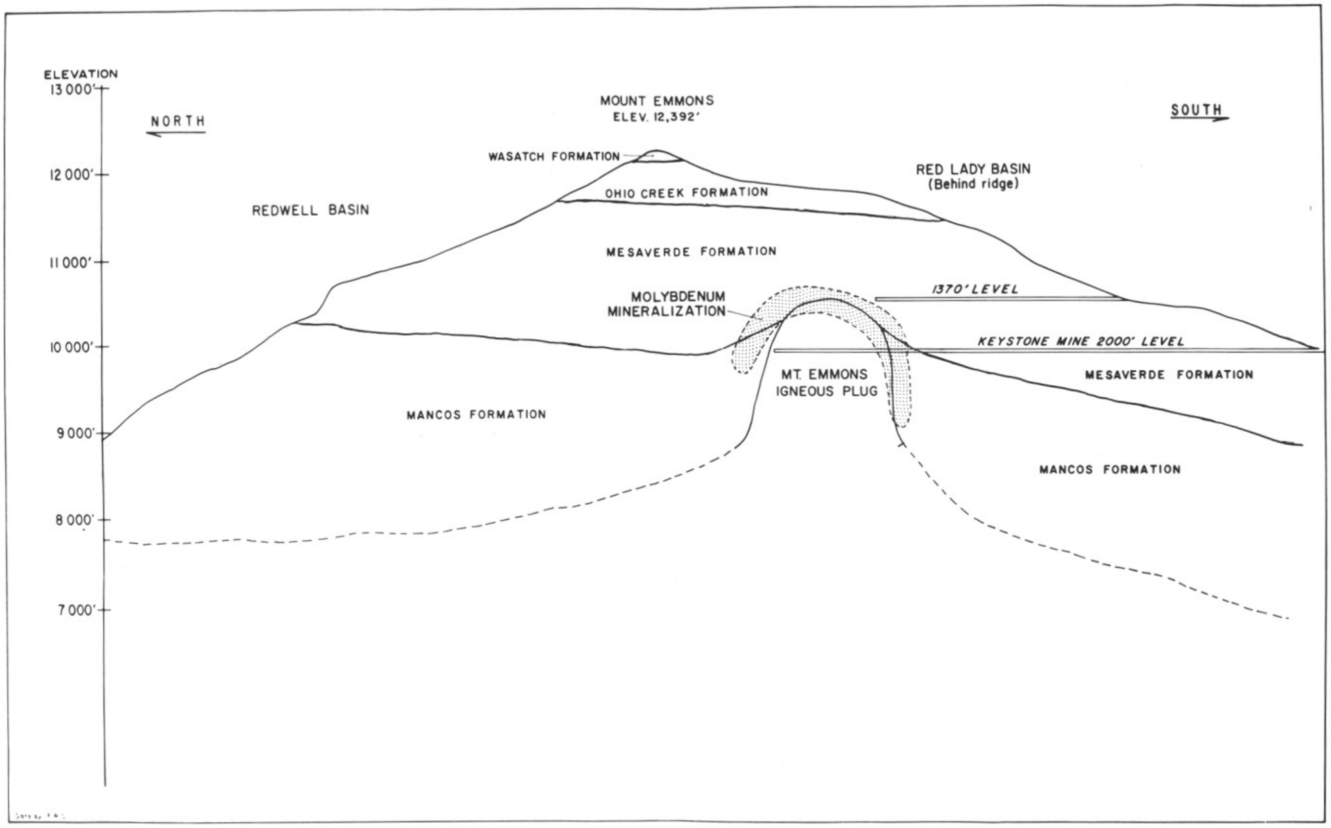

Figure 4. Generalized geology of Mount Emmons

Mid-Tertiary Intrusions

The earliest known igneous activity in the Mount Emmons area was the emplacement of sills and dikes during the mid-Tertiary intrusive events associated with laccolith development. Two compositional and textural varieties of these early intrusives have been recognized in the region.

The first of these varieties is a light green to grey rhyodacite porphyry which occurs at the upper end of Evans Basin as a sill intruded into the Tertiary Wasatch Formation. Other sills of this type have been observed in drill core from numerous locations on Mount Emmons where they intrude Cretaceous rocks.

The rhyodacite porphyry has phenocrysts of plagioclase, biotite, hornblende, and, rarely, quartz in an aphanitic groundmass composed of quartz, plagioclase, and potassium feldspar.

The second variety of mid-Tertiary igneous rock is green to grey quartz latite porphyry and latite porphyry. The quartz latite porphyry occurs as a laccolithic intrusion at Mount Axtell, and as sills and dikes in the vicinity of Mount Emmons and the Ruby Range. The quartz latite porphyry sill which forms the western ridge in Evans Basin and continues across Elk Basin is up to 200 m thick and is probably a northern extension of the Mount Axtell laccolith. The quartz latite porphyry is younger than the rhyodacite porphyry, based on crosscutting relationships and inclusions of rhyodacite porphyry in quartz latite porphyry. The quartz latite porphyry contains phenocrysts of large euhedral potassium feldspar, quartz, hornblende, plagioclase, and biotite in an aphanitic groundmass of quartz and potassium feldspar with minor plagioclase and biotite. The abundance of potassium feldspar and quartz phenocrysts varies considerably and in some areas the rock is a latite porphyry.

Late-Tertiary Intrusions (Mount Emmons Stock)

A stock of rhyolite-granite porphyry occurs below the Mount Emmons molybdenum deposit beneath Red Lady Basin (fig. 4). Three major intrusive episodes are now recognized to have formed the Mount Emmons stock. Rocks of the first igneous episode have been named the Red Lady phases; rocks of the second episode, the Keystone phases; and the third, the Union phases (fig. 5). The steep-sided stock at an elevation of 3000 m has lateral dimensions of approximately 400 to 500 m, elongate northeasterly, and enlarges slightly with depth. Similarity of rocks in the Red Lady, Keystone and Union phases suggests that they are comagmatic. K-Ar ages of 17.3 and 17.7 million years have been obtained for rocks from the Mount Emmons stock.

The Red Lady rocks have been subdivided into three separate intrusive phases: Red Lady Border, Red Lady Aplite, and Red Lady Porphyry. It was during the crystallization of these three phases that the Mount Emmons Ore body and associated hydrothermal alteration patterns were formed.

The Red Lady Border phase ranges from a meter to approximately 50 m thick and is a pre-mineralization, chilled phase of the stock that now hosts about 10 percent of the orebody. The Border phase is in contact with the Mesaverde and Mancos formations and is thickest in the southeastern portion of the stock. The rock is a light buff-grey rhyolite porphyry with 10 to 30 percent phenocrysts of quartz, potassium feldspar, plagioclase, and biotite in an aphanitic groundmass of the same minerals.

The Red Lady Aplite is the second igneous phase in the stock. It has no observed chilled margin where in contact with the Border phase but does display chilled margins where it is in contact with

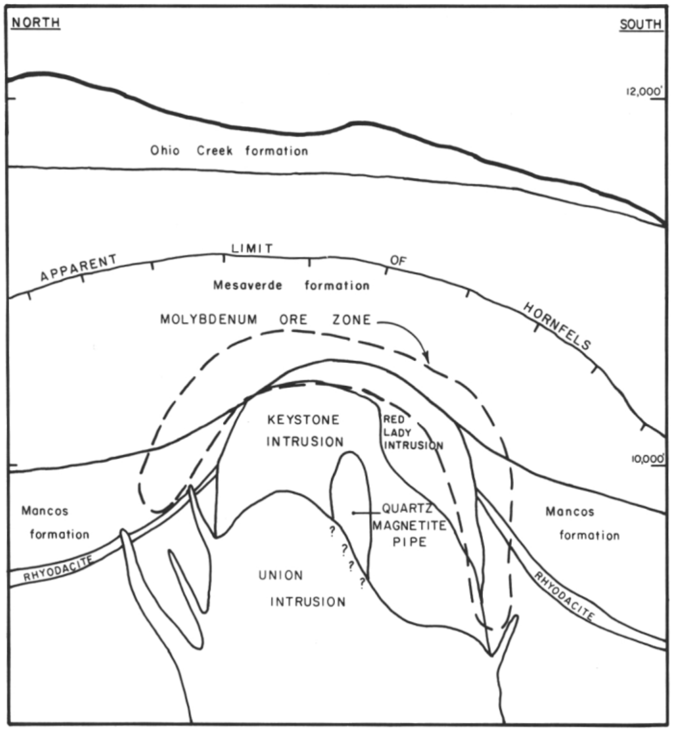

Figure 5. Geology of the Mount Emmons deposit

the Mancos and Mesaverde formations. The Aplite forms a 100-m thick zone in the upper portion of the stock. The texture of the Aplite varies from that of a fine-grained porphyritic granite to aplite to borderline rhyolite. It most typically contains 1 to 5 percent phenocrysts of quartz, potassium feldspar and plagioclase in a fine-grained aplitic groundmass of the same minerals. The Aplite hosts approximately 10 percent of the orebody.

Below the Aplite phase is the 15- to 60-m thick Red Lady Porphyry. This fine-grained granite porphyry shows no chilling at contacts with the Aplite phase but does show chilling against the Mesaverde and Mancos formations. The Red Lady Porphyry contains 15 to 35 percent phenocrysts of quartz, potassium feldspar, plagioclase, and biotite in a groundmass of the same minerals. The contact between the Aplite and Porphyry phases has been chosen where porphyritic textures predominate over aplitic textures. The Red Lady Porphyry does not contain ore-grade mineralization.

The Keystone rocks also are a multi-phase intrusion composed of several different textural units (fig. 5). The distribution and degree of conNuity ,of these textural units are not well known at this time, but s' me generalizations can be made concerning their \ occurrence. Ti e various Keystone phases are as follows: Aplite, Porphyry, Crowdet. ,

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and Biotitic. Except for the Porphyry, the different textural varlet 'les are generally localized within 60 m of the contacts with the Reciady phases and the hornfels. The bulk of the Keystone intrusion kcomposed of Porphyry with Aplite accounting for most of the r maining volume. The Keystone rocks have chilled contacts with L e Red Lady phases and hornfels and

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cut off veining in both cases: Numerous aplitic, porphyritic, and felsitic dikes that occur near the`Aower stock contacts are currently interpreted as being associated wii,th Keystone intrusive activity. The light buff-grey to pink Keystone Porphyry is generally porphyritic-phaneritic with 10 to 50 percent phenocrysts, averaging 20 to 30 percent. The phenocrysts are quartz, potassium feldspar, plagioclase, and biotite set in a fine-grained groundmass of the same minerals. Near the contacts the groundmass is locally aphanitic.

The Keystone Aplite is similar to the Porphyry except that it has only up to 10 percent phenocrysts, averaging less than 5 percent. The Aplite occurs as layers, pods, or bodies of indeterminate shape within the main mass of Porphyry.

The Union phases are the youngest intrusive phases recognized to date (fig. 5). The Union rocks cut off veins in the Keystone Porphyry and locally display chilled contacts with the Keystone Porphyry. The textural units of the Union intrusion are very similar to those of the Keystone intrusion making identification difficult where crosscutting relationships are not seen.

Late-stage alteration and weak molybdenum mineralization may be associated with the Keystone and Union intrusive activity.

Metamorphic Rocks

The wall rocks adjacent to the Mount Emmons stock display contact metamorphic effects to distances greater than 450 m laterally and 180 m vertically from the intrusive contacts (figs. 4, 5). Contact metamorphic rocks host 80 percent of the Mount Emmons molybdenite orebody. The sedimentary formations most strongly affected are the Cretaceous Mancos and Mesaverde formations.The Tertiary Ohio Creek and Wasatch formations may be weakly metamorphosed locally although the effects may be impossible to discern because of later hydrothermal alteration. Hydrothermal alteration has obscured the contact metamorphic changes in many areas above and adjacent to the molybdenite deposit.

The contact metamorphic rocks grade from the albite-epidote-hornfels facies into the hornblende-hornfels facies near the stock contact. The albite-epidote-hornfels facies is characterized by the assemblage quartz-potassium feldspar-biotite±sericite in metamorphosed sandstones, siltstones, and shales and by the assemblage quartz-potassium feldspar-plagioclase±epidote±chlorite ± biotite±actinolite in more mafic or calcareous shales. The absence of epidote and chlorite in more calcic hornfelses adjacent to the stock contact is an indication of the higher temperatures of the hornblende-hornfels facies. Hornfelses of both the Mesaverde and Mancos formations have veins that are contemporaneous with contact metamorphism and which contain the same minerals as the adjacent hornfels.

Within the Mount Emmons area the Mesaverde and Mancos formations vary from unmetamorphosed sedimentary rocks to totally recrystallized metamorphic hornfels. Generally, metamorphic intensity increases with depth and with decreasing distance to the stock contact. Textural changes are influenced both by the intensity of metamorphism and original sedimentary textures. In strongly recrystallized rocks, original grain size differences are often reflected in grain size differences in the metamorphic products. Original sedimentary layering is mimicked by mineral alignment and compositional banding in the hornfels. Recognition of such relict textures has made it possible to correlate rock units between drill holes and to recognize the Mesaverde-Mancos contact.

Hydrothermal Alteration and Mineralization

Hydrothermal alteration associated with the Mount Emmons stock occurs in several distinct overlapping zones (fig. 6). Altered rocks consist of the adjacent and enclosing Cretaceous Mancos and Mesaverde formations, and Tertiary Ohio Creek and Wasatch formations, as well as phases of the Tertiary Mount Emmons stock. Main stage alteration can be zoned from the Tertiary sediments inward in the following sequence:

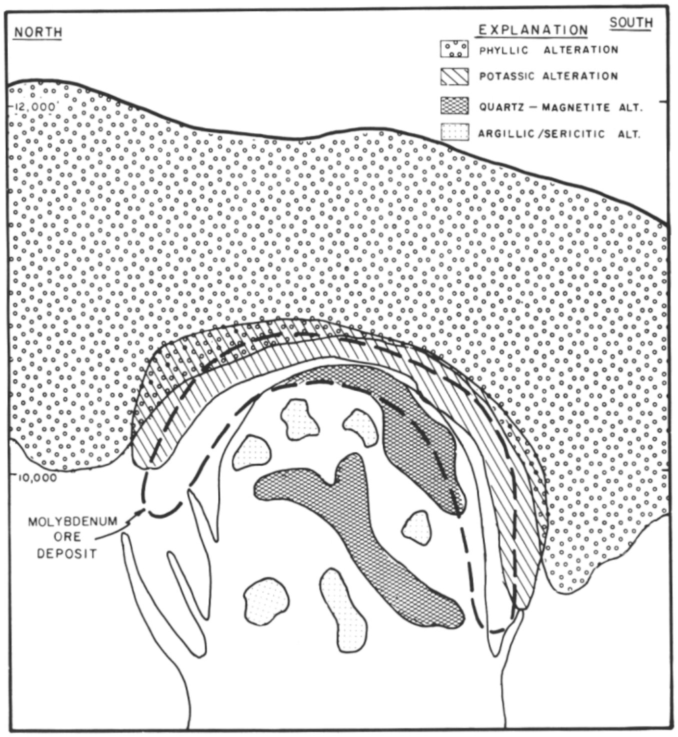

Figure 6. Hydrothermal alteration of the Mount Emmons deposit

1. An outermost zone of veins and disseminated pyrrhotite peripheral to pyrite;
2. A propylitic zone consisting of chlorite, pyrite, epidote and calcite in the Wasatch Formation;
3. A phyllic assemblage of quartz, sericite, and pyrite in the Ohio Creek, Mesaverde, and Mancos Formations;
4. A potassic zone of quartz, secondary potassium feldspar, and biotite in the Mesaverde and Mancos Formations, and in the upper Red Lady phases;
5. A zone of pervasive quartz-magnetite and local biotite and potassium feldspar within the Red Lady phases.

Late-stage hydrothermal alteration affects both the lower Red Lady phases and the upper portions of the Keystone and Union phases. Pervasive argillization mixed with sericite is the dominant late-stage alteration type. Within the Keystone phases, a deep, weak quartz-magnetite zone is present. For the most part, the Keystone and Union phases are unaltered.

Propylitic zone

Propylitic alteration effects are generally restricted to the Tertiary Wasatch Formation where it overlies the Mount Emmons deposit (fig. 4). The Wasatch is the only formation containing significant quantities of mafic minerals and calcic plagioclase, making it more susceptible to replacement by a propylitic assemblage. Minor propylitic alteration may also be seen in hornfels found in the lower lateral margins of the deposit.

In the Wasatch Formation, the propylitic assemblage is characterized by both disseminated and vein chlorite, pyrite, epidote, and minor calcite, pyrrhotite, clay, and sericite. Zonal distribution follows the northeast-southwest trend of the Wasatch in surface and subsurface exposures. Clay and sericite replacement of biotite, feldspar, and (or) matrix materials generally occurs near the Wasatch-Ohio Creek contact and probably represents a transition between the propylitic and phyllic zones.

Phyllic zone

Pervasive phyllic alteration is found in the Ohio Creek, Mesaverde, and Mancos Formations and occurs between the potassic and propylitic zones (fig. 6). Minor late phyllic alteration is also found in all Teritary intrusive rocks associated with the deposit. In both pervasive and vein alteration, an assemblage of quartz, sericite, and pyrite is characteristic, with significant fluorite commonly present.

Pyrite veinlets with quartz-sericite-pyrite envelopes are characteristics of the phyllic zone. A transition from quartz-pyrite to quartz-pyrite-molybdenite veinlets occurs as the ore zone is approached.

Within the main phyllic zone, pyrite distribution between vein and disseminated occurrences is controlled by the grain size, and possibly, the porosity of the host sediments. In coarse, porous sandstones and arkosic sandstones of the Ohio Creek and upper Mesaverde the majority of the pyrite is disseminated. In fine-grained sandstones and siltstones of the Mesaverde and locally, Mancos Formations, thermal metamorphic effects have reduced porosity and fissility, producing a more refractory and brittle rock. In these units, pyrite occurs in hairline vein stockworks, with relatively minor disseminations. Below the transition from phyllic to potassic alteration, pyrite rapidly decreases to one percent or less throughout the remainder of the deposit.

In the Mount Emmons stock, phyllic alteration is generally restricted to minor pyrite veins with quartz-sericite-pyrite envelopes, and to local replacement of plagioclase and, rarely, potassium feldspar phenocrysts.

Potassic zone

The zone of potassic alteration occurs mainly within metamorphosed Mesaverde and Mancos Formations, and partly overlaps the contact with the Mount Emmons stock (fig. 6). The zone grades into phyllic alteration above and quartz-magnetite alteration below. Most of the ore zone lies within potassically altered sediments and rhyodacite porphyry sills. Except for local recrystallization and weak flooding by potassium feldspar and biotite, hornfels matrix appears to remain intact, making potassic alteration mainly vein-related. Vein assemblages are variable, but generally contain potassium feldspar, quartz, biotite, fluorite, and molybdenite. Magnetite and pyrite may also be present.

A variation of typical potassic alteration has weak sericitic replacement of matrix biotite, plagioclase, and potassium feldspar adjacent to potassium feldspar veins. Minor sericite also accompanies potassium feldspar in the vein. Sericite in vein halos becomes diffuse within one mm of the vein.

Quartz-magnetite zone

The zone of strong quartz-magnetite alterati n is primarily restricted to the upper part of the Mount Emr ons stock (fig. 6). Quartz-magnetite alteration is located below both the potassic zone and the major portion of the ore zone's

The quartz-magnetite alteration is cha racterized by an intense stockwork of quartz veinlets with 4 to 8 volume percent magnetite. Hematite, biotite, and flur rite are minor components of the quartz-magnetite veins. Locally, the quartz-magnetite is massive with no rock fragments visible. The quartz-magnetite veining decreases greatly near the roargin of the stock and the magnetite content of the quartz vein,S also decreases.

Within the central portion of the stock a 60-m-wide pipe-like body of massive quartz-magnetite has recently been recognized (figs. 5 and 6). This quartz-magnetite pipe cuts the Keystone intrusion. The relationships between the Union intrusion and this quartz-magnetite pipe are not known at this time.

Pyrrhotite zone

A zone of pyrrhotite mineralization is peripheral to the combined hydrothermal systems of both the Redwell and Mount Emmons deposits. It occurs marginal to pyrite from the phyllic zone of the deposit and may be related to reducing conditions in carbonaceous siltstones and shales of the Mesaverde and Mancos formations.

Molybdenite mineralization

The Mount Emmons molybdenite deposit is the only known zone of economic mineralization associated with the Mount Emmons and Redwell intrusive systems.

At its shallowest point, the upper limit of the molybdenite ore zone lies approximately 270 m below the surface of Red Lady Basin (fig. 4). Geologic reserves are 155 million tons averaging 0.44 percent MoS_2 using a 0.2 percent MoS_2 cutoff. The ore zone ranges between 75 and 120 m thick (averaging 90 m), with a cross-sectional diameter averaging 650 m. It is concentrically draped over the apex of the Mount Emmons stock in the shape of an inverted cup and extends well into the metamorphosed sedimentary rocks (fig. 5). Ore-grade mineralization is locally terminated at depth by Keystone rocks.

The majority of ore in metamorphosed sedimentary rocks lies within potassically altered rock and locally within transition zones between potassic and phyllic alteration. Molybdenite was introduced as stockwork veinlets associated with the main-stage hydrothermal event of the Mount Emmons stock. Vein mineralogy is relatively simple, consisting mainly of fine-grained quartz, molybdenite, and fluorite. Potassium feldspar, magnetite, pyrite, carbonate, and occasionally biotite, may be present in minor amounts.

At the outer margins of the ore zone, stockwork quartz-molybdenite-fluorite veins die out and grade into stockwork pyrite or pyrite-quartz-sericite veins at the transition from the potassic zone to the phyllic zone of alteration. Within the Mount Emmons stock ore-grade mineralization drops off in the outer part of the quartz-magnetite altered rocks.

SUMMARY

Intrusion of granitic magma of the Red Lady Complex into the Cretaceous and Tertiary sedimentary and igneous rocks at Mount Emmons was the initial step in the formation of the molybdenum deposit. The intrusion caused some fracturing and extensive contact metamorphism in the country rocks. The magma was rapidly chilled creating the Red Lady Border phase. Continued crystallization of the magma at somewhat slower cooling rates resulted in the formation of the Aplite. Differentiation of the magma occurred during the crystallization process causing interlayered porphyritic and aplitic textures to develop deeper in the stock.

During crystallization of the Red Lady phases, hydrothermal fluids collected near the top of the magma column. These fluids were released after a period of intense fracturing in the solid upper portions of the Red Lady intrusion and the surrounding country rock. This release of fluids was responsible for the formation of the major part of the Mount Emmons molybdenum deposit and the associated alteration zones. Continued cooling and crystallization of the Red Lady magma was accompanied by minor amounts of mineralization and alteration which crosscut earlier zones.

Renewed upward intrusive pressure within the magma chamber locally caused magma to be intruded into the Red Lady rocks, cutting off alteration and mineralization. This magma solidified to form the Keystone intrusion of variably textured granite porphyries. Minor local accumulations of hydrothermal fluids produced during crystallization of the Keystone magma affected the upper part of the Keystone rocks and portions of the lower part of the adjacent Red Lady phases.

A second resurgence of magma caused intrusion of the Union phases into the Keystone rocks. Release of hydrothermal fluids from this granite magma may have created the zones of sericitic, argillic, and quartz-magnetite alteration in the overlying Keystone rocks. Quartz-sericite-pyrite alteration in the upper portions of the Union mass was probably formed by hydrothermal fluids retained in the Union magma.

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