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MAPS SHOWING ROCK TYPES, HYDROTHERMAL ALTERATION AND DISTRIBUTION OF FLUID INCLUSIONS IN THE CORNELIA PLUTON, AJO MINING DISTRICT, PIMA COUNTY, ARIZONA

By Dennis P. Cox[1]

and Eijun Ohta [2]

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1 Menlo Park, CA

2 Geologic Survey of Japan

Maps Showing Rock Types, Hydrothermal Alteration and Distribution of Fluid Inclusions in the Cornelia Pluton, Ajo Mining District, Pima County, Arizona

By Dennis P. Cox, U.S. Geological Survey, Menlo Park
and Eijun Ohta, Geological Survey of Japan *

Introduction

Examination of rocks in the Cornelia Pluton during the mineral resource assessment of the Ajo 2° Quadrangle revealed abundant, highly saline fluid inclusions in igneous quartz grains in plutonic rocks (Cox and others, 1980). In addition to Na, K and Fe chlorides minerals, these inclusions were also found to contain chalcopyrite, substantiating Gilluly's (1946) hypothesis that the pluton was the source of hydrothermal fluids that formed the porphyry copper deposit at the New Cornelia Mine to the east. Subsequent detailed mapping of the pluton has indicated a complex history of intrusion of rocks with a variety of well-defined compositions and textures. In addition we have noted sodic-calcic hydrothermal alteration assemblages (Carten, 1979) in the Cornelia pluton. These assemblages, previously recognized in the deep zones beneath the Yerington (Carten, 1981) and Ann Mason (John Dilles, oral communication, 1983) porphyry copper deposits in Nevada also lend support to the hypothesis that the Cornelia pluton is the root zone of the Ajo porphyry copper system.

In this paper we present preliminary data to serve as background for containing paleomagnetic, geochronologic and other studies. We reserve judgements regarding the relationship of the pluton to the ore deposit and the geologic history of intrusion and mineralization until a later time.

Acknowledgements

The New Cornelia Branch of Phelps Dodge Corporation kindly arranged numerous geologic tours of the pit, provided access to surface properties and furnished the geologic map of the pit included in Figure 1. Discussions with Scott Gibson and Ronald Gibbs of Phelps Dodge and Veronica UyTana of the University of Arizona were helpful in understanding the relations between the geology of the deposit and the pluton to the west. John H. C. Bain of the Australian Bureau of Mineral Resources contributed greatly to the field mapping in the first year of the project.

Structural Relations

The structure of the Ajo district was worked out by Gilluy (1946) and only minor modifications to his ideas have resulted from our work up to this time. Eastward-dipping normal faults, named Gibson Arroyo and Arkansas Mountain (figure 1) divide the Ajo district into three major blocks: The westernmost and deepest is the Cardigan Peak block, the middle is the

* Present address: Geological Survey of Japan, Hokkaido Branch
Ninami-1-jo Nishi-18-chome
Chuo-ku, Sapporo 060, Japan

Camelback Mountain block and the easternmost and shallowest is the New Cornelia block which contains the New Cornelia porphyry copper deposit (see table 1). Gilluly proposed that the New Cornelia block was originally the cupola of the pluton and was faulted down to its present position. Movement on these faults was later than hydrothermal alteration and mineralization and earlier than deposition of the Locomotive Fanglomerate. The Locomotive Fanglomerate (Gilluly, 1946, p. 35-39) was deposited on the eroded plutonic rocks in early or middle Tertiary time and the fanglomerate and underlying plutonic rocks were then tilted 50 to 65° to the south. Exposures in the southern portion of the Cornelia pluton thus represent shallower levels of the pluton than do exposures in the north part.

Cornelia Pluton rock types

Mapping in the pluton has revealed a suite of rocks similar to those described by Wadsworth (1968), however, by walking out contacts between textural and compositional variants we have found a somewhat different rock distribution pattern (see Figure 1). Our findings and those of Wadsworth (1983) are similar in that we recognize a rapidly chilled or quenched core zone in the pluton that seems to have profoundly affected more coarsely crystallized rocks around it. Geochronologic data (McDowell, 1971) however, have raised the possibility of multiple intrusive events within the pluton separated by a long period of time and the relationship of these events to the New Cornelia deposit is unclear. More geochronology must be done before firm conclusions regarding deposit genesis can be reached.

Rocks of the Cornelia pluton are described briefly below and are classified according to recommendations of the IUGS subcommission (Streckeisen, 1973) The reader should refer to Guilluly (1946) for descriptions and discussion of other rocks in the Ajo district.

Fine-grained diorite, monzodiorite and quartz monzodiorite (unit KTfd, fig. 1) is equivalent to the border facies (quartz diorite) of Gilluly (1946, p. 26-p7) and quartz diorite of Wadsworth (1968, p. 106). This unit is found along the western contact of the pluton in the Cardigan Peak block. It forms a major part of the Camelback Mountain block and is found as small, irregular bodies in the New Cornelia block (Dixon, 1966). Rocks of this unit contain plagioclase, pyroxene, and hornblende, as well as minor quartz, K-feldspar and biotite. Quartz and K-feldspar are more abundant in exposures east of the Gibson Arroyo fault.

Coarse grained quartz monzodiorite, monzodiorite and quartz monzonite (unit KTmd) is approximately equivalent to granodiorite of Wadsworth (1968, p. 106-107). This unit is exposed in a broad zone inboard of the fine-grained diorite in the Cardigan Peak block and in a small area at the north end of the Camelback Mountain block. The rocks are composed of plagioclase, hornblende, and K-feldspar, with minor quartz, biotite, and pyroxene. In the Camelback Mountain block, this unit contains less K-feldspar and slightly more quartz than equivalent rocks to the west.

Equigranular monzogranite (unit KTm) matches Wadsworth's description of equigranular quartz monzonite (1968, p. 107). This rock forms the central part of the pluton; it is lighter colored than the previously mentioned units and is composed of plagioclase, K-feldspar, quartz, hornblende, biotite and minor pyroxene.

Granodiorite (unit KTg) is similar to the equigranular monzogranite but has a higher ratio of plagioclase to K-feldspar. This rock makes up most of the Camelback Mountain block and the north part of the New Cornelia block.

Monzogranite with oikocrystic quartz K-feldspar (unit KTmo) is probably equivalent to the porphyritic quartz monzonite of Wadsworth (1968, p. 108) and is recognized by the presence of large and rounded quartz grains, several adjacent grains of which may be oriented in optical continuity. These grains enclose abundant small subhedral plagioclase crystals. Wadsworth, (1983) ascribed this distinctive texture to crystallization during boiling of contained aqueous fluids. The oikocrystic monzogranite is distributed in a zone within the monzogranite and surrounding the central core of fine-grained granite (unit KTfg). Its mapped distribution pattern strongly suggests that its origin is closely related to intrusion or crystallization of the fine-grained granite. The oikocrystic texture is illustrated in Plate 13D of Gilluly (1946).

Aplitic monzogranite and granodiorite porphyries (KTmp and KTgp) are recognized by presence of a fine-grained groundmass composed of aplitic-textured quartz and K-feldspar making up 20 to 50 percent of the rock by volume. The monzogranite porphyry forms two small bodies intimately associated with fine-grained granite in the north-central part of the pluton and is found in small dikes with chilled margins that are distributed along the southern contact of monzogranite with the precambrian Cardigan gneiss. Granodiorite porphyry is similar but has a greater abundance of plagioclase phenocrysts. It forms a small body in the Cambelback Mountain block and is abundant in the New Cornelia block. Most of the ore-bearing rock in the New Cornelia Mine is of this type. Rocks with aplitic texture are illustrated in Plate 13 E and F and plate 14 B, C, and D of Gilluly (1946).

Fine-grained granite and monzogranite (unit KTfg) is equivalent to porphyritic micro-quartz monzonite of Wadsworth (1968, p. 108). This unit is recognized by its uniformly fine, allotriomorphic granular texture and scarcity of phenocrysts. It forms one large and five or six small east-west trending bodies within the monzogranite of the Cardigan Peak block, but has not been recognized with certainty in the other structural blocks. Rocks of this unit are composed of quartz, K-feldspar, plagioclase, and biotite and show sharp but intricately anastomosing contacts into the coarser monzogranite. Pegmatites 10-20 cm in diameter, containing quartz and K-feldspar, are found in the fine-grained granite within meters of its contact with coarser monzogranite.

Porphyry dikes (unit pd) are of two types: a light colored porphyry with prominent plagioclase phenocrysts and subordinate chloritized amphiboles (feldspathic andesite porphyry of Gilluly, 1946, p. 33-34), and a dark colored porphyry with small phenocrysts and aggregates of phenocrysts of hornblende (nonporphyritic andesite of Gilluly , 1946, p. 34-35. Abundant feldspathic andesite porphyry dikes intrude fine-grained diorite and coarse-grained monzodiorite on the west side of the pluton. Some dikes extend from the monzodiorite a few tens of meters, and rarely, hundreds of meters into the monzograntie but otherwise these dikes are absent from the core of the pluton. Feldspathic andesite porphyry dikes are abundant in the Camelback Mountain block and New Cornelia block and intrude rocks as young as granodiorite porphyry (KTgp). Near the hospital in Ajo, quartz veinlets cutting altered granodiorite porphyry were observed having been cut off by a feldspar porphyry contact, suggesting that these dikes are younger than the copper mineralization. We were unable to corroborate this relationship by observations in the ore zone, however.

The hornblende andesite dikes are abundant in the Camelback and New Cornelia blocks but rare in the main pluton of the Cardigan Peak block. Dikes intrude rocks as young as granodiorite porphyry, but near the hospital, where the dikes are offset by small healed fractures, granodiorite (KTg) appears to have intruded the dikes. Gilluly (1946, p. 35) observed a similar phenomenon in the main pluton in the Cardigan Peak block. The hornblende andesite dikes seem to cut feldspathic andesite dikes in the Camelback Mountain block but in the Cardigan Peak block hornblende andesite forms borders flanking feldspathic andesite dikes (see especially exposures south of Dunns Wells). These conflicting contact relationships suggest that the dikes may represent more than one stage of intrusion and, that possibly, minor remobilization of granitic rocks occurred after dike intrusion.

Hydrothermal Alteration in the Cornelia Pluton

Alteration in the three structural blocks at Ajo is described briefly in table 1 and discussed in detail by Gilluly (1946 p. 73-77) and UyTana (1983). Sodic-calcic alteration in the Cornelia pluton (see figure 2) was referred to briefly as albitization by Gilluly (1946 p. 82). Sodic-calcic alteration is the result of replacement of biotite by pale green fibrous amphibole and of K-feldspar by coarse-grained twinned oligoclase rich in small unidentified inclusions. This replacement produces chalky white rocks that are resistant to weathering and erosion. Altered rocks may appear to have had a different primary igneous composition than their unaltered equivalents because of the conversion of biotite to amphibole. This alteration is strongly fracture controlled, forming whitish envelopes around veinlets of epidote, hematite, actinolite or, more rarely, tourmaline. Where these veinlets are abundant the alteration becomes pervasive.

Along the north and southeast contacts of the main body of fine-grained granite (unit KTfg) fracture controlled replacement of K-feldspar and biotite was preceeded by an early alteration affecting only biotite. The biotite was replaced by well-crystallized pale green amphibole and locally by diopside in the presence of stable igneous K-feldspar.

Fluid Inclusions in the Cornelia Pluton

Fluid inclusions are abundant in all coarse-grained phases of the Cornelia pluton including the small pegmatite pockets in fine-grained granite (see figure 3). The inclusions are trapped in igneous quartz and are aligned along small healed fractures or randomly distributed in the quartz grains. The several kinds of inclusions present are shown diagramatically in Figure 3 and may be described as follows:

Mineral-rich fluid inclusions contain one or more solid phases in addition to a vapor bubble. Some inclusions contain such large or abundant mineral grains that the vapor bubble is distorted and the liquid phase is difficult to see. Scanning electron microscope studies of these inclusions reveal cubic Na and K chlorides, plated Na, K, Fe chlorides, a prismatic hexagonal Fe chloride, Ca sulfate (?), hematite and rarely, sulfides of iron, copper-iron, zinc and lead. Mineral-rich inclusions homogenize mainly by dissolution of daughter minerals from 300° to above 600°. See figure 4.

Vapor-rich inclusions contain a large vapor bubble and a small amount of liquid that is often difficult to see. Rarely, a small cubic-transparent or triangular-opaque daughter mineral is present in the liquid phase. Vapor-rich inclusions homogenize as vapor from 300 to above 600° C.

Liquid-rich inclusions contain a small vapor bubble and no solid phases. They are smaller than the other two types and most homogenize between 100° and 300° C. A small number of liquid-rich inclusions homogenize at temperatures between 300 and 500° C.

Close association of mineral-rich and vapor-rich inclusions suggest that boiling of an aqueous fluid occurred in an irregular zone extending around the east, south and west contacts of the fine-grained granite (see Figure 3). The zone of boiling fluids extends southward and westward in irregular arms. The western extent of the boiling is undetermined because of the paucity of quartz grains in the fine-grained diorite. Mineral-rich and vapor-rich fluids are rare in the fine-grained granite except in pegmatite pockets near the contact where they may be large and abundant. Comparison of figures 2 and 3 shows a lack of correlation between hydrothermal alteration and evidence for boiling fluids.

Conclusions and suggestions for further study

The Cornelia pluton has a complex history of intrusive and hydrothermal events some or all of which may be related to formation of the New Cornelia porphyry copper deposit. The fine-grained granite crystallized rapidly late in the history and had profound effects on the surrounding coarse-grained rocks, chief among these being oikocrystic crystallization of quartz in monzogranite, early alteration of biotite to amphibole and pyroxene and boiling of fluids in the coarse-grained rocks. Assuming that all rocks of the pluton are roughly the same age, these effects can be explained as a result of intrusion and rapid pressure quenching of granite magma at a time when the monzogranite pluton was only partly crystallized. The pressure release that quenched the granite also resulted in boiling of aqueous fluids that had accumulated in the monzogranite. These conditions, according to Wadsworth (1983), are responsible for the distinctive oikocrystic growth of quartz in the monzogranite. The absence of inclusions formed by boiling fluids in the rocks exposed on the north side of the fine-grained granite is expected in light of the fact that the north side of the pluton represents the deeper (hence higher pressure) part of the system.

A second explanation would have to be sought if geochronologic data show that the fine-grained granite represents a new and unrelated intrusion of magma into the core of the pluton after cooling of the monzogranite. In this situation boiling fluids and oikocrystic quartz growth would have resulted from some early crystallization phenomena within the monzogranite.

In order to sort out which features of the Cornelia pluton are important recognition criteria for deep zones of porphyry copper systems, the chronology of intrusion and mineralization in both the pluton and the ore deposit must be worked out in detail.

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TABLE 1

Structural Blocks	Cardigan Peak	Camelback Mountain	New Cornelia
Rock Types	Diorite, monzogranite and granite.	Diorite, granodiorite, and monzogranite. Volcanic rocks (unit Kc) probably comagmatic with pluton.	Granodiorite, minor diorite. Volcanic rocks (unit Kc) probably comagmatic with pluton.
Rock Textures	Equigranular and coarse-grained. Fine-grained granite and diorite. Minor porphyry with aplitic groundmass.	Equigranular grano-diorite, fine-grained diorite, minor aplitic porphyry.	Mainly porphyry with aplitic groundmass.
Dominant Alteration	Sodic-Calcic (K-feldspar altered to oligo-clase; biotite to actinolite) partly overprinted by late propylitic alteration.	Propylitic (chlorite + epidote + actinolite ± calcite.	Potassic (K-feldspar anhydrite + chalco-pyrite + bornite + magnetite). Hydrothermal biotite altered to chlorite. Late sericite-pyrite alteration locally. North of the mine area mainly propylitic alteration.
Fluid Inclusions	Abundant mineral-rich and vapor-rich inclusions indicating boiling, with homogenization temperatures from 300° to > 600° C. Minor liquid-rich inclusions homogen-izing at temperatures between 100° and 300° C.	Mostly liquid-rich and some vapor-rich two phase inclusions.	Mostly liquid-rich homogenizng between 200 and 250°C. Rare mineral-rich and vapor-rich inclusions with pressure-corrected closing temperatures up up to 470° C (UyTana, 1981).

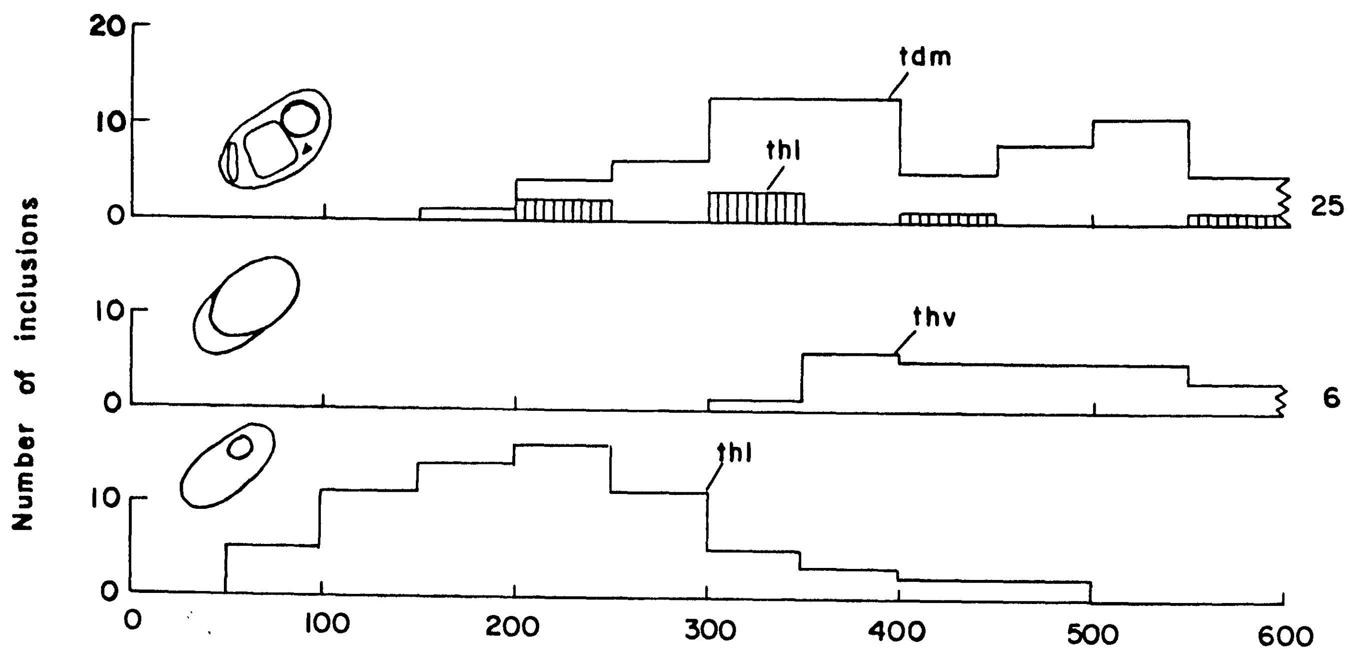

Figure 4 Temperatures of homogenization of fluid inclusions in the Cornelia Pluton in degrees Celcius. Temperature of homogenization by dissolution of daughter minerals (tdm). Temperature of homogenization by disappearance of vapor bubble (thl). Temperature of homogenization by disappearance of the liquid phase (thv).