MULTILEVEL GEOCHEMICAL PATTERNS AT THE FORTITUDE GOLD SKARN, BATTLE MOUNTAIN MINING DISTRICT, NEVADA

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ABSTRACT

Distribution of elevated contents of proximal (Cu, Au, Ag) and distal (Pb, Zn) metals around the Fortitude Au skarn reveals that a prominent Pb–Zn halo mantles the distal parts of the orebodies, more or less duplicating, at large scale, the district-scale relations between proximal and distal metals previously recognized in production data from widespread polymetallic veins. The geochemical haloes that surround the Fortitude orebodies are complicated and multilevel, including mushroom- and pillar-shaped parts. In addition, present-day topography impacted significantly these geometrically complex haloes as exemplified by apparent removal by erosion of part of a Pb locus near the northern end of the Fortitude orebodies. Further, mineralized rocks of the Pennsylvanian and Permian Antler sequence at the Nevada Mine are inferred to represent the northern leading edge of mineralized rocks that make up the Fortitude and Phoenix deposits in the Antler sequence farther to the south. Finally, Pb–Zn ores at the 700–ft level in the Copper Canyon underground mine, as well as a reversal in district metal zoning at the Tomboy-Minnie Au–skarn deposits, are inferred to be related to another site in the southern part of the Copper Canyon area near the Midas Au skarn where influx of mineralizing fluids occurred. Both of these sites where influx of metals may have occurred may be related to apices of mineralized cupolas of altered granodiorite.

INTRODUCTION

Geochemical data from mineralized drill core into the Fortitude Au skarn (the largest producer of Au in the Battle Mountain Mining District) define deposit-scale metal distribution patterns around skarn zones which are related to a 38– to 40–Ma skarn-related, porphyry Cu system at Copper Canyon (fig. 1; Wotruba and others, 1986; Myers, 1994; Kotlyar and others, 1997). Mining of ores from the Lower Fortitude deposit occurred between 1984 and 1993. Gold-skarn mineralized rocks in the Lower Fortitude deposit contained approximately 2.1 million oz Au, and are largely restricted to the generally flat-lying Pennsylvanian and Permian Antler Peak Limestone—middle formation of the Pennsylvanian and Permian Antler sequence—present below the Golconda thrust. These rocks extend at depth below the Golconda thrust as much as 1,000 m from the northern contact of an altered 38– to 40–Ma granodiorite at the core of the system (fig. 1; Wotruba and others, 1986; Myers, 1994).

A north-south geochemical profile was studied, through the two major orebodies that comprise the Lower Fortitude Au skarn: Orebody I, proximal to the altered granodiorite of Copper Canyon, and the other distal, II (fig. 2). The Copper Canyon area also includes the Phoenix Au skarn immediately south of the Fortitude deposit (deposit no. 3, fig. 1)—the Phoenix deposit contains at least 900,000 oz Au (Doebrich and others, 1996; see also, Kotlyar and others, 1998), and is currently (early 1998) being permitted for mining. A number of drill holes that were analyzed for Cu, Au, Ag, Pb, and Zn in the general area of the Fortitude deposits were selected for study of their metal distributions at depth around the two major orebodies that make up the Lower Fortitude (fig. 2). The Nevada Mine, near the north end of the cross section, is a polymetallic replacement and vein occurrence hosted in rocks of the Antler sequence, which were exposed in a structural window through the Golconda thrust (Theodore and Blake, 1975). The Nevada Mine produced about 273 oz Au and 28,000 oz Ag from 1902 to 1948 (Roberts and Arnold, 1965).

These studies form a small part of a protracted examination of the behavior of Au in pluton-related geologic environments. This examination, in part, is designed to provide a better understanding of geometric relations of highly zoned mineralized systems in these environments that are widespread throughout much of northern Nevada (Peters and others, 1996). A more detailed description of these relations is presented by Kotlyar and others (1998).

COMPUTER-CONTOURING PROCEDURES

Down-hole gridding and filtering procedures were used to establish loci of Au, Cu, Ag, Pb, and Zn metallization in 982 drill-core samples analyzed along a north-south section through the Lower Fortitude orebodies (fig. 2). The computer-contouring procedures follow those described by Kotlyar and others (1995, 1998). The “Au” symbol, for example, is placed visually at the center of gravity of normalized, gridded, and

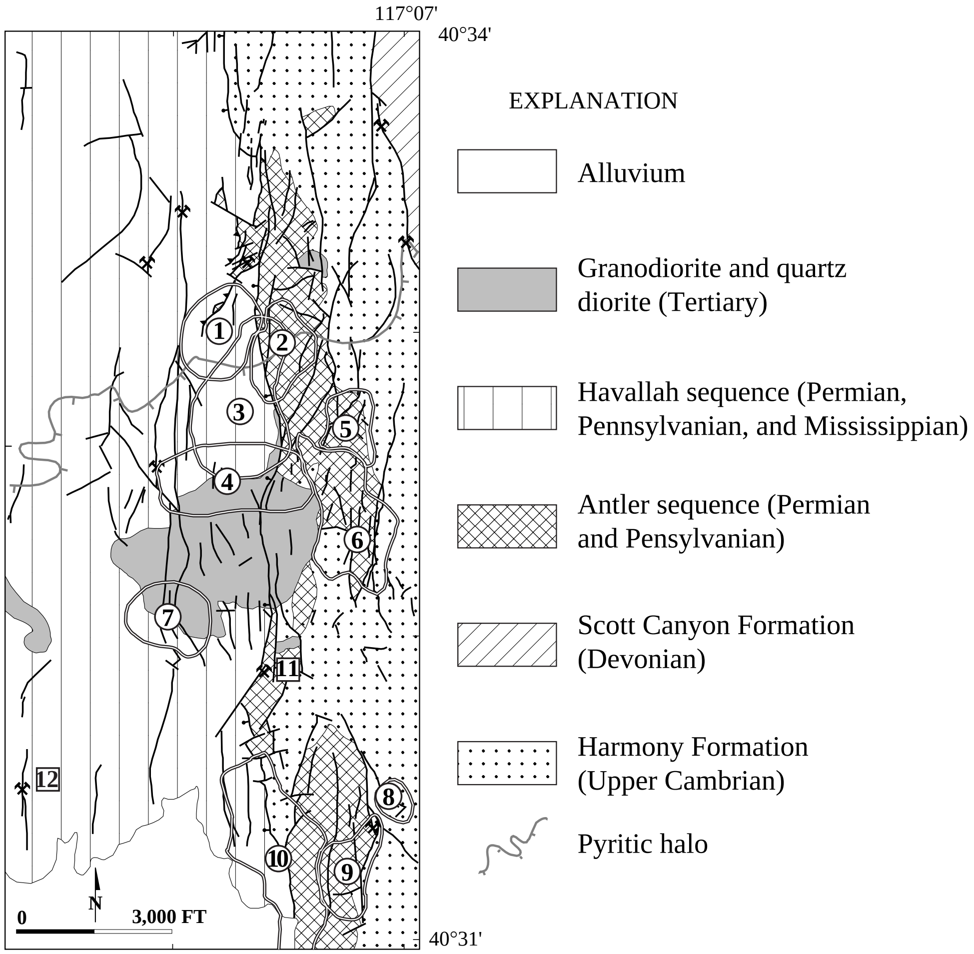

Figure 1. Geology of the Copper Canyon area, Battle Mountain Mining District, Nevada. Modified from Theodore and Blake (1975). Deposit nos. 1–12 are deposits discussed in report. 1, Lower Fortitude; 2, Upper Fortitude; 3, Phoenix; 4, West Orebody; 5, Northeast Extension; 6, East Orebody; 7, Reona; 8, Minnie; 9, Tomboy; 10, Midas; 11, Copper Canyon underground (Cu–Pb–Zn); 12, Wilson-Independence (Au–Ag). Deposit nos. in circles indicate large Au–Ag deposits mined by open-pit methods; squares, deposits mined by underground methods.

filtered data for Au—contours are in standard deviations. Greater intensity gray shades indicate higher deviation from the mean Au content across the plane of the section. Normalization of the data involved calculation of $(X_C - X_{Mean})/X_{Standard\ Deviation}$, where all values are logarithms and X_C is the concentration for a selected element in an analyzed sample, resulting in contours showing deviations (σ) from the mean. The locus of Au–mineralized rock along the section is compared with loci of other metals, established by using the same technique, and shows a progression, respectively, from south to north of Au, Cu, Ag, Pb, and Zn loci of mineralized rock (fig. 2). These loci are more or less coincident with the projected trace of the Lower Fortitude orebodies onto the cross section—the locus for Au is at the proximal end; that is, proximal to the granodiorite of Copper Canyon (fig. 1), and Zn is at the distal end (fig. 2). Thus, zonation of metals around the Fortitude orebodies may be grouped into a proximal suite (Cu, Au, Ag) and into a distal one (Pb, Zn).

Examination of analyzed drill-core samples showed that mineralized rock that surrounds the Fortitude orebodies also comprises multilevel and complex metal contents—a relation that was not that readily obvious during examination of untreated raw data. A lower level Au anomaly, made up of rocks inferred to contain as much as 0.25σ Au, is present well below the Lower Fortitude orebodies, and this lower anomaly comprises two parts: (**1**) a mushroom-shaped part elongated north-south, and (**2**) a pillar-shaped part which connects the lower anomaly with Au concentrations centered just below the Lower Fortitude orebodies (fig. 2*B*). In contrast to the other metals examined, two widely separate loci of equally intense Pb–mineralized rocks are present along the section: an upper one that may be arcuate shaped with parts removed

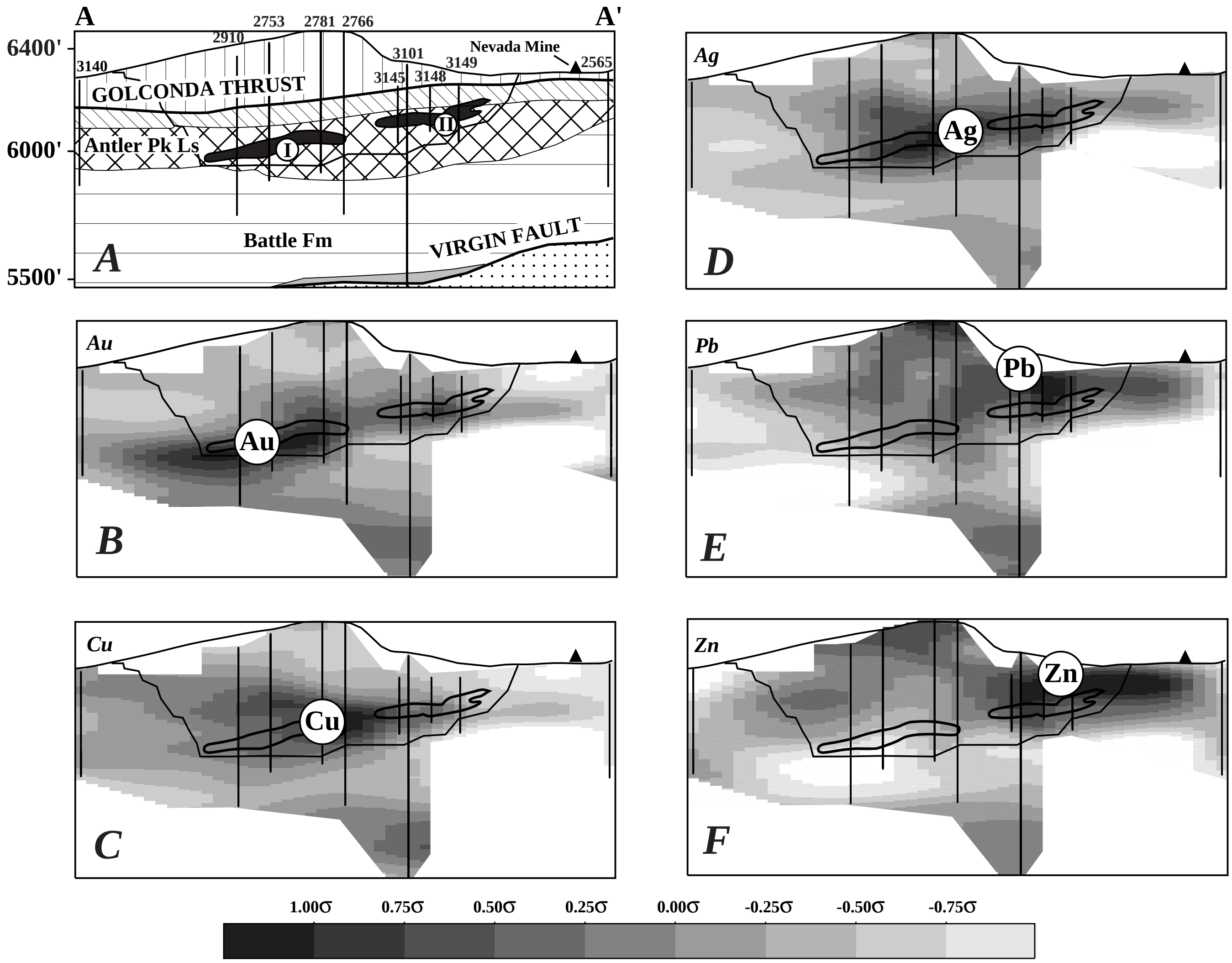

Figure 2. Geology (***A***) and normalized, gridded, and filtered (see text) distributions of Au (***B***), Cu (***C***), Ag (***D***), Pb (***E***), and Zn (***F***) in a north-south profile through the Lower Fortitude gold skarn deposit, Nevada. Explanation for ***A*** same as figure 1, except diagonal- lined pattern, Permian Edna Mountain Formation; doubly diagonal-lined pattern, Pennsylvanian and Permian Antler Peak Limestone; horizontal lined pattern, Pennsylvanian Battle Formation. Black, projection of ore in Lower Fortitude to plane of section. More densely shaded patterns (in ***B***–***F***) represent higher standard deviations (s) as shown in graduated gray scale. Circled chemical symbols repesent respective loci for most intensely concentrated presence of proximal (Cu, Au, Ag) and distal metals (Pb, Zn). I, Southern orebody of Lower Fortitude; II, Northern orebody of Lower Fortitude.

by erosion above the north end of the Lower Fortitude orebodies—our preferred interpretation—and a lower one that is mushroom shaped deep below the Lower Fortitude orebodies and connected to the upper anomaly by a pillar-shaped part (fig. 2*E*). This lower level Pb anomaly below the Fortitude orebodies is associated spatially with the lower level Au anomaly. The lower level Pb anomaly at the Fortitude orebodies probably is analogous to Pb–Zn–Ag mineralized rock in the 700–level at the Copper Canyon underground mine (Roberts and Arnold, 1965). Further evaluation of these data by comparing computer-contoured distributions with untransformed metal concentrations in the drill holes reveals that the statistically defined anomalies found are not artifacts of the contouring procedures employed (Kotlyar and others, 1998).

A three-dimensional configuration of gold-metallized rock in the southern parts of the Lower and Upper Fortitude deposits also was constructed on the basis of Au contents in exploration drill holes by Battle Mountain Gold Co. (fig. 3). The three-dimensional 1–ppm Au outer halo that surrounds the Fortitude

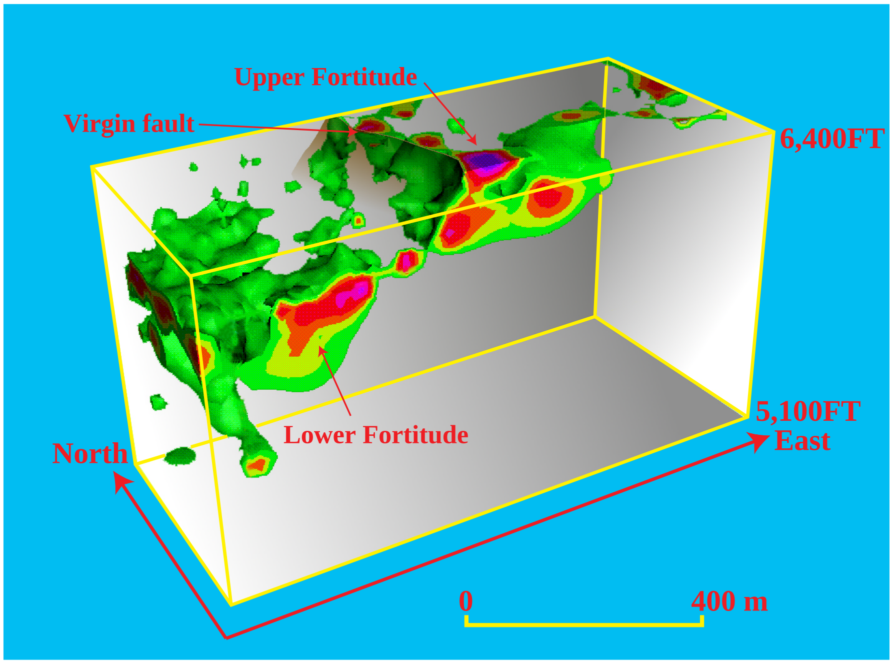

Figure 3. Block diagram showing three dimensional configuration of roughly southern one-third of Lower and Upper Fortitude Au–skarn orebodies and approximate trace of Virgin fault. Depicted outermost halo comprised of 1–ppm Au.

orebodies is much more complex than previously envisioned—compare with figure 2*A*—and the geometry of this halo primarily reflects distribution of chemically receptive rocks in the premineral calcareous Antler sequence below the Golconda thrust (fig. 2*A*). These rocks predominantly were broken and displaced by premineral normal movements along the Virgin fault and numerous other contemporaneous north-south striking faults in the Copper Canyon area (fig.1). Cumulative displacements along these faults, including the significant Copper Canyon fault, are approximately 400 m, west blocks down.

CONCLUSIONS

Distribution of elevated contents of proximal (Cu, Au, Ag) and distal (Pb, Zn) metals around the Fortitude Au skarn reveals that a prominent Pb–Zn halo mantles the distal parts of the orebody, more or less duplicating, at large scale, the district-scale relations between proximal and distal metals previously recognized by Roberts and Arnold (1965) in production data from widespread polymetallic veins. The geochemical haloes that surround the Fortitude orebodies are complicated and multilevel, including mushroom- and pillar-shaped parts. In addition, topography impacted significantly these geometrically complex haloes as exemplified by apparent removal by erosion of part of a Pb locus concentrated near the northern end of the Fortitude orebodies. Further, mineralized rocks of the Antler sequence at the Nevada Mine (fig. 2) are inferred to represent the northern leading edge of mineralized rocks that make up the Fortitude and Phoenix deposits in the Antler sequence farther to the south. The Pb–Zn ores at the 700–ft level in the Copper Canyon underground mine (deposit no. 11, fig. 2) and the reversal in district metal zoning at the Tomboy-Minnie deposits (Theodore and Blake, 1986) are inferred to be related to another site in the southern part of the Copper Canyon area where influx of mineralizing fluids occurred. This site appears to be somewhere near the Midas deposit (deposit no. 10, fig. 2). Both sites where influx of metals may have occurred, one beneath the Lower Fortitude deposits and the other beneath the Midas, may be related to apices of mineralized cupolas of altered granodiorite physically separate from the altered granodiorite of Copper Canyon which lies astride the major tectonic blocks (fig.1; see also Kotlyar and others, 1998).

Primary dispersion haloes for Cu, Ag, Pb, and Zn in the Fortitude deposit are quite analogous to those reported at the Nikolaevskoye polymetallic skarn in the Former Soviet Union (Beus and Grigorian, 1977)—apparently Au is not present in the Nikolaevskoye polymetallic skarn, however. The Nikolaevskoye polymetallic skarn—a generally shallow-dipping orebody at approximately 700– to 1,000–m depths below the surface—contains sphalerite, galena, pyrite, and pyrrhotite in a hedenbergite skarn. Particularly analogous to the Fortitude deposits, Pb and Zn make up a well-developed halo quite distal to the Nikolaevskoye orebody by occurring as much as 850 m above it. Copper is confined tightly to the orebody, as is Ni and much of the Sn in the system. However, the distributions of Ag and As at the Nikolaevskoye polymetallic skarn largely mimic the distribution of Pb, which differ somewhat from those that we found at the Fortitude. Nevertheless, the vertical extent of the multielement dispersion surrounding the Nikolaevskoye deposit is comparable to the Fortitude.

Finally, metal distributions in a porphyry environment must be considered relative to their configurations in three-dimensional space. Presence or absence of metals should be evaluated carefully by considering (**1**) non-orthogonal prograde fluid paths during metallization; and (**2**) the potential influence of prograde metal zonations—some quite subtle—from other nearby loci of mineralized rock. Filtering and gridding procedures turned out to be a wonderful tool, in our judgment, to enhance the syntheses of enormous amounts of geochemical data at Copper Canyon, and to model, thereby, concepts of fluid flow.

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