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Vol. 99, pp. 887–916

The Lithologic, Stratigraphic, and Structural Setting of the Giant Antamina Copper-Zinc Skarn Deposit, Ancash, Peru

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Abstract

Antamina, located at latitude 9° 32' S and longitude 77° 03' W in the Ancash Department of north-central Peru, is the largest known Cu-Zn skarn ore deposit. It incorporates a mineral reserve of 561 Mt, which has an average grade of 1.24 percent Cu, 1.03 percent Zn, 13.71 g/t Ag and 0.029 percent Mo, calculated at a 0.7 percent Cu equiv cutoff grade. The grandite-dominated calcic skarn formed in and around an upper Miocene porphyritic monzogranite stock emplaced into Upper Cretaceous carbonate strata that had experienced thin-skinned, northeast-verging thrusting and folding in the late Eocene Incaic orogeny. The exoskarn Cu-Zn ore is discordant to the strata of the Jumasha and overlying Celendín Formations, which comprise, respectively, massive to thick-bedded, relatively pure limestones and thin-bedded, predominantly marly limestones. The Jumasha Formation, the upper contact of which is locally defined as the top of the uppermost thick-bedded limestone or marble unit, hosts approximately three-quarters of the known exoskarn. Approximately the same fraction of the contiguous endoskarn Cu ore occurs adjacent to this formation. The overlying Celendín Formation is less extensively mineralized but, because it is widely metamorphosed to hornfels and locally converted to diopsidic skarnoid, may have inhibited the upward and outward migration of hydrothermal fluids, thereby promoting the development of the unusually large endoskarn ore zone. Ore also occurs in late hydrothermal breccias emplaced during the formation of mineralized endoskarn.

The preskarn thermal metamorphic aureole around the ore deposit is expressed differently in the two host formations. Jumasha Formation limestone is coarsened and bleached to banded gray marble and locally to white marble peripheral to the intrusion and skarn. Minor scapolite occurs in dark gray bands in marble, concentrated in a discontinuous halo tens of meters wide and commonly separated from the skarn by tens of meters. Three facies of calc-hornfels are recognized in the marl beds of the Celendín Formation adjacent to the intrusion extending hundreds of meters beyond sulfide-bearing skarn: a peripheral, very fine grained, light brown phlogopitic facies; an intermediate, fine-grained, gray tremolitic facies; and a proximal, medium-grained, light green diopsidic facies. At an X_{CO_2} of 0.1 to 0.9 and P = 100 MPa, these zones reflect temperatures increasing to circa 495°C adjacent to the intrusion. In addition, in nodular beds of the Celendín Formation that have been metamorphosed to hornfels, diagenetic calcite nodules are selectively replaced by diopside for distances of tens of meters beyond the skarn front. Such calc-silicate formation through both metamorphism and metasomatism, together with a 9 km^2 cluster of Pb-Zn-Ag vein deposits, provides district-scale vectors to ore.

The Antamina deposit lies on a newly recognized cross-strike structural discontinuity in the segmented Incaic Marañón thrust and fold belt, the northeast-trending Querococha arch. Southeast of the arch, Incaic folds and thrust faults strike north-northwest, but northwest of the arch they strike northerly. The plunge of fold axes concomitantly changes from south-southeast to north. Stratigraphic relationships indicate that the arch was a paleohigh, at least in the Jurassic and possibly throughout the late Paleozoic-early Mesozoic interval. The middle Miocene Carhuish pluton is exposed on the arch 30 km southwest of Antamina, whereas coeval Calipuy Supergroup volcanic units lie at similar altitudes to the north and south. Only scattered hydrothermal centers of late Miocene age are known in the Cordillera Negra, but an apparent swarm of intrusions, including the Antamina stock, occurs along the Querococha arch.

Antamina is situated where the locus of changes in the strike of folds and faults and the plunge of folds steps left along the arch. At Antamina, a pair of fault-bend folds above frontal thrust ramps show approximately 500 m of dextral apparent offset across the deposit and are inferred to have been separated by a northeast-striking transfer fault or lateral ramp, itself localized by a left-stepping jog in the Valley fault, an underlying, similarly oriented transverse structure. The jog in the Valley fault is inferred to have also controlled intrusion and skarn development. This local-scale jog in the Valley fault mimics the regional step along the arch. The arch may reflect a transform segment of the originally jagged, rifted continental margin, which persisted as a transverse basement weakness. Northeast-striking, originally sinistral, basement structures affected regional-scale sedimentation and structural patterns, including articulation of the thrust and fold belt. At a local scale, they

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* In Memoriam. On July 17, 2001, Keith Glover died unexpectedly but peacefully in his sleep, immediately after returning from fieldwork. He had an infectious passion for rocks and great patience in teaching about them. He was a skilled structural geologist and a professional ore deposit specialist with acute perception and a love for *walking the rocks.* Keith had been consulting internationally for 14 years and was respected for his intellect and breadth of geological understanding. He also managed admirably to balance his love for geology with that for his family. Keith was well liked for his generous spirit and humanity, and he is greatly missed.

0361-0128/01/3439/887-30 $6.00

influenced lateral ramp formation and related fracture development in the overlying thrust sheets. In the proposed model, they also localized later uplift and the rapid transit of small volumes of productive melt into a shallow crustal setting, conditions favorable for formation of a giant magmatic-hydrothermal ore deposit.