

## Paragenesis, Elemental Distribution, and Stable Isotopes at the Peña Colorada Iron Skarn, Colima, Mexico

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### Abstract

The Peña Colorada iron skarn is located in the southern part of the Guerrero terrane. It contains 150 million metric tons (Mt) with a grade of 36 percent magnetite. The deposit occurs at the contact of a 68 Ma equigranular diorite with mid-Cretaceous volcano-sedimentary rocks of the Tepalcatepec Formation. Volcanic units within this formation have tholeiitic affinity and REE patterns that are compatible with a primitive arc setting. The Peña Colorada diorite and associated voluminous aplitic phases are part of a Late Cretaceous calc-alkaline continental arc that subsequently intruded this basin. Northeast-vergent deformation affected the region in the Late Cretaceous. North-south and east-west reverse, and northwest and northeast strike-slip faults localize the mineralization.

The alteration halo around the diorite intrusion is 500 m wide. Within an inner 200-m halo, the volcano-sedimentary section was affected by an early metamorphic event, with discontinuous bands of pyroxene ( $\text{Di}_{68}\text{Hd}_{29}\text{Jo}_3$ ) hornfels and garnet ( $\text{Gr}_{61}\text{Am}_{36}\text{Ad}_3$ ) disseminations. Metasomatic pyroxene, garnet, and plagioclase cut the early metamorphic event preferentially replacing carbonate and volcanic units up to and including a 35-m-thick marl located 200 m above the intrusion. Metasomatic pyroxene and garnet have average compositions of  $\text{Di}_{77}\text{Hd}_{21}\text{Jo}_2$  and  $\text{Ad}_{76}\text{Gr}_{20}\text{Am}_2\text{Sp}_1\text{Py}_1$ , respectively. Pyroxene compositions reach  $\text{Di}_{94}\text{Hd}_5\text{Jo}_1$ , whereas garnet exhibits intragrain compositional zoning from  $\text{Ad}_{49}\text{Gr}_{46}$  in the core to  $\text{Ad}_{100}\text{Gr}_0$  in the rim. Albitization of preexisting protoliths modified igneous plagioclase compositions from  $\text{Ab}_{67}\text{An}_{32}\text{Or}_1$  up to  $\text{Ab}_{96}\text{An}_3\text{Or}_1$ . Albitization is followed by abundant fracture-controlled Fe-epidote and Cl-bearing chlorite ( $\text{Ch}_{84}\text{Cli}_{14}\text{Pen}_2$ ) that extend from the marl unit outward some 300 m. This association is cut by a later assemblage of epidote-chlorite-prehnite that affects the entire 500-m width of the alteration halo and part of the intrusion. Chlorite ( $\text{Ch}_{54}\text{Cli}_{45}\text{Pen}_1$ ) from this later event is richer in Mg than that from the previous association. Igneous hornblende in the intrusion is altered to actinolite. A potassic alteration event related to a hydrothermal breccia and aplitic dikes overprints the pre-existing calc-silicate associations. Alteration minerals in the breccia and the 200-m potassic halo around it, evolve from early K feldspar-(biotite)-quartz, to late jasperoid-fluorapatite-calcite veins. Mg-rich biotite ( $\text{Phl}_{77}\text{Ann}_{23}$ ) and REE-rich apatite contain F/Cl/OH ratios of 1/0/3 and 1/0/0, respectively.

Massive magnetite (36%)-specular hematite (7%)-sulfide (<5%) mineralization was deposited contemporaneously with metasomatic plagioclase, forming a shallow-dipping replacement body after the 35-m-thick marl unit located 200 m above the diorite intrusion. Calcite, dolomite and chlorite are the main interstitial constituents. The thickest ore section trends north-south through the middle of the orebody, and is rooted in a "blind" fault that is not observed above the marl unit. Ti and Cr in magnetite remain more or less constant throughout the orebody, while Mn and V increase with distance from the diorite intrusion. Co/Ni ratios in pyrite increase away from the diorite. Sulfides contain traces of gold. Ninety million metric tons of disseminated iron oxide was deposited with the retrograde epidote-chlorite-prehnite alteration event. This 20-m-wide magnetite-hematite-(pyrite) endoskarn occurs at depth along the diorite-carbonate contact in the western sector of the mine. High Ti magnetite from this zone contrasts with the Ti-poor massive ore magnetite. The postmineral potassic alteration event locally dissolved and re-deposited iron and REE from the orebody but is otherwise barren.

O, C, S, and H stable isotope determinations on minerals from the calc-silicate association are consistent with an igneous source for the initial fluids, which mixed outward with an increasing component of trapped seawater or evaporite. However, water in equilibrium with magnetite exhibits unusually enriched  $\delta^{18}\text{O}$  values relative to other coexisting mineral-derived fluids. A solution that equilibrated with limestone at relatively high temperature is required to explain these heavy values.