

**Polliand, M. (2006) Genesis, evolution, and tectonic setting of the Upper Cretaceous Perubar Ba-Pb-Zn volcanic-hosted massive sulfide deposit, Central Peru.**

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See also: Polliand M., Schaltegger U., Frank. M. & Fontboté L. (2005) Formation of intra-arc volcanosedimentary basins in the western flank of the central Peruvian Andes during Late Cretaceous oblique subduction: field evidence and constraints from U–Pb ages and Hf isotopes. *International Journal of Earth Sciences*, v. 94, p. 231-242.)

## Abstract

During late Early to Late Cretaceous, the Peruvian coastal margin underwent fast and oblique subduction and was characterized by important arc plutonism (the Peruvian Coastal Batholith) and formation of volcanosedimentary basins known as the Western Peruvian Trough (WPT). Field observations, satellite image interpretation, and plate reconstructions, suggest that dextral wrenching movements along crustal lineaments were related to oblique subduction. Wrench tectonics are therefore considered to be the trigger for the formation of the WPT as a series of pull-apart basins and for the emplacement of the Coastal Batholith.

The WPT, represented by the Lancones, Huarmey and Cañete volcanosedimentary basins, contains a number of Volcanic-Hosted Massive Sulfide (VHMS) deposits. One of the major known massive sulfide mineralization is the Perubar VHMS deposit, located in the northeastern part of the Cañete basin (50 km east of Lima, 11°55'S 76°34'W), where a total of 6 Mio tons of massive sulfide ore has been extracted from 1978 to 2000 with an average grade of 11.8% Zn and 1.4% Pb.

High-precision zircon U–Pb ages from conformable volcanic and crosscutting intrusive rocks within submarine volcanosedimentary strata part of the WPT and hosting the Perubar massive sulfide deposit yield concordant U–Pb ages ranging from 67.89 ±0.18 to 69.71 ±0.18 Ma, indicating that basin subsidence, submarine volcanism and plutonic activity occurred in close spatial and temporal relationship within the Andean magmatic arc during the Late Cretaceous.

The zircon initial  $\epsilon_{\text{Hf}}$  values of the dated magmatic rocks fall between 5.5 and 7.4, and indicate only very subordinate influence of a sedimentary or continental component. The absence of inherited cores in the zircons suggest a complete lack of old basement below the WPT, in agreement with previous U–Pb and Sr isotopic data for batholithic rocks emplaced in the WPT area. This is supported by the presence of a most likely continuous block of dense (~3.0 g/cm<sup>3</sup>) material observed beneath the WPT area on gravimetric crustal cross sections. This gravimetric anomaly may correspond to a piece of lithospheric mantle and/or oceanic crust inherited from a possible Late Permian-Triassic rifting. Such young and mafic crust was the most probable source for arc magmatism in the WPT area.

The volcanosedimentary strata hosting the Perubar deposit are mainly composed of submarine volcanic rocks and pyroclastic deposits of intermediate to felsic composition, intercalated with detrital sediments, volcanoclastic sandstones, tuffaceous mudstones, calcareous volcanoclastics, and limestones. The massive sulfide mineralization is found in close spatial association with an andesitic to dacitic dome-like complex and formed during a period of coeval submarine volcanism and carbonate sedimentation. Intrusive rocks belonging to the Peruvian Coastal Batholith were emplaced shortly (<~1 Ma) after the mineralizing event and resulted in the contact metamorphism of the Perubar deposit. Contact metamorphism occurred in closed system conditions, the original bulk sulfur isotope composition of the Perubar deposit being mostly preserved.

In its present situation, the Perubar VHMS deposit consists of four main massive barite-sulfide orebodies (Graciela, Juanita, Cecilia Norte, Cecilia Sur), originally forming two massive ore lenses that were dislocated shortly after deposition, following an abrupt fault-block subsidence event attributed to a tectonically controlled piecemeal caldera collapse, with a total downsag >500 m. When put back in its supposed original situation, the Perubar VHMS deposit presents the following ore zonation: (1) a basal *stockwork/replacive* zone, overlain by (2)

*massive pyrite-(magnetite) ore* and *massive pyrite-rich semiblack ore*, on top of which are found (3) *massive black and banded barite-sulfide ores*. In addition, *ferruginous chert* fragments are found within breccias situated in the upper levels of the deposit. The different ores have generally high Zn, medium Pb and very low Cu grades, with base metal content progressively decreasing, and a barite content progressively increasing towards the outer zones of the deposit. The quasi absence of Cu suggests that the thermal maximum stage attained during mineralization did not reach temperatures above  $\sim 300^{\circ}\text{C}$ .

A typical zoned footwall hydrothermal alteration was recognized at Perubar and mainly comprises: (1) a central siliceous core within the feeder pipe; (2) a chlorite-pyrite-(sericite) alteration zone surrounding the siliceous core; (3) an extensive quartz-sericite alteration zone developed semi-conformably below the ore-bearing horizon down to about 100 m within footwall rocks; (4) a quartz-K feldspar alteration zone developed on the fringes of the system, showing progressive overprinting relationships with the quartz-sericite alteration, and extending in the host and direct hangingwall rocks in the distal parts of the deposit. Geochemically, the footwall hydrothermal alteration pattern is characterized by widespread  $\text{Na}_2\text{O}$  depletion. Strong  $\text{K}_2\text{O}$  and Ba enrichments are more specifically found in the quartz-sericite to quartz-K feldspar alteration zones and strong  $\text{Fe}_2\text{O}_3$  and Cu enrichments, together with intense silica metasomatism expressed by significant  $\text{Al}_2\text{O}_3$  depletion, are restricted to the siliceous core and chlorite-pyrite-(sericite) alteration zones. Hangingwall hydrothermal alteration mainly consists of a chlorite-sericite-(quartz) alteration zone that extends at least 200 m up in the hangingwall rocks atop of the main orebodies.

A sulfur isotope study carried out on barite and sulfide minerals from various textural ore types at Perubar indicates that the sulfur contained in the mineralizing hydrothermal solution was dominated by reduced sulfur species ( $\text{H}_2\text{S}$ ), with a (pre-metamorphic) isotopic composition most likely comprised between about 1.3‰ to  $-1.3$ ‰ during the  $\sim 300^{\circ}\text{C}$  thermal maximum stage, and between about  $-2$ ‰ and  $-4.2$ ‰ during formation of barite-sulfide-bearing ores precipitated during the waxing stage (average  $T \approx 250^{\circ}\text{C}$ ). The hydrothermal  $\text{H}_2\text{S}$  is likely to have been generated by inorganic partial reduction of coeval seawater sulfate (anhydrite buffer model), although significant leaching of sulfide-sulfur from the footwall volcanics and/or direct input of magmatic sulfur can not be excluded. The sulfur isotope data support mixing at the seafloor between the  $\text{H}_2\text{S}$ -dominated hydrothermal solution and coeval Maastrichtian seawater as the main mechanism responsible for the precipitation of the massive barite-sulfide ores.

Strontium isotope data obtained on ore barite and volcanosedimentary host rocks indicates that the isotopic composition of the hydrothermal strontium was  $0.70600 \leq ^{87}\text{Sr}/^{86}\text{Sr} \leq 0.70669$  and that the latter was dominantly acquired during the interaction of the hydrothermal fluid with both the footwall volcanic/subvolcanic and volcanogenic detrital-sedimentary rocks. At least part of the detrital components was derived from older plutonic and/or volcanic rocks than the coeval footwall volcanics. A direct input of magmatic strontium can not be excluded. By extension, the origin of barium and base metals was most probably identical to the one proposed for strontium. In line with the sulfur isotope interpretation, the ore barite strontium isotopic composition, ranging between 0.70669 and 0.70710, results from the mixing of hydrothermal strontium ( $0.70600 \leq ^{87}\text{Sr}/^{86}\text{Sr} \leq 0.70669$ ) with coeval Maastrichtian seawater strontium (0.70760 to 0.70808).

The most likely tectonic setting during sedimentation, submarine volcanism and ore deposition at Perubar was an intra-arc pull-apart basin, developed during dextral wrenching movements attributed to the almost northerly motion assumed for the paleo-Pacific slab during Late Cretaceous times, at the same location where, and time when the Peruvian Coastal Batholith arc magmatism was active. In addition, general observations (such as the tectonic setting, the absence of macroscopic and/or microscopic fauna in the studied sedimentary material, or the spatial distribution of the limestone banks and their relative thickness) suggest a restricted and relatively shallow ( $<1000$  m?) marine environment at the time of the Perubar deposit formation.

The Perubar VHMS deposit represents a multistage hydrothermal system. Four distinct hydrothermal stages most likely occurred during the ore-forming process: (1) early low temperature ( $<100^{\circ}\text{C}$ ?) hydrothermal stage with precipitation of hematite  $\pm$  Fe-hydroxides ores; (2) main waxing mineralization stage (average  $T \approx 250^{\circ}\text{C}$ ), with precipitation at the seafloor of banded barite sulfide ore lenses, their inner parts being progressively enriched in sulfides through dissolution and recrystallization processes to eventually form Zn-rich massive black ore; (3) thermal maximum stage ( $T \approx 300^{\circ}\text{C}$ ), during which the black ore minerals (i.e., sphalerite, pyrrhotite, galena, and barite) are dissolved away from the lower part of the ore pile and replaced by pyrite to form massive pyrite and pyrite-rich semiblack ores; (4) waning stage, with precipitation of low-temperature ( $T < 150^{\circ}\text{C}$ ) silica iron exhalative layers on top of the deposit.