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The Mississippi Valley-type Zn-Pb deposit of San Vicente, Central Peru: an Andean syntectonic deposit

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ABSTRACT: Ore-related structures at the Zn-Pb Mississippi Valley-type San Vicente deposit, Central Peru, display a systematic geometry with respect to bedding and a regional thrust, interpreted as Miocene in earlier studies. Sparry dolomite veins and breccia bodies have a constant NS direction, and are either perpendicular to bedding with dips ~70° to the east, or parallel to bedding, dipping ~25-30° westerly. Zebra structures display identical concordant and discordant relationships relative to bedding. The preferential orientation of the gangue structures is interpreted within a dextral shear zone model, where they are either controlled by tensile fractures formed during thrusting or by pre-existent anisotropies, such as bedding planes. It is concluded that the San Vicente deposit is coeval with the host thrust zone, and therefore Late Andean in age.

1 INTRODUCTION

Many genetic models suggest that Mississippi Valley-type (MVT) deposits formed during brine expulsion from sedimentary basins at continental margins. Expulsion of brines beyond their parent basin may occur as a result of sedimentary overpressuring, regional tilting, hinterland recharge, and regional thrusting (Oliver 1986, Kesler 1994). Despite the suggested link among tectonics, fluid circulation, and formation of MVT deposits, there are very few field-based studies documenting this genetic relationship.

The MVT Zn-Pb San Vicente mine is one of the largest Zn producers of Peru, about 300km east of Lima. The deposit is located along a major Andean thrust zone, probably Miocene in age (Mégard 1984), which affects the eastern part of the Pucará basin. This basin consists predominantly of limestone and dolomite, where the latter is the host rock of the MVT deposit. A relationship among regional tectonics, fluid migration and ore formation has been proposed in earlier studies. Fontboté and Gorzawski (1990) suggested that brine circulation was related to uplift of the Marañon geoanticline at the end of the Jurassic, and Moritz et al. (1996) proposed that the San Vicente deposit was contemporaneous with the Incaic phase of the Andean orogeny at ~40 Ma. Underground mine extensions in recent years have revealed abundant ore-bearing structures suggestive of a syntectonic origin for the San Vicente deposit. Thus, the deposit might be as young as the host thrust zone, that is about Miocene in age according to Mégard (1984). In this contribution we present new structural data gathered at the San Vicente deposit in order to test the later scenario. The geometric relationships and the orientations of ore-bearing elements and various structural features within the mine environment have been measured along representative mine faces, and are correlated with the major Andean thrust events described by Mégard (1984).

2 GEOLOGICAL SETTING

The San Vicente deposit lies in the Subandean morphostructural zone, and is hosted by the eastern part of the NNW-trending Pucará Basin at the margin of the Brazilian Shield. In the San Vicente district, platform carbonate rocks of the Upper Triassic - Lower Jurassic Pucará Group overly magmatic and continental siliciclastic rocks of the Upper Permian - Lower Triassic Mitu Group. Phyllites of the Lower to Middle Palaeozoic Excelsior Group occur regionally below the Mitu Group (Fig. 1). During Late Permian - Early Triassic time, various intrusions were emplaced, such as the San Ramon granite and the Tarma granodiorite (Fig. 1).

In the San Vicente area, the Tarma granodiorite and Precambrian metamorphic basement rocks have been displaced over the Pucará carbonate rocks from west to east along the Utcuyacu thrust (Fig. 1). Minor thrust zones also occur in the Pucará Group. According to Mégard (1984), the thrust and fold belts

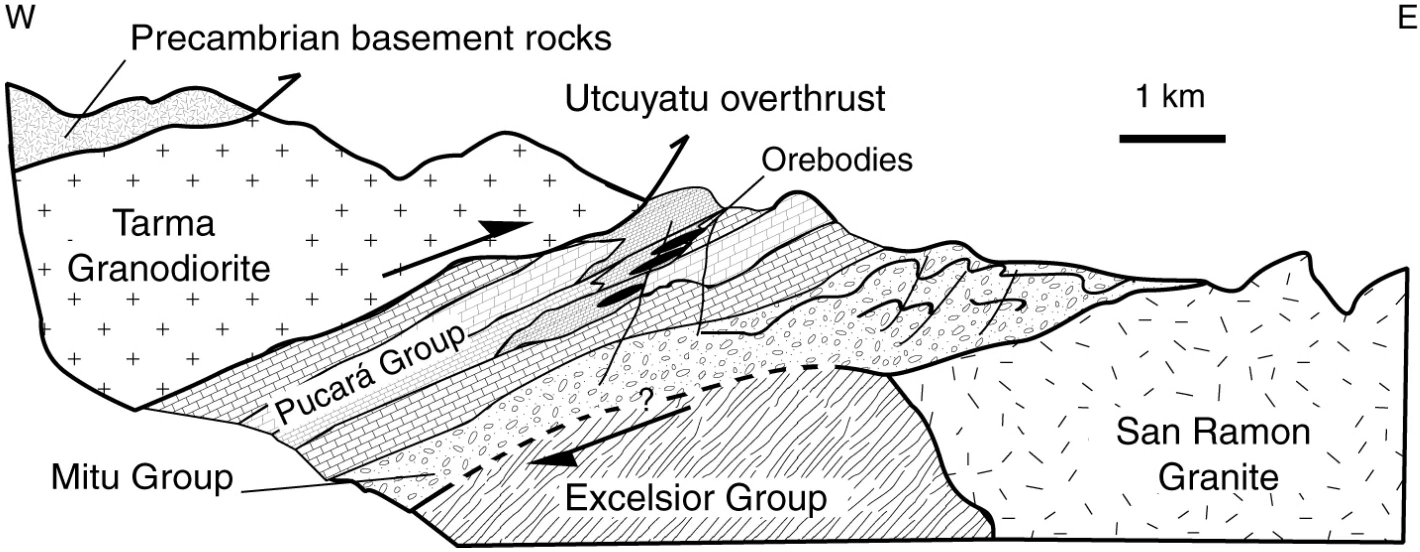

Figure 1. Conceptual cross-section of the San Vicente district. The Pucará Group has been overthrusted by the Tarma Granodiorite along the Utcuyatu fault. The Pucará Group is interpreted as a sequence undergoing shearing along a plane dipping ~25-30° westerly (after Dávila et al. 2000).

of the Subandean zone are linked to the Late Miocene Quechua 3 phase of the Andean orogeny.

The main ore horizons are hosted by dolomitized oolitic grainstones of a peritidal barrier facies. They are laterally delimited by dolomitized lagoonal facies and upwards by a finer, deeper and anoxic facies. The ore horizons are lens-shaped and are parallel to subparallel to the bedding (Fontboté & Gorzawski 1990). However, in deeper parts of the mine some orebodies are parallel to thrust planes (Dávila et al, 2000).

3 MINERALOGY AND TEXTURE OF THE OREBODIES

Sphalerite and galena are the main ore minerals, with accessory pyrite and traces of marcasite, chalcopyrite and sulphosalts. The gangue consists predominantly of dolomite with accessory calcite. Different generations of hydrothermal carbonates can be distinguished: (1) early, dark replacement dolomite; (2) open-space filling, white sparry dolomite; (3) late stage void-filling dolomite and calcite; and (4) dolomite and calcite replacing sulphates in evaporitic units.

Most of the sphalerite occurs in the same paragenetic position as the hydrothermal dolomite. Fine-grained, dark brown sphalerite accompanies early, dark replacement dolomite, and coarse-grained brown to yellow sphalerite is associated with white sparry dolomite. Galena precipitated mainly with late stage void-filling dolomite (Fontboté & Gorzawski 1990).

Three major types of gangue structures can be recognised at the San Vicente mine (Fig. 2): (1) rhythmic, inter-layering of dark replacement and white sparry dolomite, typically called zebra structure; (2) breccia with clasts of dark replacement dolomite in a matrix of white sparry dolomite; and (3) veins filled with white sparry dolomite. These structures are recognised in both economic and barren areas of the mine. In ore-bearing areas, brown to yellow sphalerite generally occurs between dark dolomite and white, sparry dolomite, whether it is zebra, breccia or vein-type ore (Fontboté & Gorzawski 1990).

4 STRUCTURAL ANALYSIS

Eight representative sites have been selected in the mine for a structural analysis. They include different types of gangue structures, with or without metals. Figure 1 shows the tectonic model proposed for San Vicente. The Pucará carbonate rocks are considered as a sequence undergoing shearing, between the overlying Tarma granodiorite and the underlying Mitu Group and San Ramon granite. Since the main thrust component is in an E-W direction, the eight representative sites were selected along approximately E-W oriented mine galleries in order to map and measure the ore-bearing structures and other structural features on vertical faces, along the main kinematic orientation.

On average, bedding in the mine environment has roughly a NS direction with a dip of ~25-30°W. In places, the bedding plane becomes steeper, but the direction stays constant about NS. The direction of the entire thrust structure as displayed in Figure 1 is NS to NNW and dips also ~25-30°W. In detail, fault planes occurring within the thrust can display variable dips from subhorizontal to ~65°W.

The different types of gangue structures, including the white dolomite veins, breccia, and zebra structure show a fairly systematic geometry with respect to bedding and average thrust orientation.

Veins filled with white sparry dolomite have a thickness of a few millimetres to centimetres, and a decimetric to decametric length. They have a bimodal orientation. One group is parallel to the bedding and has a N to NNW direction with a dip of ~25-30°W. A second group is subperpendicular to the bedding with a similar N to NNW direction and a dip of ~70°E. In many faces, the latter are arranged in an en-échelon pattern, with an interval of few decimetres between the veins (Fig. 2a).

Breccia bodies are less abundant than the white dolomite veins. They are a few centimetres to meters thick and the lateral extension is up to a few hundred metres. They are repeated periodically at an interval of several tens of meters. The breccia contains angular fragments of the immediate host rock, showing little to no displacement or rotation. The breccia occurs as lenses or pipes with the same orientation as the smaller dolomite veins (Figs 2d, e), where the lenses are concordant with bedding (N to NNW direction, dip of ~25-30°W), and the pipes are subperpendicular to the bedding (N to NNW direction, dip of ~70°E).

A majority of the zebra structures are parallel to the bedding. However in several places, the zebra structures are strongly discordant with it. Two main discordant zebra structures have been observed in the mine: (1) zebra spots (Figs 2b, d), and (2) en-échelon, zebra structures in a vein (Fig. 2c). Generally, the zebra spots only occupy a surface of a few dozen of cm^2. The spots are periodically repeated along bedding planes or in an en-échelon pattern throughout the host rock, and form several meter long spotted walls (Figs 2b, d). The zebra veins with an en-échelon pattern (Fig. 2c) are parallel to the bedding and are periodically repeated in different layers. Typically, they are 20 cm thick and more than 5 m long. In the central parts of the veins, the zebra structures are at an angle of 30 to 40° with respect to the bedding, while their extremities near the walls of the veins are bent and become parallel to the bedding plane (Fig. 2c).

Formation of the zebra structures predates the breccia pipes, since clasts with a zebra structure are included in the latter. In several areas, normal and reverse faults crosscut the white dolomite veins, breccia, and zebra structure (e.g. Fig. 2d). The dip of these faults are variable, but their direction is usually ~NS to NNW. Centimetric to decimetric-long displacement along the faults is both eastward and westward.

5 DISCUSSION

While the dip of the white dolomite veins, breccia lenses and pipes, veins with zebra structures and of the normal and reverse faults can be variable, they have a more or less constant NS direction. We conclude that this preferential orientation reflects a structural control.

The white dolomite veins (Fig. 2a) and the breccia pipes (Fig. 2e) subperpendicular to the bedding are interpreted as tensional structures within a dextral single shear zone model (Fig. 3). The bedding parallel dolomite veins and breccia lenses reflect strength anisotropy during their development, in other words preferential opening along planes of weakness (bedding planes) during tectonic deformation. The spots with zebra structures discordant to the bedding (Fig. 2b) are interpreted as small releasing step-over faults, i.e. pull apart systems, with a dextral displacement. The kinematics of the zebra veins is also consistent with the orientation of the regional overthrust. Indeed, the slip component is along the bedding plane, and the internal en-échelon zebra structure reflects reverse displacement (Fig. 2c). The late normal and reverse faults are inter-

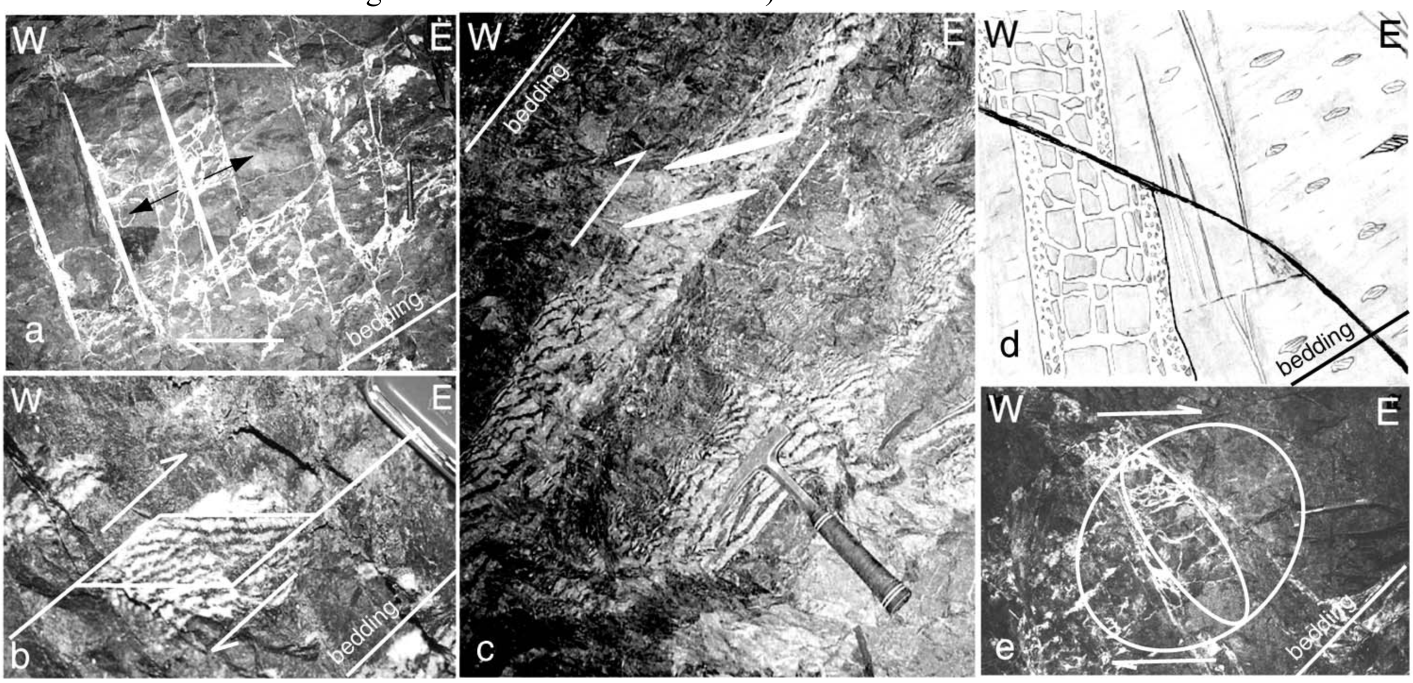

Figure 2. Different gangue structures: a) white sparry dolomite veins and breccia lenses and pipes with an en-échelon pattern; b) zebra spots forming discordant structures; c) zebra texture with an en-échelon pattern; d) reverse faults cutting a breccia pipe; e) breccia pipe interpreted as a tensile fracture.

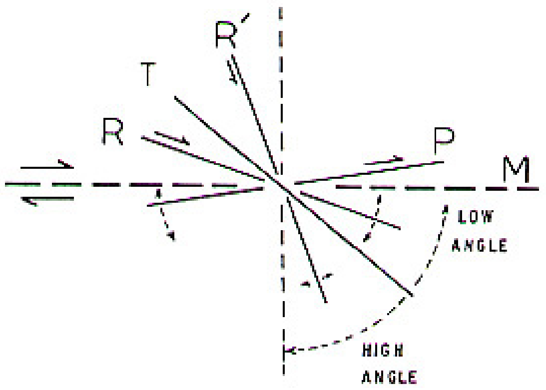

Figure 3. Terminology for description of elementary secondary fractures in a shear zone context (after Petit 1987).

preted as small thrusts and backthrusts (Fig. 2d) for the ones with an eastward and a westward displacement, respectively.

Thus, the various gangue structures, whether mineralised or barren, and faults are either controlled by structures formed during simple dextral shearing or pre-existent rheological anisotropies, such as bedding planes. Since part of the zebra structures are highly discordant and structurally controlled, it is concluded that the zebra structures concordant to the bedding also formed during regional thrusting by displacement and opening along pre-existent planes of weakness, alike the bedding concordant white dolomite veins and breccia lenses.

Fluids expulsed during the late Andean orogenic phase circulated preferentially along zones of high permeability, i.e. bedding planes and tensile fractures formed by simple shear. From the central part of the ore deposit, the fluids used permeability contrasts between rock units to migrate along strike to the north and south, as suggested by orebody morphology (Dávila et al. 2000).

The recognised sequence of events with clasts of early zebra structures within breccia pipes, and late normal and reverse faults crosscutting the pre-existent structures is diagnostic of ore deposition in an orogenic context. It indicates that ore formation occurred during a prolonged time span as thrusting was proceeding and was propagating easterly, whereby earlier formed structures were progressively crosscut and displaced by later faults. Such overprinting sequence of structural events is a typical feature of ore deposits formed in thrust environments (e.g. Jolley et al. 1999).

6 CONCLUSIONS

The Zn-Pb MVT San Vicente deposit comprises different types of gangue structures, including white dolomite veins, breccia, and zebra structures, which are partly overprinted by later reverse and normal faults. All the structures display a systematic geometry with respect to bedding and the orientation of a regional Upper Miocene thrust. The preferential orientation of gangue structures reflects a structural control. The various gangue structures are either controlled by tensile fractures formed during simple shear or by pre-existent rheological anisotropies, such as bedding planes. The geometry of the gangue structures and faults is compatible with dextral simple shear of the Pucará Group carbonate rocks as older basement rocks were thrust over them. Notably, the bedding-concordant zebra structures are interpreted as structures initiated during regional thrusting and opening along pre-existent planes of weakness, i.e. bedding. It is concluded that the San Vicente MVT deposit is a Late Andean syntectonic mineralisation.

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