Boletin de la Sociedad Geologica del Perú

journal homepage: www.sgp.org.pe ISSN 0079-1091

Limestone stratigraphy of the Ferrobamba porphyry - skarn deposit, and the protolith control on exoskarn formation, las Bambas cluster, southern Peru

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ABSTRACT

The Ferrobamba Formation limestone protolith composition has a direct control on resultant skarn type and mineralogy of the giant Eocene-Oligocene Ferrobamba porphyry-skarn deposit. The limestone sequence can be subdivided into pure micritic limestone, four shaley limestone units with higher Al, Mg and K, a black carbonaceous laminated limestone unit, and a high-Mg altered limestone unit. Where skarn altered close to the productive intrusions, the pure micritic protolith forms coarse well mineralised garnet skarns, the Mg-rich units (shaley limestone and high Mg atered limestone) form Mg rich skarns dominated by diopside and variable Mg-chlorite, actinolite-tremolite, dolomite-calcite, phlogopite, smectite talc and serpentinite. The carbonaceous unit forms mainly diopside skarn due to its reduced nature. Understanding the controls and distribution of the skarn types in the deposit is important for resource, metallurgical and geotechnical domaining.

Keywords: limestone, stratigraphy, skarn, garnet, pyroxene, diopside, micritic limestone, high Mg limestone, smectite, Ferrobamba Formation

LAS BAMBAS DEPOSIT

The Las Bambas porphyry – skarn deposit in the Apurimac Province, southern Peru, is owned by MMG through its Peruvian subsidiary Minera Las Bambas. Ferrobamba is the largest deposit in the Las Bambas cluster, which includes Chalcobamba, Sulfobamba (both owned by MMG) and Haquira (First Quantum Minerlas). The 2017 Ferrobamba global resource stands at 1.47 Bt @ 0.64% Cu and 181 ppm Mo , and production reached 454 ktpa in 2017. Intrusions of the Andahuaylas – Batholith range between 42 and 33 Ma, with mineralisation dated by Mo Re-Os ages averaging 34.5 Ma being associated with monzonite and monzodiorite stocks and dikes during latest stages of magmatic activity (Wise et al., in prep; Cannell et al., 2017). These intrusions have been emplaced into the Late Cretaceous Ferrobamba Formation limestone, which is a series of mudstones, wackestones and minor packstones in a transgressive to regressive sequence developed on a carbonate platform on the edge of the Cusco-Puno high (Benavides-Caceres, 1999; Carlotto et al. ,2008). This paper identifies separate mappable subunits of the Ferrobamba Formation in the mine area, and how the different protolith subunits influence resultant skarn type. Detailed sedimentological descriptions of the subunits have not yet been done.

The deposit is composed of high grade skarns hosted in the Ferrobamba limestone, and large tonnage and lower grade porphyry stockwork mineralisation hosted in pre-mineralisation and syn-mineralisation intrusions. Exoskarn zones are focussed primarily around the syn-mineral Jahuapaylla Stock, and to a lesser degree at the contacts of several other pre-mineral stocks, dikes and sills. Complex intrusive geometries and a previously unrecognised bedding control can result in irregular exoskarn geometries at the mapping scale. The marble halo extends irregularly several hundered metres from the intrusive margins. Main exoskarn ore types are summarised below:

- Garnet skarn is composed of predominantly andradite with hypogene sulphides (bornite, chalcopyrite and lesser chalcocite) infilling interstitial spaces between the garnet crystals accompanied by a gangue assemblage including calcite, quartz, diopside, specularite, mushketovite, chlorite, biotite and smectite (Cannell et al., 2017).
- Pyroxene skarn is dominated by diopside and variable amounts of calcite / dolomite, Cu-Fe sulphides, and smecitite (mainly saponite), actinolite/tremolite and Mg chlorite. Moderate amounts of garnet are present, which can be green which appears to be due more to abundant diopside inclusions in the garnet rather than a grossular (Al-rich) composition
- Magnetite skarn has a Mg-rich assemblage of magnetite and diopside, and minor but variable dolomite, calcite, Mg chlorite, saponite, tremolite / actinolite, phlogopite, talc, and serpentinite and local Cu-Fe sulfides.
- “Altered marble” occurs outboard from the exoskarn zones composed of mainly Mg-rich assemblage of veins and diffuse alteration zones in marble wall rock extending up to 30m from the skarn front.
- Focussed close to the Jahuapaylla Stock is a late overprinting alteration assemblage composed of dark green Fe-rich pyroxene, actinolite, biotite, magnetite and Cu-Fe sulphides, accompanied by a quartz-magnetite-sulfide veins.

FERROBAMBA FORMATION SUBUNITS

The Ferrobamba Formation wall rocks in and around the Ferrobamba deposit can be subdivided into the following units (Fig. 1).

MICRITIC LIMESTONE (LMT_M)

The dominant lithology is a dark grey micritic pure limestone (Mg < 1%, Al < 0.5%) that is generally massive to thickly bedded. In the deposit area it is altered and recrystallised to a white to light grey to medium grey marble. Lower in the sequence are zones of bioclastic debris, and cherty nodules.

SHALEY LIMESTONE (LMT_S)

There are four shaley limestone units identified from mapping and logging in and around the deposit, each unit between 15 and 40m thick. These are heterogeneous zones composed of shaley (or dirty) limestone, calc to non-calc shale (up to 4m thick), and pure limestone (LMT_M) interbeds up to 8m thick. Geochemically they are characterised by variable but generally high Al, Mg and K. The Al reflects the shale component in the protolith, high Mg indicates a dolomitic component, and the high K is due to potassic alteration of the shale component. Late, bedding parallel tectonic – hydrothermal breccias are common in these zones, focussed in the more incompetent and altered shale beds which can develop a foliation. They have also been locally intruded by bedding parallel sills, and cut by dikes. Above LMT_S3 (Fig. 1) is a 2-20m thick bedding parallel breccia zone that passes into a late-mineral quartz monzodiorite sill. The breccia zone has a rock flour – smectite matrix and contains abundant clasts of the MZQ sill (and also LMT, shale and skarn clasts) that appear shattered, and locally concave, and interpreted to be of magmatic-hydrothermal origin.

CARBONACEOUS LIMESTONE (LMT_C)

There is a single well laminated carbonaceous limestone unit that lies above LMT_S3 (Fig. 1). It is up to 50m thick, and composed of a lower section of black to grey carbon-rich well laminated limestone, that passes gradationally upwards to a medium grey straight to wispy laminated limestone. Both subunits are well laminated, the main difference is an increase of the carbon content downwards. The units is characterised by a slightly elevated Al and K content compared to the LMT_M units.

HIGH-MG LIMESTONE

The high-Mg limestone is a unit up to 100m thick below LMT_S4 (Fig. 1), and transitions gradually into LMT_M at depth. It is most clearly defined by its high but variable Mg assays (2-10% Mg). This Mg enrichment appears to be due to an early stage of alteration / marbleisation event that for some reason has been concentrated in a layer parallel zone. In the marble zone the high Mg intervals are always bleached white to pale grey with primary sedimentary textures destroyed. There are no distinguishing features preserved (e.g. coarse grain size, more permeable) indicating why it has been Mg-altered, and there is no evidence of a primary sedimentological dolomitic component, other than the bedding parallel nature of the Mg enrichment. There are also several thin high Mg limestone layers within massive micritic limestone throughout the sequence (thin blue layers in Fig. 1).

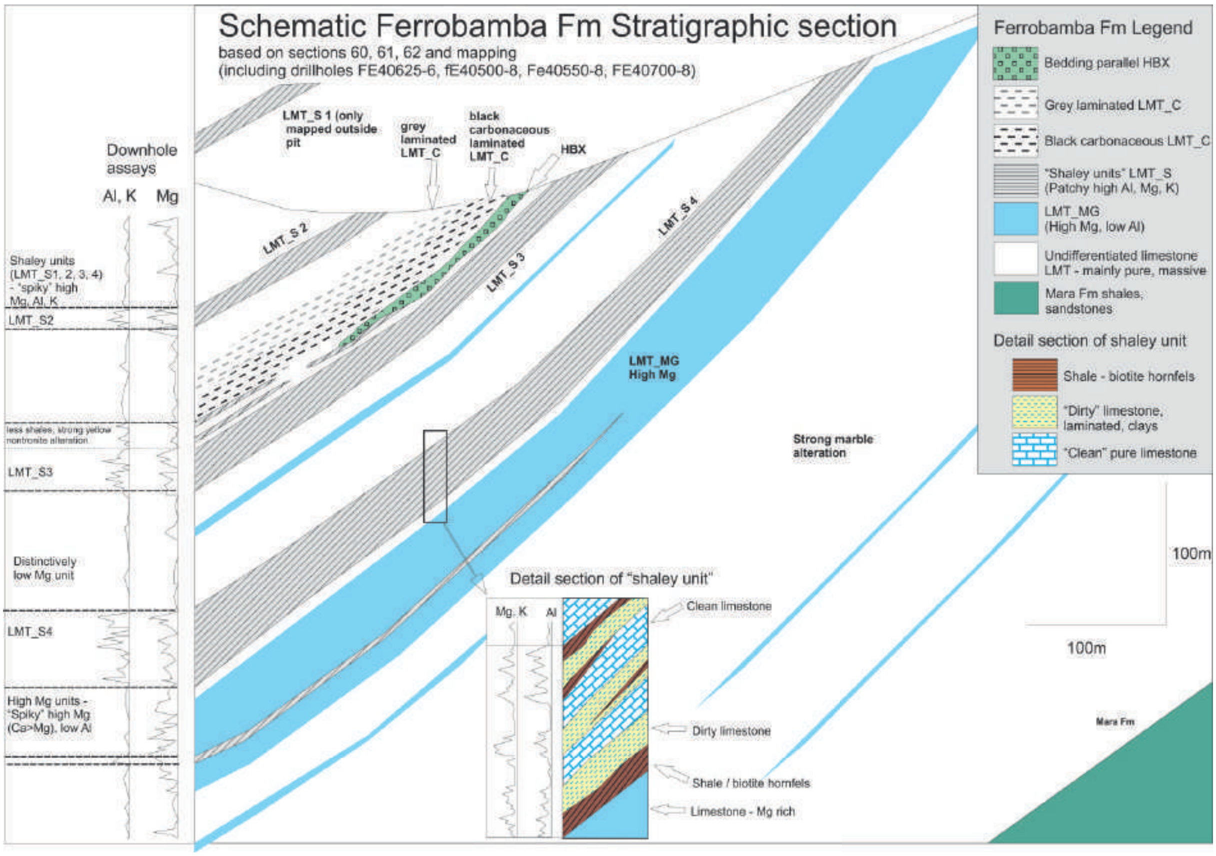

Figure 1. Ferrobamba Formation sequence of the Ferrobamba deposit. The figure depicts the sequence in place as it exists in the western side of the deposit, showing the current erosion surface. Intrusions have been removed for clarity. Note the heterogeneity within the shaley limestone units.

PROTOLITH CONTROL ON ALTERATION AND SKARN FORMATION

Detailed logging and sectional interpretation has found that the limestone protolith has a direct control on skarn formation, which is largely governed by the Mg and Al protolith content, and to a lesser degree the redox state. Al appears to be largely immobile during exoskarn formation. The protolith Mg content exerts a direct control on resultant skarn mineralogy, however within the exoskarn zones the Mg content is variable and displays evidence of local scale mobility. For example, Mg is depleted in garnet skarn and has been remobilised by the magmatic-hydrothermal skarn forming fluids and concentrated in a magnesian halo at their outer skarn edge. This magnesian halo is expressed as a zone of pyroxene skarn or altered marble peripheral to the proximal garnet skarn.

In the micritic limestone the pure limestone composition results in the formation of clean locally coarse grained garnet (andradite) skarn. Several metres of Mg enrichment can occur in the adjacent marble, forming a local thin rim of pyroxene skarn or altered marble.

In the shaley limestone protolith the spiky, variable Mg and Al contents results in zones of mixed skarn composed of clean garnet skarn (in the pure limestone interbeds) and pyroxene skarns and minor magnetite skarns in the more Mg-rich shaley units. Smectite contents tend to be higher in these zones due to the high Al and Mg contents. The shale beds are consistently altered to biotite (± phlogopite, chlorite) due to potassic alteration of the shale component. At the outer skarn edge there is a considerable Mg-enrichment halo in the adjacent marble, resulting in thick zones of altered marble.

The carbonaceous, reduced nature of the LMT_C protolith results in predominance of pyroxene skarn with lesser. Diopside contains ferrous Fe (Fe^{2+}) so is reduced in comparison to andradite which contains ferric Fe (Fe 3^{+}), and hence diopside skarns are favoured in reduced wall rocks. Garnet in these zones tends to be pale yellow or green coloured due to pyroxene inclusions, and fine grained, and never forms the coarse grained garnet skarn with abundant interstitial sulfides. Bedding laminations are preserved in the skarn, forming a distinctive layered skarn.

The high_Mg altered limestone unit forms a distinctive magnesian skarn assemblage. This unit forms zones of massive and chaotic pyroxene skarn and magnetite skarn and thick altered marble zones, with abundant soft green Mg-rich minerals. The mineral assemblage includes diopside, magnetite, garnet, smectite, talc, serpentinite, tremolite, phlogopite and Mg-chlorite (from petrographic and hyperspectral studies). Laminated convolute replacement textures (tactite) are locally present, but it is important not to confuse this texture with sedimentary laminations in the biotite-altered shaley units, which would lead to protolith misidentification.

The late Fe-pyroxene, magnetite, actinolite, biotite and sulphide alteration / quartz veining event overprints all previous skarn types indiscriminately.

CONCLUSIONS

Stratigraphic subdivision of the Ferrobamba Formation limestone units which form the wall rocks to the giant Ferrobamba porphyry-skarn deposit has proven to be a worthwhile exercise as they exert a direct control on resultant skarn mineralogy. What were previously thought to be chaotic and intermixed skarn zones can now be separately domained for resource estimation, metallurgical and geotechnical purposes.

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