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Report on a reconnaissance visit to examine mineralization in the Cordillera Fueguina, Tierra del Fuego, Argentina

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Lentes de sulfuros masivos en riolitas. Arroyo rojo, Tierra del Fuego

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REPORT ON A RECONNAISSANCE VISITTO EXAMINE MINERALIZATION IN THE CORDILLERA FUEGUINA, TIERRA DEL FUEGO, ARGENTINA

Marcelo Marquez and D.F. Sangster

INTRODUCTION

This report describes observations made of metallic mineralization in the Cordillera Fueguina, Tierra del Fuego province. These activities relied on the collaboration and logistic support of Yamana Resources Inc. who, through the cooperation of resident geologist Ken Gibson, allowed the authors access to all information obtained during exploration in the last three years. The work during the field trip between February10 -13, 1998 consisted of: A) the examination of mineralized drill core intersections from the Arroyo Rojo and Sargent prospects and a review of geological reports and maps; B) geological reconnaissance of the Beatrice mine and Lapataia areas, and C) reconnaissance of the geology and mineralized areas of the Monte Olivia and Río Hambre.

The most important objective was to define the mineralization characteristics and, if possible, to suggest a preliminary genetic model.

REGIONAL SETTING

The oldest lithostratigraphic unit that crops out in this sector of the Cordillera Fueguina is the Lapataia Formation, consisting of slate with fine banding and intense polyphase folding. Its chronostratigraphic position is controversial and, according to the opinions of diverse authors, ranges from Paleozoic to pre-Jurassic. The first alternative is in agreement with the regional geologic setting and the second alternative considers these rocks to be a more deformed and metamorphosed facies of the Yaghán Formation shales.

These metamorphic rocks are overlain in some sectors by volcanic and pyroclastic rocks of the Lemaire Formation (middle to late Jurassic) consisting of rhyolitic-dacitic units with porphyritic feldspar and quartz in a fine-grained matrix of white to pale greenish color. Several areas contain sedimentary-pyroclastic interbeds. The rocks are intensely affected by tectonic foliation that nearly obliterates the original igneous texture.

In some sectors, where the volcaniclastic sequence interfingers with black shales, large accumulations of pepperites developed, especially 200 km to the west in Chile. Some interbedded marine shales could also be observed in the Sierra de Sorondo, coinciding with the location of several Yamana mining prospects. It was speculated, however, that at least some of the sedimentary-volcanoclastic interfingering could be due to tectonic, rather than original depositional, reasons.

Between the Late Jurassic and Early Cretaceous time in the region a backarc basin was developed, filled by a thick pelitic sequence with oceanic floor affinity represented by flood basalts, which occur within the shales. More rocks of an ophiolitic complex appear to the south in Chile. These sediments constitute the host rock of mina Beatriz and of other minor vein occurrences .

The geologic history continues with marine platform deposition between the Late Cretaceous and Tertiary, followed by the development of small basins of pull-apart type with continental deposits, the intrusion during the Late Cretaceous of small discrete plutons of acidic to basic composition, and extensive glacier deposits during the Quaternary.

Tectonic events that have an intimate association with the geologic evolution of the district include pre-Jurassic deformational episodes that affect the metamorphic rocks of the Lapataia Formation. A principal deformation episode belonging to the Patagonian cycle, prior to the intrusion of plutons between 78 - 80 Ma, closed the backarc basin and defined elongate east-west blocks limited by low angle reverse faults associated with folds and the intense foliation that affects a majority of the Mesozoic rocks. Thrust reactivation during the Tertiary produced lateral displacement of the Patagonidic faults oblique to the main fault orientation.

ESSENTIAL FEATURES OF VOLCANOGENIC MASSIVE SULFIDE TYPE DEPOSITS (VMS)

- Association with submarine volcanism.
- Significant thickness (meters) of massive sulfides (>70%), dominantly pyrite.
- Hydrothermal alteration of chloritic-sericitic type and sulfide veinlets (stringers) in the immediate footwall.

- Presence of other exhalative products, such as chert, with or without Fe and Mn, above or in lateral continuity with the massive sulfide deposit.

OBSERVATIONS

a) Drill core reconnaissance

In the offices of the Yamana Resources Inc., we undertook a brief examination of the drill cores (mineralized intersections only) of N° 2 drill hole in the Arroyo Rojo area and one drill hole in the Sargent area. In both cases the cores came from sectors with intense mineralization and they showed the relationships with the host rock and the characteristic texture and mineralogy of the mineral assemblages.

It should kept in mind that most of the rocks of the Sierra de Sorondo, where the mineral deposits are located, are affected by an intense deformation resulting in a strong tectonic foliation that commonly obliterates many of the original textural features and makes lithological identification difficult. Some of the micaceous minerals (e.g., chlorite-sericite) are suspected to have a tectonic origin inasmuch as most of the rocks we examined are now essentially schists. In the comments that follow, it must be understood that the rock names in this report are field terms and have been taken from the regional mapping by Noranda. In the drill core of Arroyo Rojo area (ARG 97- 2) the following lithological and mineralizations types were identified:

- Massive hyaloclastic andesite: corresponds to a rock of igneous texture, without preferred orientation of the plagioclase and mafic phenocrysts in a fine-grained, light green matrix. This rock shows vesicles filled with white, fine-grained silica. Road cuts along Route #3 reveal local columnar jointing and pillow morphologies. Similar features have been observed in the río Olivia.
- Hyaloclastic foliated andesite: corresponds to a rock with characteristics similar to the previous but which has been overprinted by an intense tectonic foliation.
- Shales: black rocks of very fine grain with marked foliation.

According to the maps of Arroyo Rojo area rocks of rhyolite composition crop out, with massive and foliated textures, and also resedimented hyaloclastic andesites, although they were not observed on the drill cores.

The first impression of mineralization was that, even in the best intersections, total sulfide content appears to be very low, i.e. the mineralized interval was not "massive" although short intersection (several centimeters) could be regarded as "massive".

Mineralization appears to be of two main types:

i) coarse-grained, crustiform, undeformed pyrite-sphalerite, minor galena and chalcopyrite associated with white quartz "flooding". Some drill intersections displayed vein-like material with pyrite interior and sphalerite rims. The veins are filled with, first, white quartz with abundant pyrite, sphalerite, galena, and chalcopyrite in euhedral crystals of several millimeters diameter, second, a young generation of calcite accompanied of variable proportions of chalcopyrite and, finally, a generation of white quartz without sulfides. All examples in the core best described as "wispy" or "vein-like. Several examples of mineralization cutting foliation were observed.

ii) very fine-grained "massive" sulfide in which it was difficult to identify the sulfide mineral components. This type of mineralization, in contrast to the first type, exhibited a very well-defined foliation; in fact, its texture could best be described as a "sulfide mylonite". Small fragments (pea size and smaller) of the white quartz of Type i) mineralization could commonly be seen within the foliated sulfides..

This banded massive sulfide mineral assemblage commonly grades into pyritized and/or chloritized volcanic rocks with a strong foliation. The foliated rock, in turn, grades into massive volcanic rock with little or no foliation or pyritization-chloritization.

In the drill core of one of the holes in the Sargent area, the distribution of the banded massive sulfides shows almost the same features described for Arroyo Rojo except that the massive sulfide texture is less common, there is a greater abundance of chalcopyrite relative to the other sulfides, and the host rock is a foliated rhyolite(?) with feldspar phenocrysts and minor quartz in a fine-grained white to light green matrix. According to the geologic sections shown to us, the sulfide assemblages retain the same relationships relative to the structures and foliation as those in the Arroyo Rojo area.

b) Mina Beatriz and Bahia Ensenada Reconnaissance

On the north coast of Beagle Channel between Bahia Ensenada and Mina Beatriz sedimentary rocks were with fine compositional layering were observed. Millimetric alternations of black layers (shale?) with another lithology of slightly larger grain size and white colour are intensely affected by tectonic foliation which, in many places, can be observed parallel to bedding suggesting the presence of isoclinal folding in the area. Near Mina Beatriz the black foliated shales incorporate variable proportions of volcanic fragments, easily recognized by their white colour and porphyritic texture. A majority of the fragments have massive texture and have behaved like a rigid element during deformation, resulting in a deflection of the foliation around them; somewhat similar textures were observed around white quartz fragments. These rocks have been mapped by diverse authors as turbidites and are the host rock of the Mina Beatríz mineralization.

Approximately ten meters north of the mine, the shales are deformed into an almost isoclinal fold of decametric size with a fold axis in N50°E (magnetic) direction.

On the left side of the gallery entrance to Mina Beatríz - whose main gallery strike is N79°E - a short length of an elongated mineralized structure crops out striking N72°-74°W and dipping 80° SE. As the strike of the foliation in the mine is N80°E, dipping 65°to 70°SE, mineralization cuts this foliation at a small angle, both in strike and dip. In the upper part of the gallery mouth the presence of thin beds (?) of volcanic rocks intensely foliated was determined with strike 60°east and dip 52° to the southwest. In the tectonic contact with the volcanic fragment bearing shales, a small tectonic breccia filled with abundant calcite and chalcopyrite is localized. The strike the of adit (and mineralization?) appears to coincide with a fault seen to the south across a ~100-meter wide valley where foliated volcaniclastics are brought into vertical contact with a highly silicified rhyolite(?) dome(?), suggesting a possible fault control to Beatriz mineralization.

Examination of dump material revealed two styles of mineralization:

i) coarse-grained, undeformed crustiform sulfides (pyrite, sphalerite, galena, chalcopyrite) associated with coarse-grained, undeformed white quartz and minor carbonate (possibly ankeritic).

ii) massive, black, fine-grained sulfide in which it is impossible to discern individual sulfide minerals with small fragments of white quartz.

Veins and veinlets of barren milky white quartz were observed to cut foliation in several areas. Almost 100 m east of the gallery mouth white volcanic rocks crop out with intense tectonic foliation, bearing feldspar and quartz phenocrysts in tectonic contact with shales carrying felsic volcanic fragments. Further to the east several outcrops of sulfide veins were observed cutting the principal foliation.

At the intersection of national route N°3 with the trail that leads to the Bahía Ensenada igneous rocks of greenish color with porphyric texture were observed and which other authors have regarded as metamorphosed ocean floor basalts. They show both massive and foliated texture.

A reconnaissance of the Lapataia peninsula was carried out where we

observed intensely-folded fine grained, greenish-coloured rocks with well-defined compositional layering. These we identified as slates without felsic volcanic fragments.

c) Río Olivia, Valle de Carbajal, río Hambre and Paso Garibaldi

In the mouth of Olivia river, just north of the bridge, volcanic rocks of basic to mesosilicic composition and greenish color were observed. Fragments with chilled borders were incorporated in the black shales of the Yaghan Formation (i.e., pepperites). The black shales that include (?) and overly the basic volcanics show a contact relationship that, at least, is partly tectonized. These rocks are mesoscopically similar, according to Yamana geologist Ken Gibson, to those observed in drill core hosting the Arroyo Rojo mineralization.

Continuing toward to the north following the route, on the northerly flank of the monte Olivia, fragments of foliated volcanic rocks of white color were recognized, possibly of rhyolitic to dacitic composition with white feldspar phenocrysts and minor quartz in a fine-grained matrix intensely affected by pervasive silicification and several generation of quartz-pyrite veinlets with abundant euhedral pyrite crystals (pyritization?). According to Ken Gibson this is the same rock type that hosts the Sargent mineralization.

Along the Carbajal-Larsiparsack valley it is possible to observe numerous color anomalies, ranging from reddish to yellow, in contrast to the white to black country rock. An important percentage of them coincides with the prospect areas currently under evaluation, e.g., Arroyo Rojo, Sargent, Gregores, Cerro Portillo, etc.

On the sides of the río Hambre a little to the north of national route N° 3, felsic volcanic rocks crop out with similar characteristics to those observed at the foot of monte Olivia There one could see that the foliation that affects the rocks is cut by veins and veinlets of quartz and pyrite in varying proportions. The euhedral pyrite crystals clearly cut the foliation planes.

According to the regional geologic maps produced by the Yamana company, a majority of the contacts between lithological units is sharp, abrupt and normally linear, orientated parallel to the principal planes of reverse faults of the region; normally they have a general direction east-west and variable inclination to the south.

Observations on report by R.W. Hodder to Westmin, Dec. 12/96

- excellent photo documentation of many varieties of volcanic breccia.
- good photos of chert at Sargent Prospect but which occurs tens (to hundreds?) of meters stratigraphically above the Sargent sulfide zone. According to Gibson, no sulfides were seen in this chert nor was it ever assayed for base metals.
- Photo 23-2 (Sargent) shows a sulfide «clast» in «rhyolite breccia-foliated». Question - is this really a clast or a tectonically-inserted fragment? According to Gibson, this «fragment» consisted of barren pyrite.
- Hodder suggests some of the «rhyolite domes» mentioned by Gibson as being related to mineralization may, in fact, be simply fold noses.
- Hodder describes Gregores showing as an «interflow chemical sediment».
- he also suggests Fin del Mundo deposits are possibly hybrid intermediate between VMS and epithermal deposits. Suggests comparison with Eskay Creek (Canada) and Denali (Alaska) deposits.
- he does not hesitate to refer to volcanic rocks as «submarine» but offers no supporting evidence. In contrast, Bruhn (GSA Bull., 90, 998-1012, 1979) repeatedly refers to these volcanics as «subaerial» or at least transitional between submarine and subareal environments.

DISCUSSION

On the basis of observations of drill core and maps, we note especially the following:

1. A sawn sulfide-rich sample from mina Beatriz clearly demonstrated that the two mineralization types recognized at Arroyo Rojo are identical with those at Mina Beatriz. The sawn slab also demonstrated that: i) the coarse-grained type clearly cuts host-rock foliation; ii) the «mylonite» type cuts the coarse-grained type. An office sample of Gregores occurrence, when cut, revealed it to be identical with the «sulfide mylonite» style at Arroyo Rojo and Beatriz. Thus it appears that the same mineralization event was responsible for Beatriz, Arroyo Rojo, Sargent, and Gregores.

2. After examining the drill cores of the mineralized sectors of Arroyo Rojo and Sargent is clearly noted that there are no important thicknesses of banded massive sulfide. At best they have an apparent thickness that reach 1-1.2 m and true thickness of 0.60 m or less (0.20 m in the case of Sargent). The rest is foliated host rock silicificated and pyritizated with variable amounts of chlorite and/or sericite.

3. Assays of the mineralized drill core from Arroyo Rojo shows values of 0.30% Cu, 0.90% Pb, 2.30% Zn, and 13 ppm Ag for a true thickness of 15.40 m and an apparent thickness of 25.30 m. The 15.40 m section is composed of minor intersections of banded massive sulfides and sulfide veins while the most abundant material is the volcanic host rock generally affected by pyritization and silicification. This could be clearly seen in sketches provided by Yamana, for example the Arroyo Rojo prospect.

4. The mineralization commonly occurs in zones of intense tectonic foliation which are coincident with contacts between lithologic units (suggesting widespread structural, rather than depositional, contacts). The foliation shows the same or similar orientation as the abundant fractures that affect the rocks both locally and regionally.

5. In the report "Fin del Mundo Project - Yamana Resources, Inc.", the Index Map «Volcanogenic Sulfide Occurrences, Fin del Mundo Project» (by M.L. Klohn, 3/96) shows all sulfide occurrences and «rusty rhyolites» joined by a near-straight 500m-wide corridor of «conspicuous iron staining».

6. The distribution of the prospects is not limited to specific lithologic units but instead shows a wide distribution within the felsic to basic volcanics. In addition, veins crosscut lithologic contacts and are accompanied by silicic and pyritic alteration.

CONCLUSIONS

1. Neither the Fin del Mundo Project occurrences examined nor the Beatriz showing exhibit features which would indicate they are VMS deposits.

2. All occurrences display features indicating they are structurally-controlled replacement and open-space sulfide-quartz(-carbonate) veins discordant to the present foliation and situated in unknown relationship to original bedding of the host rocks. It is possible that this crustiform-style of mineralization was produced during the Late Cretaceous or Early Tertiary and was controlled by structures generated during the Patagonidic deformation.

3. The same, post-deformation, vein-forming mineralization event was responsible for Beatriz, Arroyo Rojo, Sargent, and Gregores (and probably all other occurrences in the region).

4. The initial crustiform vein sulfide material was affected by a later deformation (Miocene?) which produced a massive fine-grained «sulfide mylonite» with rolled and stretched fragments of the original white vein quartz.

5. There exists at least an implied suggestion that the corridor of "conspicuous iron staining", referred to by Klohn, is a primary, syn-volcanic controlling structure. We regard as unlikely that, in such a highly-deformed terrain, any original controlling fracture would still be preserved as a straight line. The "corridor" is more likely to be a secondary (i.e., structural) feature; we note its parallelism with present foliation and thrust faults.

RECOMMENDATIONS

1. Host rocks of the Lemaire Formation should be the subject of at least a reconnaissance-level petrographic, major-element geochemical, and structural study to determine: i) the original rock types and their composition; ii) the nature and extent of alteration, both regionally and peripheral to the major sulfide occurrences; iii) the structural history and, in particular, the relationship of sulfide mineralization to the structural fabric of the region.

2. The two styles of sulfide mineralization should be confirmed and their textural and mineralogical characteristics documented by detailed petrographic studies. These studies should include examination of large polished slabs of sulfide mineralization so that the interrelationships between sulfides (two types) and host rock foliation may be established.

3. Pb-isotopic analyses of galena should be performed on Beatriz and several of the Yamana properties to test the assertion made here that they all belong to the same population of mineralization. Samples collected by DFS for this purpose are being held by Marta Godeas in the SEGEMAR office in Buenos Aries.

Potential for Lemaire Formation to contain VMS deposits

Although our brief examination concluded that the known mineralization in the area is probably not VMS-type, this should not be interpreted to mean that the potential for VMS deposits is therefore precluded. Because the primary control on VMS formation is that they occur in a submarine environment, the potential for the Lemaire Formation to contain undiscovered VMS deposits is directly proportional to the volume of submarine volcanic rocks present in the formation. Because Bruhn (1979), among others, suggests the probability that the Lemaire Formation may contain a significant, if not dominant, proportion of subaerial volcanic rocks, it is essential that all evidence of submarine volcanism be collected and plotted on geological maps of the north and south ranges of Lemaire Formation. Features suggestive of a marine environment that come to mind are: i) layered chert (e.g., Sargent prospect); ii) pepperites (such as seen on Highway #3); iii) pillowed basalt (such as reported at base of Lemaire Formation; and, iv) significant thicknesses of pelitic sediments. Other lithological identifiers of a submarine environment might be added by those geologists familiar with these rocks.

Plotting these «indicator» features on a map will quickly determine whether they are widespread and abundant in the Lemaire Formation or whether they are confined to a particular level (or levels) in the volcanic edifice. Exploration for VMS deposits should be directed to those areas of submarine volcanism.

An accompanying activity to the above exercise should be a complete petrographic and geochemical study of the various cherts reported in the volcanic sequence to determine if they are of biogenic (i.e., radiolarian) or exhalative origin. The absence of microfossils might suggest the latter. Exhalative cherts should be analyzed to determine if they contain diagnostic exhalative «signature» elements such as Cu, Pb, Zn, Ba, Mn, etc. and/or the equivalent sulfide/sulfate minerals. Many exhalative cherts are also known to be Na-rich as evidenced by the presence of authigenic albite. The objective here is to determine whether the cherts are of biogenic or exhalative origin and, if exhalative, to determine if they are «barren» or contain evidence they may be related to base-metal VMS mineralization.