Skarn, porphyry, vein, and replacement mineralization in the Toqui District, Southern Chile

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- Introduction and History
- Regional Geologic Setting
- District Geology
- Alteration and Mineralization
- Geochronology
- Genetic Model
Introduction - Location

1300 km south of Santiago in the Aysen Region of southern Chile, South America
Regional Geologic Setting 1

- Somuncura (North Patagonia) massif
- Carboniferous suture
- Deseado massif
- Chon Aike volcanic province
- Rio Mayo embayment
- Patagonia Batholith
Regional Geologic Setting 2

Faults:
- ▲ thrust
- ● covered
- — inferred
- — certain

Geologic Units:
- Water
- Quaternary sediments
- Upper Cretaceous and younger sedimentary and volcanic rocks
- Late Cretaceous Divisadero Group volcanic rocks
- Early Cretaceous Coyhaique Group sedimentary rocks
- Upper Jurassic Ibañez Group volcanic rocks
- Upper Jurassic to Neogene Patagonia Batholith and granitic stocks
- Paleozoic metamorphic rocks

Points:
- Puerto Chacabuco
- Lago La Plata
- Lago Fontana
- Toqui mine
- Coyhaique

Scale:
20 Kilometers
Regional Geologic Setting 2

Lagos La Plata and Fontana fold and thrust belt

Iannizzotto et al., 2004
District Geology – main manto limestone
District Geology – Geologic Map

1. Zuñiga-Antolin
2. Concordia
3. Mallines
4. Estatuas
5. San Antonio
6. Mallin-Monica
7. Doña Rosa
8. Mina Profunda
9. Aserradero
10. Porvenir

Legend:
- Orebody, projected to surface
- Stratified Rocks:
  - Quaternary cover
  - Upper Divisadero
  - Lower Divisadero
  - Katterfeld Fm
  - Toqui Fm
  - Ibañez Gp
- Intrusive Rocks:
  - Altazor andesite
  - San Antonio rhyolite
  - Gemelos andesite

- Stream
- Fault
- Inferred fault
- Relative motion:
  - U - up
  - D - down
District Geology – Cross Sections
Mina Profunda - Geology
Porvenir and Aserradero - Geology
Mina Profunda, Porvenir and Aserradero - Geology

Geologic units:
- ash tuff and sandstone
- upper manto
- banded tuff
- main manto
- pumice lapilli bed
- rhyolite sill
- calcareous sandstone
- andesite tuff

Legend:
- MP

Scale:
- 10 meters
- 100 meters
District Geology – Main Manto Alteration

Porphyry-style mineralization encountered at depth

- Zuñiga-Antolin
- Concordia
- Mallines
- Estatuas
- San Antonio
- Mallin-Monica
- Doña Rosa
- Mina Profunda
- Aserradero
- Porvenir

Faults in main manto:
- garnet>25%
- pyroxene>garnet
- amphibole>pyroxene
- epidote>pyroxene
- chlorite+sericite
- unaltered main manto

San Antonio rhyolite
District Geology – Alteration at Depth

654.85m
Marked silicious halo around Py - Chl veins

Fm Ibáñez DEL-05

688.70m
Chloritic halo
Sericitic halo
Sil - Py vein with double alteration halo

Fm Ibáñez DEL-05

Pozo DEL-05 1H16.30 m
Mo

ATZ-3-973
District Geology – Main Manto Alteration

1. Zuñiga-Antolin
2. Concordia
3. Mallines
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8. Mina Profunda
9. Aserradero
10. Porvenir

- Faults in main manto
- Orebody
- San Antonio rhyolite
- Main manto alteration:
  - garnet > 25%
  - pyroxene > garnet
  - amphibole > pyroxene
  - epidote > pyroxene
  - chlorite + sericite
  - Unaltered main manto

Scale: 1 Km
Mina Profunda, Porvenir and Aserradero - Alteration
Pyroxene-rich skarn

Aspy
p
s

PDT 66-333m

PDT 15-226m

opaque
halite
sylvite

ATZ 1-891m

1 cm

10 μm
Amphibole-rich skarn

Aserradero slab
LCS 11-55m
ASN 9-223m
Metal Zonation - Zn

Zn%

- >30
- 20-30
- 10-20
- 5-10

5 m 100 meters
Metal Zonation - Zn
Metal Zonation - Zn

amphibole > pyroxene

pyroxene > amphibole

Shells replaced by sphalerite

Aserradero underground
Metal Zonation - As

As %
- >10
- 5-10
- 1-5
- 0.1-1

5 m 100 meters
Metal Zonation - Au
Metal Zonation - Au

cobaltite  Kspar  Aserradero underground
District Geology – Zonation

Fe-poor sphalerite
Pyrite-only
Pb & Ag-rich
As-poor

No skarn minerals: chlorite, sericite, rhodochrosite;
local silicification

Fe-rich sphalerite
pyrrhotite + pyrite
magnetite locally
Pb & Ag-poor
As-rich;
late gold event

Garnet, pyroxene
skarn with a zone
of late amphibole
District Geology - Geochronology

1 - Palacios et al., 1996
2 - Townley and Palacios, 1999
District Geology – Mineralization Timing

Possibility 1

North Toqui carbonate-replacement and veins 118 Ma
San Antonio rhyolite sills 120 Ma
porphyry-style stockworks 118-120 Ma

South Toqui Zinc skarn and Au-Co actinolite 113-109 Ma
Porvenir daite sill Au+Co+actinolite 113 Ma

Possibility 2

North and South Toqui 118-120 Ma
San Antonio rhyolite sills 120 Ma
porphyry-style stockworks 118-120 Ma

South Toqui Au-Co actinolite 113-109 Ma
Porvenir daite sill 113 Ma
Au+Co+actinolite
Prior to mineralization, a system of NNW-trending faults was present in the Toqui district.
Garnet-Pyroxene Skarn

- Early generation of a single-phase liquid from magma under lithostatic conditions
- Subsequence phase separation to hyper-saline liquid and vapor
- High temperature hyper-saline fluid rose along faults in the Ibañez Gp and entered the lower Toqui Fm and formed early garnet-pyroxene skarn
Base Metal Mineralization

- Cooling and uplift resulted in transition to hydrostatic conditions
- Generation of a single-phase fluid that rose along NW-trending faults through the Ibañez Gp and formed retrograde epidote-chlorite±amphibole skarn and base metal sulfide mineralization
Gold - Cobalt Mineralization

- Late generation of magmatic fluid under increasing depth and pressure forms gold-rich fluid that ascends along a NNW-trending structural zone.
- Fluid reacts with early skarn to form retrograde amphibole and deposits gold.
- On-going compressive deformation may have been important to help generate late gold-rich fluid.
Conclusions

• The Toqui district consists of seven skarn orebodies, two replacement deposits, and two Zn-Pb-Ag vein deposits.

• Total geological resource for the district is 20 Mt grading 8.2% Zn and 1.5 g/t Au.

• Mineralization is hosted predominately in limestone at the base of the Cretaceous Toqui Formation.

• Mineral zonation reveals progressively distal assemblages from SE to NW, suggesting the source of hydrothermal fluids was under the SE part of the district.

• Recently discovered porphyry-style alteration and veining demonstrate that it is a large integrated mineral system, zoned from a porphyry center to distal, skarns, mantos, and veins.

• There were multiple episodes of magmatic-hydrothermal activity in the district peaking at 120.1±0.4 to 117.8±0.7 Ma and possibly 113.2±0.5 to 105±3 Ma that are synchronous with regional compressive deformation.

• A paragenetically late stage of gold mineralization in the southern part of the district formed the Aserradero and Mina Profunda Au skarn orebodies and was associated with retrograde amphibole alteration of early garnet-pyroxene skarn.
Thank You