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Base and precious metals geochemistry of rock units of the mainland Aysén region, Chilean Patagonia

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Abstract

In order to evaluate the applicability of regional rock geochemistry as an aid in mineral exploration, over 1000 rock chip samples of the Aysén region, Chile, were taken during the period 1993–1995. All samples were analyzed at commercial laboratories for 30 elements by induced coupled plasma atomic emission spectrometry (ICP–AES), and in addition, Au was determined by atomic absorption spectrometry (AAS). Rock samples were classified into two broad groups: (1) unaltered unmineralized rocks; and (2) altered and mineralized rocks. The geologic–tectonic setting of the area is a segment of the active continental margin of South America where, during the Late Jurassic and Cretaceous, a magmatic arc developed accompanied by an easterly marine back-arc basin. The basement is formed of Paleozoic metamorphic rocks that are interpreted as sedimentary wedges accreted to the Gondwana continent. The back-arc basin was filled by the end of the Mesozoic, and Tertiary volcanic and terrestrial sedimentary rocks that represent local basins and within-plate volcanism lie uncomformably on older units. The main mineralization in the region is coeval with Late Jurassic–Cretaceous magmatism and this is consistent with the geochemical data presented in this paper. Younger rocks show low geochemical values, suggesting that the change of tectonic regime by the end of the Mesozoic resulted in limited mineralizing processes during the Tertiary in the region. The regional rock geochemistry shows that unaltered unmineralized rock units of this region are well within global mean ranges for similar rock types, excepting As, which exhibits a conspicuous positive anomaly for most rock types. Altered and mineralized rock geochemistry and statistical treatment of data suggest potential for polymetallic mineralization in the region, the most prospective rock units being the volcanic Mesozoic rocks.

Keywords: exploration geochemistry; Chile; Patagonia; mineralization

1. Introduction

In order to evaluate the applicability of regional rock geochemistry as a tool for mineral exploration, over 1000 rock chip samples from different rock units of the Aysén region, Chile (between 44º00′–47º30′S and 71º00′–73º45′W; Fig. 1), were collected during 1993–1995. This work formed part of a 4-year research program on metallogenesis and its applications in mineral exploration in this region, project FONDEF MI-15, undertaken by the Department of Geology, University of Chile.

All samples were analyzed at ACME laboratories

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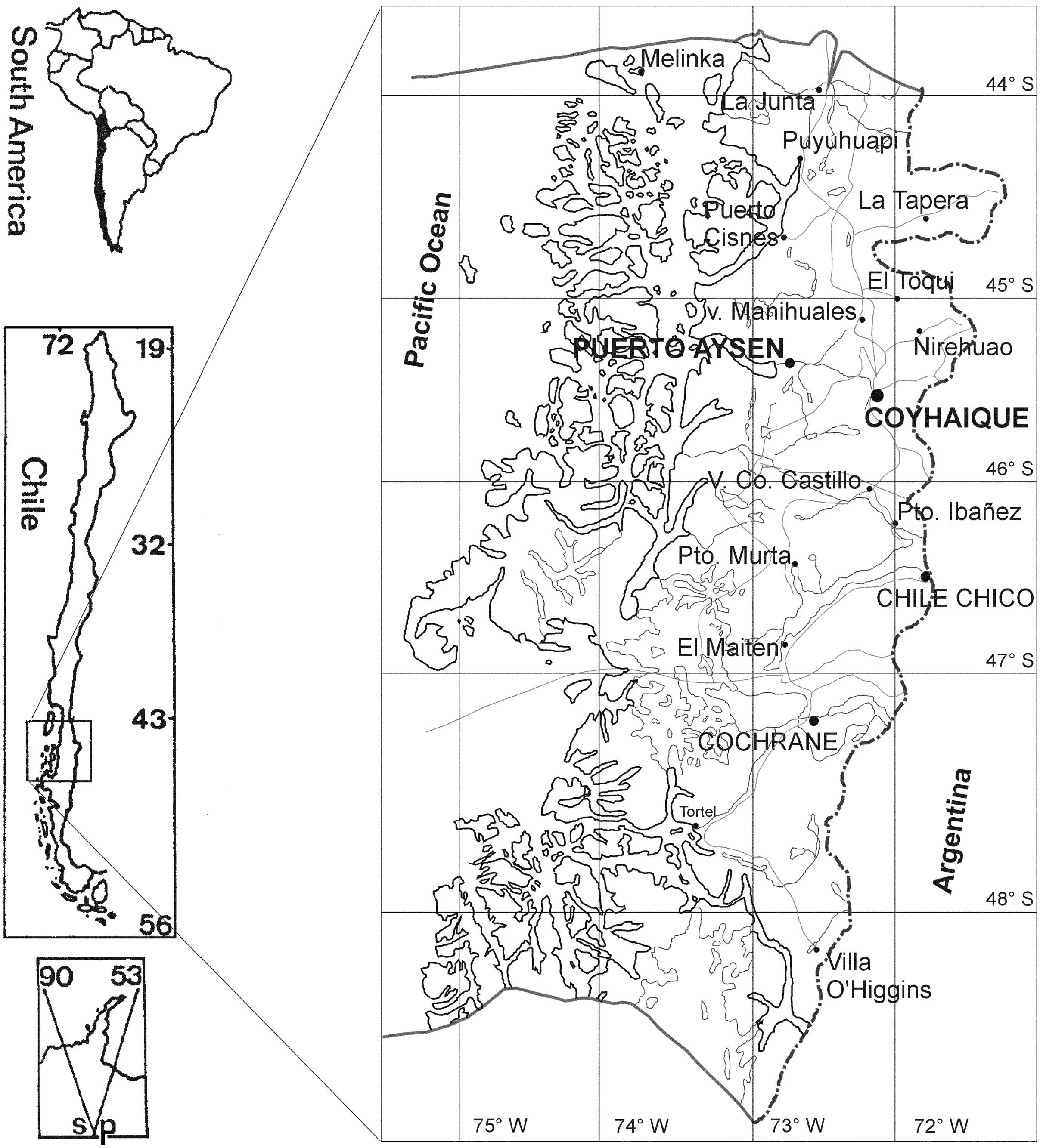


Fig. 1. Location map of the Aysén region.

in Santiago, Chile, and Vancouver, British Columbia. Each sample was analyzed for 30 elements by inductively coupled plasma atomic emission spectrometry (ICP–AES; Vancouver), and in addition, Au was determined by atomic absorption spectrometry (AAS; Santiago). Detection limits for selected elements are

Table 1
Detection limits and regression and variance analysis of repeats (only values above detection limit where considered)

Element (ppm)	Detection limit	N	R	F ratio
Mo	1	27	0.996	1,834
Cu	2	50	0.999	63,209
Pb	2	50	0.999	12,040
Zn	2	50	0.999	26,920
Ag	0.1	31	0.964	248
As	2	31	0.996	2,449
Au [a]	1	27	0.943	120

[a] In ppb.

Table 2
Standard sample statistical report

Element (ppm)	N	Ref. actd. value [a]	Mean	σ	% ($\pm 2\sigma$)
Mo	90	19 ± 0.3	18.9	1.4	95.6
Cu	90	60 ± 0.6	59.9	2.7	96.8
Pb	90	39 ± 0.4	39	1.9	96.7
Zn	90	128 ± 1	128.4	4.8	95.6
Ag	90	7 ± 0.2	7	0.3	95.6
As	90	41 ± 0.4	41	2.1	98.9
Au [b]	90	500 ± 8	497.5	40	94.5

Accuracy analysis (standard C for ICP-30, ACME Labs., Vancouver, and standard Au–R for AAS–Au, ACME Labs., Santiago; ACME Labs. internal standards).
[a] Best accepted value for reference sample.
[b] In ppb.

indicated in Table 1. For ICP–AES, a 0.5 g subsample was digested with a 3 ml 3–1–2 $HCl–HNO_3–H_2O$ leach at 95ºC for 1 h, then diluted to 10 ml with water. For Au-AAS, a 10 g subsample was digested with aqua regia at 95ºC for 1 h, then diluted to 100 ml with water. A MIBK extraction was used. Gold analysis in altered rock samples in which strong silicification was identified (over 70% silicified) were leached with hot $HF + HClO_4–HNO_3–HCl$, instead of aqua regia.

To estimate the reproducibility of the chemical analysis, one repeat sample was included for every 20 samples analyzed. A regression and variance analysis of repeats was done, and results are included in Table 1, indicating correlation values (R) all above 0.9, and F ratio values well above critical values for the 95% confidence level.

To assess the accuracy of analysis, repeated analysis of a standard sample was done (standard C for ICP-30, 0.5 g, ACME Labs., Vancouver, and standard Au–R for AAS–Au, 10 g, ACME Labs., Santiago; internal ACME Labs. standard samples). The mean and standard deviation values of the reference samples are reported in Table 2, and distributions for each element were compared to the accepted reference values by use of control diagrams. These results show that more than 95% of standard sample repeats are within 2σ of the reference mean (Table 2), and that all data fall within 3σ of the mean. The highest variabilities are observed for Au and Ag.

Samples taken in this region were divided into two broad categories: (1) unaltered and unmineralized rocks; and (2) altered and mineralized rocks. Samples among each data group were also subdivided according to rock type and lithostratigraphic unit. Sample grouping criteria were based on detailed hand sample description, field descriptions and geological maps of sampled areas. In the case of unaltered unmineralized samples much care was taken in avoiding weathered rocks.

2. Geologic setting and tectonic evolution

The Aysén region consists of a Paleozoic metamorphic basement covered by an unconformable Upper Jurassic–Cretaceous volcanic and sedimentary sequence. These are in turn overlain unconformably by Tertiary basalts and lesser marine and continental sedimentary rocks. The Paleozoic to Cretaceous rocks are intruded by granitoid stocks related to the Patagonian Batholith. Local recent and active volcanism occurs in a minor portion of the area. The regional geological framework for the study area is presented in Table 3 and Fig. 2.

The early tectonic evolution of the southern Andes took place in the early Paleozoic, during the development stages of the metamorphic basement that represent sedimentary wedges accreted to the Gondwana plate along a western subduction margin, westward from the Paleozoic magmatic arc. Accretion took place as a series of orogenies as activity shifted from the border of the continental plate to the west, starting in the Cambrian and continuing well into the Triassic (Miller, 1984).

Table 3
Table of formations for the Aysén region in southern Chile

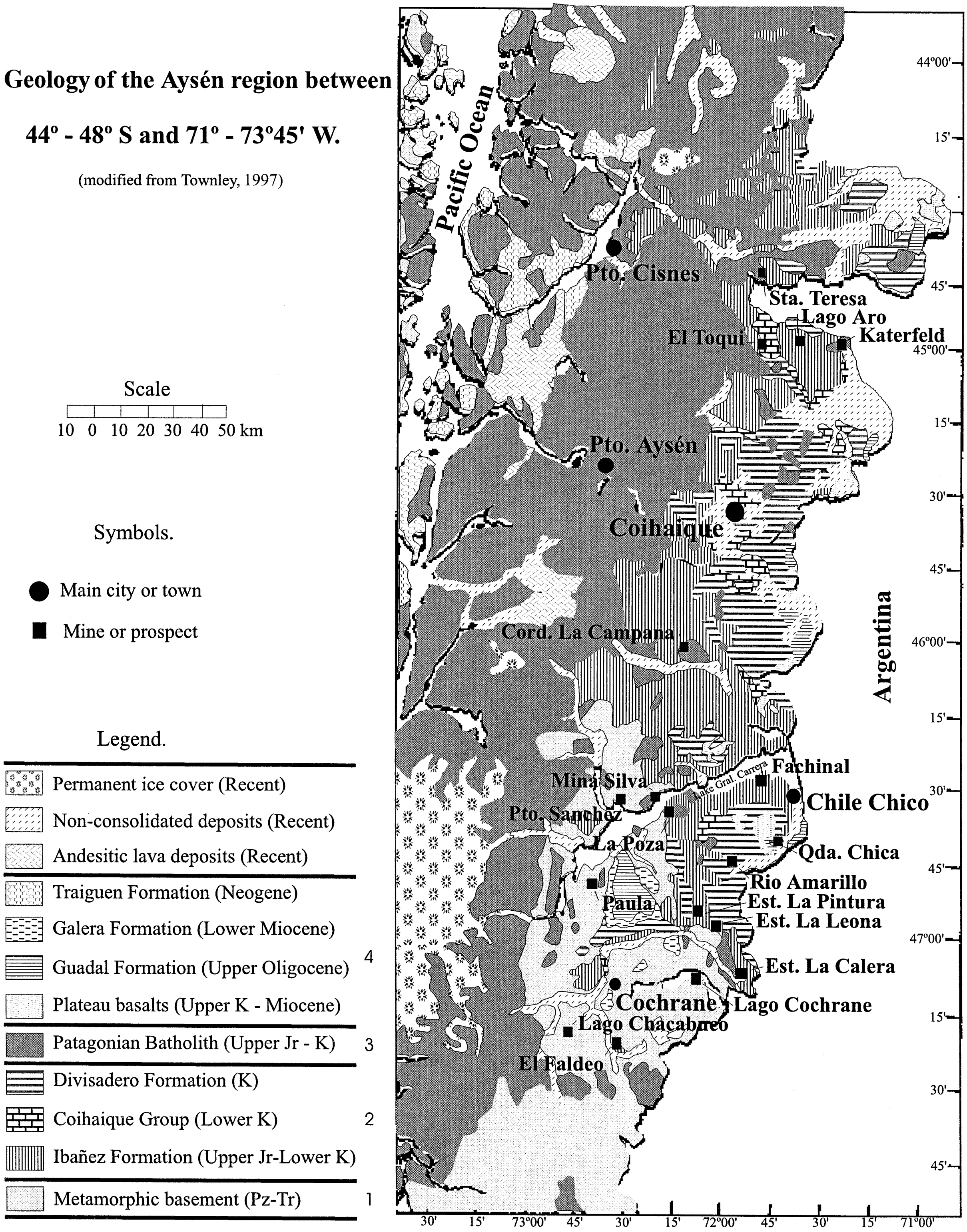
Formation	Age	Description
Stratified rocks		
Traiguén Formation	Neogene	Welded tuffs, tuffaceous breccias interstratified with basalts and andesites and marine sedimentary rocks.
Galera Formation	Lower to Middle Miocene	Continental sandstones and conglomerates interstratified with basalts of the Patagonian Plateau.
Guadal Formation	Upper Oligocene–Lower Miocene	Marine sandstones and fossiliferous shales interstratified with basalts of the Patagonian Plateau.
Patagonian Plateau basalts	Upper Cretaceous–Recent	Calc-alkaline and mainly tholeiitic basalts and andesitic basalts, lesser rhyolitic lavas and plugs and associated subvolcanic intrusives.
Divisadero Formation	Lower to Upper Cretaceous	Welded tuffs, tuffaceous breccias and subvolcanic intrusions, mainly dacitic and lesser andesitic.
Coihaique Group	Lower Cretaceous	Marine sediments, fossiliferous limestones, shales and sandstones, and occasional andesitic lavas.
Ibañez Formation	Upper Jurassic–Lower Cretaceous	Andesitic, basaltic–andesitic and lesser rhyolitic lavas and epiclastic deposits.
Metamorphic basement	Carboniferous to Upper Triassic	Schists, phyllites, quartzites, slates, marbles and metavolcanics.
Intrusive rocks		
Patagonian Batholith	Upper Jurassic to Upper Cretaceous and Paleocene to Miocene	Granites, granodiorites, diorites and gabbros.

Subduction of the oceanic Nazca plate under the South American continent began in the Late Triassic–Early Jurassic, and the volcanic arc shifted from its previous position in the east, to the west coast of the South American continent (Bartholomew and Tarney, 1984). Emplacement of the magmatic arc is evidenced by Upper Jurassic–Lower Cretaceous volcanic rocks of the Ibañez Formation and by intrusive rocks of the Patagonian Batholith. These rocks have bimodal characteristics, including basaltic-andesites and rhyolites, with a western position of the basaltic-andesites within the magmatic arc, and the rhyolites extending to the east, interbedded with the basaltic-andesites, and dominant on the upper portions of the volcanic sequence. The basaltic-andesites are thought to have been originated by partial melting of the tholeiitic subducting slab and the mantle wedge, while the rhyolites may have been originated by lower crustal melting due to rising mantle diapirs or to mafic magma underplating (Baker et al., 1981). There are interpretations that this lower crustal melting process triggered a back-arc extensional environment and originated a marginal back-arc basin in the Lower Cretaceous (De Wit and Stern, 1981; Baker et al., 1981).

The marginal back-arc basin had a wedge-shaped form, widening southward and pinching out to the north. The character of volcanism was also different from north to south: in the north, andesites of calc-alkaline affinity are interbedded with marine sediments, while in the south, mafic–ultramafic rocks of ocean floor affinity occur (De Wit and Stern, 1981). Closure of the back-arc basin in the northern section consisted in simple filling, while in the south it took place with widespread emplacement of oceanic crust slivers and development of penetrative tectonic fabrics (De Wit and Stern, 1981).

In the Aysén region, closure of the back-arc basin and crustal shortening was accompanied and followed by uplift of the area of the main volcanic arc,

Fig. 2. Geology of the Aysén region between 44º–48ºS and 71º–73º45′W. Rock units may be grouped in four main map units, indicated in the legend (*1–4*). Mines and prospects, in which some mineral showings are also included, are listed in Tables 4 and 5. Note that Estero La Pintura, Estero La Leona and Estero La Calera, all belong to the Halcones–Leones prospective area.



Geology of the Aysén region between
44° - 48° S and 71° - 73°45' W.
(modified from Townley, 1997)
Scale
10 0 10 20 30 40 50 km
Symbols.
Main city or town
Mine or prospect
Legend.
Permanent ice cover (Recent)
Non-consolidated deposits (Recent)
Andesitic lava deposits (Recent)
Traiguen Formation (Neogene)
Galera Formation (Lower Miocene)
Guadal Formation (Upper Oligocene)
4
Plateau basalts (Upper K - Miocene)
Patagonian Batholith (Upper Jr - K)
3
Divisadero Formation (K)
Coihaique Group (Lower K)
2
Ibañez Formation (Upper Jr-Lower K)
Metamorphic basement (Pz-Tr)
1
Pacific Ocean
Argentina
Pto. Cisnes
Sta. Teresa
Lago Aro
El Toqui
Katerfeld
Pto. Aysén
Coihaique
Cord. La Campana
Fachinal
Mina Silva
Lake Gral. Carrera
Chile Chico
Pto. Sanchez
La Poza
Qda. Chica
Rio Amarillo
Est. La Pintura
Paula
Est. La Leona
Est. La Calera
Cochrane
Lago Cochrane
Lago Chacabuco
El Faldeo
44°00'
15'
45'
45°00'
15'
30'
45'
46°00'
15'
30'
45'
47°00'
15'
30'
45'
30'
15'
73°00'
45'
30'
15'
72°00'
45'
30'
15'
71°00'

and by erosion and eastward transport of sediments. The foci of further intrusive activity associated with volcanic rocks of the Cretaceous Coihaique Group and the Divisadero Formation migrated slightly to the east, and many stocks intrude rocks of the Ibañez Formation and the Coihaique Group (upper Albian, ~100 Ma).

Arc volcanism continued until the Late Cretaceous, as evidenced by felsic volcaniclastic, pyroclastic and epiclastic rocks of the Divisadero Formation. Incipient extension during the Late Cretaceous, interpreted to have been triggered by lower crustal melting (Baker et al., 1981), terminated calk-alkaline volcanism along the volcanic arc, and the foci of volcanism shifted eastward, evidenced by 'within-plate' mafic volcanism (mainly tholeiitic basalts) and back-arc marine and continental deposits which are interbedded with these basalts. These events are represented by rocks of the Patagonian Plateau basalts and by the sedimentary Guadal and Galera formations.

3. Deposit geology

The study area embraces a number of significant mines and prospects. Deposits are listed together with a summarized description in Tables 4 and 5. Active mine areas, from north to south, are (Fig. 2) given below:

(1) Toqui mine (Tables 4 and 5). A stratiform Au-rich massive sulphide replacement skarn manto hosted by coquinoid limestone and lesser veins hosted by dacitic volcanic rocks. Past production and reserves total about 10 million metric tonnes, averaging 8% Zn, 0.6% Cu, 1.5% Pb, 1.5 g/t Au and 50 g/t Ag (Palacios et al., 1994).

(2) Mina Silva and Manto Rosillo (Tables 4 and 5). A skarn-manto Zn-rich but Au-poor massive sulphide marble and black schist replacement. Past production and reserves are uncertain, but both mines have been worked since the early 1940s. Mina Silva is currently closed, and Manto Rosillo is worked at a very small scale.

(3) Fachinal (Tables 4 and 5). An epithermal base metal and Au–Ag-rich vein and breccia deposit with reserves estimated at 18.7 million tonnes, averaging 1.11 g/t Au and 32 g/t Ag (Tippet et al., 1991).

These three mine areas and other prospects summarized in Tables 4 and 5 illustrate the variable geological character, and the significant tenor and potential of deposits within the study area.

4. Geochemical results

As the regional project FONDEF MI-15 was exploration oriented, most rock chip samples were taken from mineralized and altered areas. A lesser amount of unmineralized unaltered rocks were taken for general lithological background determinations. These samples were selected in the field from fresh outcrops, and weathered portions were avoided. Therefore, for statistical analysis, the geochemical data were separated in the two broad groups mentioned in Section 1. A widespread area of the region was sampled (Fig. 3), including samples from many of the different lithological units, and then further grouped regarding lithological types when possible.

The main formational units considered for sample grouping are: (1) metamorphic basement, (2) Ibañez Formation, (3) Coihaique Group, (4) Divisadero Formation, (5) Plateau basalts, and (6) the Patagonian Batholith.

4.1. Unaltered unmineralized rocks

Samples of this type are the least numerous and were selected based on field and macroscopic description. This sampling was intended to give general lithological background value ranges. Basic statistical analysis results presented in Table 6 show the mean values for different lithological units, also indicating the number of cases considered, percentage of samples below detection limit, standard deviation, standard deviation of the mean ($s/n^{0.5}$), and an upper limit value calculated as the mean plus two standard deviations of the mean (hereon defined as the re-

Fig. 3. General sample distribution map for unaltered unmineralized and altered and mineralized rock samples. Sample locations are approximate and intend only to show widespread distribution of sampling.

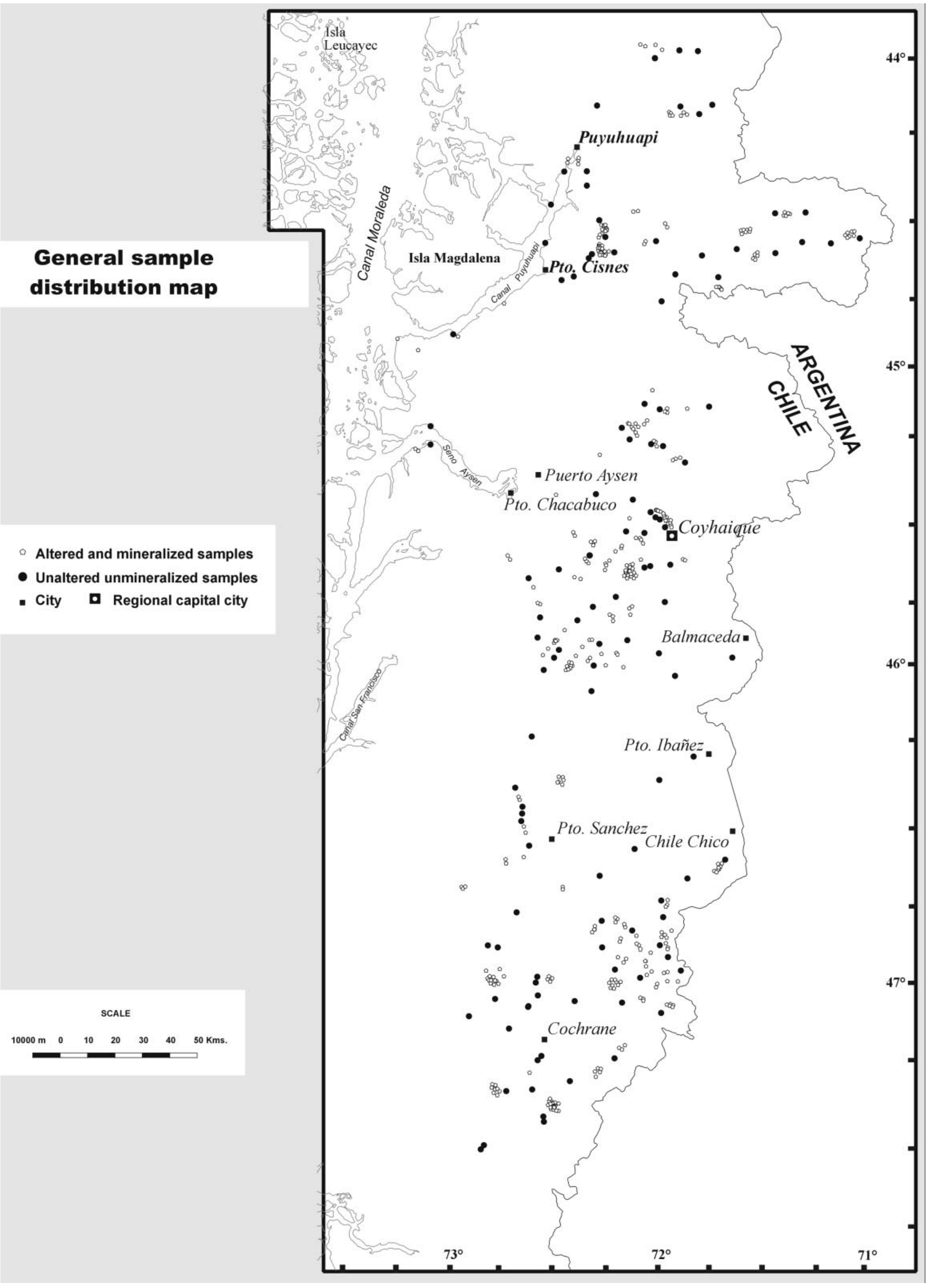

General sample distribution map
Altered and mineralized samples
Unaltered unmineralized samples
City
Regional capital city
SCALE
10000 m 0 10 20 30 40 50 Kms.
Isla Leucayec
Canal Moraleda
Isla Magdalena
Canal Puyuhuapi
Puyuhuapi
Pto. Cisnes
Seno Aysen
Puerto Aysen
Pto. Chacabuco
Coyhaique
Balmaceda
Canal San Francisco
Pto. Ibañez
Pto. Sanchez
Chile Chico
Cochrane
ARGENTINA
CHILE
44°
45°
46°
47°
73°
72°
71°

Table 4
Summary description of ore deposits, prospects and mineral showings of the Aysén region, Chile

Deposit or prospect	Location (lat./long.)	Type	Ore	Mineralization [a]	Alteration types	Ore grades	Tonnage (M)
Santa Teresa	44°46′S/71°53′W	Epithermal Low sulphidation	Polymetallic	Py–Sph (Cpy)–Ga–Th–Cpy–Au–Ag–Cv–Di	Argillic and lesser silicification and propylitic	5.3 g/t Au; 46.4 g/t Ag; 0.12% Cu; 1.23% Pb; 1.97% Zn	0.071
Katerfeld	45°05′S/71°35′W	Epithermal Low sulphidation	Polymetallic	Py–Cpy–Sph–Ga–Cc–Au–Ag	Argillic and quartz–sericite, widespread propylitic	7.6 g/t Au; 14 g/t Ag; 0.37% Cu; 0.68% Pb; 1.79% Zn	0.013
Lago Aro	45°05′S/71°47′W	Base metal–quartz vein	Zn–Pb (Au–Ag)	Py–Sph–Ga and lesser Au–Ag	Silicification and lesser quartz–sericite	No data	??
El Toqui	45°S/71°56′W	Zn–Pb skarn	Zn (Au)	Sph–Py–Po–Ga–Cpy–Aspy–Th–Ag–Au	Skarnification and propylitic, lesser argillic and quartz–sericite	8.48% Zn; 4.2% Pb; 0.1% Cu; 2.43 g/t Au; 21 g/t Ag; 0.86% Cd	10
Cordillera La Campana	46°05′S/72°27′W	Base metal–quartz vein	Zn–Pb (Au)	Py–Sph–Ga–Cpy lesser Au–Ag	Silicification and quartz–sericite	No data	No data
Mina Silva (Sil) and Rosillo (Ros)	46°33′S/72°24′W	Zn–Pb skarn	Zn–Pb–Ag (Sil) Zn (Ros)	Ga–Sph–Py–Aspy–Cpy–Th–Ag (Sil) Sph–Py (Ros)	Chlorite–epidote–calcite skarn, lesser quartz–sericite and argillic (Siland Ros)	0.86% Pb; 9.6% Zn; 113.7 g/t Ag; 0.06% Cu; 0.07% Cd (Sil)	?? (Sil)
						4.7% Zn; 0.04% Pb; 0.015% Cu; 22 g/t Ag; 0.04% Cd (Ros)	5.5 (Ros)
Fachinal	46°32′S/71°53′W	Epithermal Low sulphidation	Au–Ag	Py–Sph–Cpy–Bo–Aspy–Ga–Cv–Th–Fr–Pr–Ag–Au	Silicification, argillic, quartz–sericite, lesser quartz–adularia	3.15 g/t Au; 148 g/t Ag	18.7

Table 4 (continued)

Deposit or prospect	Location (lat./long.)	Type	Ore	Mineralization [a]	Alteration types	Ore grades	Tonnage (M)
Quebrada Chica	46º37′S/71º51′W	Epithermal Low sulphidation	Au–Ag	Py–Sph–Ga–Cpy–Bo–Th–Aspy–Fr–Si–Au–Ag–El	Silicification, argillic, lesser quartz–sericite and propylitic	0.5 g/t Au; 28 g/t Ag; up to: 5 g/t Au; 340 g/t Ag; 0.45% Pb; 0.25% Zn	No data
Río Amarillo	46º47′S/72ºW	Epithermal (?)	Au–Ag (?)	Py–Ga–Sph–Cpy lesser Au–Ag	Silicification, argillic and lesser propylitic	No data	No data
Halcones–Leones	46º50′S/72º49′W	Polymetallic veins Epithermal (?)	Zn–Pb–Cu Au–Ag	Py–Ga–Sph lesser Au–Ag	Silicification, argillic, quartz–sericite and lesser propylitic	0.1 g/t Au; 6 g/t Ag; up to: 2 g/t Au; 90 g/t Ag; 0.5% Pb; 0.8% Zn; 0.3% Cu	No data
El Faldeo	47º27′S/72º20′W	Zn–Pb skarn (?) (Sk) + Epithermal (Ep) Low sulphidation	Zn–Pb (Au–Ag) (Sk) Au–Ag (Ep)	Aspy–Py–Sph–Cpy–Ga–Th–Ag–El (Sk) Sph–Aspy–Py–Ga–Au–Ag–El (Ep)	Chlorite–epidote–calcite skarn (sk) Silicification, quartz–sericite and argillic (Ep)	up to: 4% Zn; 2% Pb (sk) up to: 2 g/t Au; 140 g/t Ag (Ep)	No data
Lago Azul	47º10′S/72º46′W	Cu porphyry (?) + Epithermal (??)	Cu Au–Ag	Py–Cpy–Au–Ag and lesser Sph–Ga	Silicification, quartz–argillic and quartz–propylitic	up to: 1% Cu; 140 g/t Ag; 1 g/t Au	No data
Lago Chacabuco	47º20′S/72º46′W	Massive sulphide vein	Zn–Pb–Cu–Au–Ag	Py–Sph–Ga–Cpy–Po–Aspy and lesser Au–Ag–El	Silicification and lesser quartz–sericite	up to: 2% Cu; 1.5% Pb; 10% Zn; 62 g/t Ag; 7.5 g/t Au	No data
Lago Cochrane	47º16′S/72º10′W	Base metal–quartz vein	Zn–Pb–Cu	Sph–Ga–Cpy–Py	Silicification and lesser quartz–sericite	No data	No data

[a] Py = pyrite; Sph = sphalerite; Cpy = chalcopyrite; Ga = galena; Th = tetrahederite; Cv = covellite; Di = digenite; Cc = chalcocite; Po = pyrrhotite; Aspy = arsenopyrite; Bo = bornite; Fr = freibergite; Pr = proustite; Si = silvanite; El = electrum.

Table 5
Summary description of ore deposits, prospects and mineral showings of the Aysén region, Chile (continued)

Deposit or prospect	Host rock	Structures (faults)	Age	Temperature [e] (ºC)	Salinity (NaCl% eq.)	Boiling evidence	Estimated depth (m)	Origin of fluids
Santa Teresa	Granodioritic and andesitic porphyries, fault hosted	NNW–SSE and lesser NW–SE	Lower K (?)	247 avg.	5.3 avg.	yes	approx. 400	Meteoric, with lesser magmatic input
Katerfeld	Andesitic porphyry (brecciated, fault zone hosted)	NE–SW NW–SE	Lower K 96 ± 2 Ma [a]	Veins: 173 avg. Breccias: 164 avg.	Veins: 4.75 avg. Breccias: 2.82 avg.	Veins: yes Breccias: yes	50 to 100	Meteoric
Lago Aro	Dacitic tuffs	No data	Lower K (?)	No data	No data	No data	No data	No data
El Toqui	Coquinoid limestones	NS and NW–SE lesser EW	Lower K 103 ± 3 Ma [a] 106 ± 18 Ma [a]	From 450 to 160	From 1 to 20	no	estimated at 1300	Magmatic–meteoric
Cordillera La Campana	Dacitic tuffs and granitic porphyry	No data	Lower K (?)	No data	No data	No data	No data	No data
Mina Silva (Sil) and Rosillo (Ros)	Marbles and black phyllites	NS, NE–SW, NW–SE and EW	Lower K 100 ± 2 Ma [b]	220 avg. (Sil); 237 avg. (calcite, Ros), 456 avg. (Sph, Ros)	6.57 avg. (Sil); 7.33 avg. (calcite, Ros)	no	estimated at 1500	Magmatic–meteoric
Fachinal	Dacitic and rhyolitic tuffs	NS, NNE–SSW; caldera related	Lower K 113 ± 2 Ma [a] 114 ± 3 Ma [c]	From 123 to 321	From 1.43 to 4.29	yes	From 300 to 150	Meteoric and lesser magmatic input
Quebrada Chica	Dacitic and rhyolitic tuffs	NW–SE and lesser NE–SW	Lower K (?)	225 avg.	4.66 avg.	yes	approx. 230	Meteoric and lesser magmatic input

Table 5 (continued)

Deposit or prospect	Host rock	Structures (faults)	Age	Temperature [e] (ºC)	Salinity (NaCl% eq.)	Boiling evidence	Estimated depth (m)	Origin of fluids
Río Amarillo	Dacitic and rhyolitic tuffs	No data	Lower K (?)	No data	No data	No data	No data	No data
Halcones–Leones	Andesitic and dacitic tuffs, quartz-feldspar porphyry	NS and NW–SE, lesser NE–SW	Lower K 130 ± 2 Ma [a]	From 120 to 240	From 0.1 to 2.1	no	From 400 to 100	Meteoric
El Faldeo	Dacitic and rhyolitic tuffs and lavas, granodioritic porphyry	NW–SE, NS and lesser NE–SW	Upper Jr 158 ± 5 Ma [a] 140 ± 4 Ma [d] 142 ± 5 Ma [d]	296 avg. (Sk) 151 avg. (Ep)	15 avg. (Sk) 1.3 avg. (Ep)	no no	approx. 850 (Sk) approx. 50 (Ep)	Magmatic–lesser meteoric (Sk); meteoric (Ep)
Lago Azul	Andesitic and dacitic tuffs and lavas, granodioritic porphyry	NW–SE, NS and NE–SW	Upper Jr (?) (Sk); Upper K overprint 80 Ma [b]	341 avg. (breccia) 229 avg. (veinlets)	18.33 avg. (breccia) 7.75 avg. (veinlets)	yes	approx. 1250	Magmatic
Lago Chacabuco	Black schists and phyllites	NW–SE	Upper Jr (?)	311 avg.	1.2 avg.	yes	approx. 1250	Meteoric
Lago Cochrane	Black schists	No data	Upper Jr (?)	No data	No data	No data	No data	No data

[a] Townley (1997) (Ar/Ar).
[b] Toloza (1987) (K/Ar).
[c] Tippet et al. (1991) (K/Ar).
[d] Palacios et al. (1994) (K/Ar).
[e] Fluid inclusion data from Townley (1997) (except El Toqui, taken from Bertens (1993)).

Table 6
Rock chip geochemical mean values for un-altered rocks of the Aysén region, southern Chile. Also included are standard deviation values, standard deviation of mean values ($s/n^{0.5}$), mean values plus two standard deviation of mean values, and a compilation of global mean values here presented in ranges

Element (ppm)	*N*	% Samples < det. lim.	Mean value [a]	Std. dev.	Std. dev. of mean	Mean + 2 std. dev. of mean	Global mean values [b]
Metamorphic basement							
Mo	22	59.1	2	2.7	0.6	3.2	1–3
Cu	22	0	42.7	47.9	10.2	63.1	42–50
Pb	22	0	19.4	26.9	5.7	30.8	10–25
Zn	22	0	70.6	49.4	10.5	91.6	20–100
Ag	22	72.7	0.12	0.13	0.03	0.18	0.05–0.19
As	22	50	13.3	27.1	5.8	24.9	2.5–15
Au [c]	22	68.2	1.3	1.4	0.3	1.9	4–5
Andesites Ibañez Fm.							
Mo	31	19.4	4.1	7.5	1.3	6.7	1.0–1.5
Cu	31	0	16.6	15.7	2.8	22.2	30–72
Pb	31	0	12.5	17.2	3.1	17.7	4–15
Zn	31	0	46.4	30.7	5.5	57.4	60–94
Ag	31	80.6	0.09	0.08	0.01	0.11	0.07–0.10
As	31	45.2	8.2	14.3	2.6	13.4	1.5–2.0
Au [c]	31	80.6	1	1.1	0.2	1.4	3.2–4
Volcanic rocks Ibañes Fm.							
Mo	12	58.3	1.5	1.4	0.4	2.3	1.0–1.5
Cu	12	0	8.3	6.1	1.8	11.9	30–72
Pb	12	0	17.7	17.7	5.1	27.9	4–15
Zn	12	0	76.6	70.1	20.2	117	60–94
Ag	12	50	0.23	0.25	0.07	0.37	0.07–0.10
As	12	41.7	9.3	17	4.9	19.1	1.5–2.0
Au [c]	12	50	1.7	1.3	0.4	2.5	3.2–4
Coihaique Group							
Mo	14	50	1.6	1.3	0.3	2.2	1–3
Cu	14	0	16.6	6.7	1.8	20.2	42–50
Pb	14	0	14	6.7	1.8	17.6	10–25
Zn	14	0	66.1	33.1	8.8	83.7	20–100
Ag	14	35.7	0.18	0.11	0.03	0.24	0.05–0.19
As	14	21.4	8.1	5.1	1.4	10.9	2.5–15
Au [c]	14	85.7	0.8	0.7	0.2	1.2	4–5
Divisadero Formation							
Mo	22	40.9	2	1.8	0.4	2.8	1.5–2.0
Cu	22	0	14.2	13.6	2.9	20	10–12
Pb	22	13.6	9.5	13.2	2.8	15.1	18–20
Zn	22	0	38.6	15.1	3.2	45	40–51
Ag	22	86.4	0.07	0.05	0.01	0.09	0.03–0.04
As	22	59.1	8.2	12.8	2.7	13.6	1.5–2.1
Au [c]	22	59.1	1.6	1.4	0.3	2.2	2.3–4.0
Plateau basalts							
Mo	13	15.4	3.9	4.2	1.2	6.3	1–1.5
Cu	13	0	12.6	8.7	2.4	17.4	72–100
Pb	13	15.4	7	4.2	1.2	9.4	4–5
Zn	13	0	32	15.5	4.3	40.6	94–100
Ag	13	53.8	0.13	0.1	0.03	0.19	0.1
As	13	38.5	13.4	23	6.4	26.2	1.5–2.0
Au [c]	13	46.2	3	4	1.1	5.2	3.2–4.0

Table 6 (continued)

Element (ppm)	N	% Samples < det. lim.	Mean value [a]	Std. dev.	Std. dev. of mean	Mean + 2 std. dev. of mean	Global mean values [b]
Patagonian Batholith							
Mo	21	61.9	1.6	1.7	0.4	2.4	1.0–1.5
Cu	21	0	21.9	21.7	4.7	31.3	30–72
Pb	21	19	9.9	19.1	4.2	18.3	4–15
Zn	21	0	43.4	20.9	4.6	52.6	60–94
Ag	21	95.2	0.06	0.05	0.01	0.08	0.07–0.10
As	21	61.9	11.8	25.9	5.7	23.2	1.5–2.0
Au [c]	21	57.4	2.7	3.3	0.7	4.1	3.2–4

[a] Mean values were calculated including values below detection limit, considering those as half the detection limit.
[b] Global mean value ranges were compiled from the following references: Turekian and Wedepohl (1961); Wedepohl (1969); Wedepohl (1969–1978); Levinson (1974); Turekian (1977); Saager et al. (1982). Values for the metamorphic basement rocks are obtained with respect to most probable protolith, shale and limestone. Ibañez Formation volcanic rocks are obtained with respect to granodioritic and mafic rock values. Divisadero Formation rocks are obtained with respect to granitic rock values.
[c] In ppb.

gional upper limit). Both the mean and the regional upper limit are compared to global values referenced in the same table. The mean values were calculated assuming data below detection limit as half the detection limit value. In addition, to determine inter-relations among elements, a Pearson product–moment correlation matrix was calculated for all data presented in Tables 4 and 5. As geochemical distribution of trace elements in nature better approximates a log-normal distribution (Ahrens, 1957), all data were logarithmically transformed prior to correlation calculations. Results are discussed briefly as follows.

Molybdenum. In general, neither mean nor upper limit values differ much from global ranges (Table 6), with the exception of andesites of the Ibañez Formation and rocks from the plateau basalts. The andesites of the Ibañez Formation have a regional upper limit of 6.7 ppm and a mean value of 4.1 ppm, considerably higher than the 1 to 1.5 ppm range observed in global values. Rocks of the plateau basalts have a regional upper limit of 6.3 ppm and a mean value of 3.9 ppm, also considerably higher than the global mean range. Volcanic rocks of the Ibañez Formation, rocks of the Divisadero Formation and rocks of the Patagonian Batholith have only slight positive anomalies with respect to global value ranges.

Copper. Most lithological units in this region have low Cu contents, with the exception of rocks of the metamorphic basement and rocks of the Divisadero Formation. The mean value for the metamorphic basement is within global mean range, and a slight positive anomaly in the regional upper limit is observed (Table 6). Rocks of the Divisadero Formation have mean and regional upper limit values above global mean range, but conforms only a slight positive anomaly. All other lithological units in the region exhibit negative Cu anomalies, the plateau basalts being the most marked.

Lead. With the exception of volcanic rocks of the Ibañez Formation, rocks of the Divisadero Formation and rocks of the plateau basalts, all other lithological units show normal Pb contents with respect to global mean ranges for each specific lithologic type. In the case of the volcanic rocks of the Ibañez Formation and rocks of the plateau basalts, a slight positive anomaly is observed for the mean and regional upper limit. In the case of rocks of the Divisadero Formation, a slight negative anomaly is observed for both the mean and regional upper limit.

Zinc. Mean and regional upper limit values are negatively anomalous in andesites of the Ibañez Formation and in rocks of the Patagonian Batholith, and markedly negatively anomalous in rocks of the plateau basalts. A slight positive anomaly (only regional upper limit) is observed in volcanic rocks of the Ibañez Formation. All other units are well within normal global ranges.

Silver. Mean values are within normal global mean ranges in most cases, with the exception of volcanics rocks of the Ibañez Formation, which exhibit a positive anomaly (Table 6). Rocks of the

Table 7
Correlation matrixes for unaltered rocks of the Aysén region

	Mo	Cu	Pb	Zn	Ag	As	Au
Metamorphic basement — N = 22							
Mo	1						
Cu	0.312	1					
Pb	0.203	−0.159	1				
Zn	0.089	0.273	0.419	1			
Ag	0.517	0.137	0.393	0.466	1		
As	0.490	0.431	0.158	0.371	0.064	1	
Au	0.329	−0.026	0.520	0.554	0.423	0.447	1
Andesite, Ibañez Formation — N = 31							
Mo	1						
Cu	−0.001	1					
Pb	0.025	−0.516	1				
Zn	−0.330	0.342	0.183	1			
Ag	−0.181	−0.058	0.567	0.322	1		
As	−0.117	−0.268	0.109	−0.030	−0.159	1	
Au	−0.118	0.101	−0.029	0.061	0.154	0.287	1
Felsic rocks, Ibañez Formation — N = 12							
Mo	1						
Cu	0.026	1					
Pb	0.273	0.322	1				
Zn	−0.153	0.675	0.631	1			
Ag	0.228	0.250	0.109	0.253	1		
As	0.430	0.283	0.658	0.603	0.574	1	
Au	0.547	0.518	0.440	0.405	0.457	0.662	1
Coihaique Group — N = 14							
Mo	1						
Cu	0.540	1					
Pb	0.590	0.649	1				
Zn	0.711	0.709	0.691	1			
Ag	−0.576	−0.370	−0.571	−0.290	1		
As	0.544	−0.208	0.039	0.155	−0.454	1	
Au	−0.367	0.070	−0.012	−0.020	0.445	−0.368	1
Divisadero Formation — N = 22							
Mo	1						
Cu	−0.140	1					
Pb	0.308	−0.161	1				
Zn	−0.182	0.090	−0.194	1			
Ag	0.385	0.289	0.120	0.215	1		
As	0.607	−0.018	0.415	−0.288	0.668	1	
Au	0.397	−0.161	0.125	−0.330	0.013	0.349	1
Plateau basalts — N = 14							
Mo	1						
Cu	−0.568	1					
Pb	0.306	−0.578	1				
Zn	−0.395	0.437	−0.838	1			
Ag	−0.059	0.610	−0.258	−0.074	1		
As	0.813	−0.593	0.568	−0.678	0.040	1	
Au	0.371	−0.123	0.566	−0.475	−0.055	0.257	1

Table 7 (continued)

	Mo	Cu	Pb	Zn	Ag	As	Au
Patagonian Batholith — N = 21							
Mo	1						
Cu	−0.161	1					
Pb	0.098	−0.334	1				
Zn	−0.362	−0.220	0.255	1			
Ag	−0.151	−0.106	0.024	0.029	1		
As	0.067	0.327	−0.056	−0.541	−0.136	1	
Au	0.259	0.230	0.113	−0.672	−0.178	0.657	1

Coihaique group, the Divisadero Formation and the plateau basalts show slight positive anomalies. It must be noted though that the lower limit of global mean value ranges falls below the detection limit of analysis, and also that Ag, for all rock types, has the highest percentage of samples below detection limit.

Arsenic. Arsenic is the single most anomalous element present in rocks of the Aysén region. It exhibits strong positive anomalies in all volcanic and intrusive rocks (Ibañez and Divisadero formations, the plateau basalts and the Patagonian Batholith), the highest anomaly observed in rocks of the plateau basalts. In rocks of the metamorphic basement it only shows a slight positive anomaly (only the regional upper limit).

Gold. Mean values are only within normal global ranges for rocks of the plateau basalts and rocks of the Patagonian Batholith. In all other cases a negative anomaly is observed, in some cases being strongly negative (smaller than half the lower limit global range). It must be noted though that an important percentage of samples in most cases is below detection limit.

Table 7 shows the results of a Pearson product–moment correlation between all elements for logarithmically transformed data of each lithologic unit considered. A correlation factor (R) above 0.5 was considered significant, and an R value above 0.8 was considered excellent. Note that good correlations among elements that are mostly below detection limit were not taken into consideration. Significant positive correlation values ($R > 0.5$) were observed for Cu–Pb in andesites of the Ibañez Formation, for Cu–Zn, Cu–Au, Pb–Zn, Pb–As and Zn–As in felsic rocks of the Ibañez Formation, for Cu–Pb, Cu–Zn and Pb–Zn in rocks of the Coihaique Group and for Mo–As and Pb–Zn in rocks of the plateau basalts.

4.2. Altered and mineralized rocks

4.2.1. Element concentrations

Rock samples studied in this section are those that exhibit strong alteration and metallic mineralization, and are by far the most abundant (Fig. 3). The most common alteration type is silicification, followed by argillic, propylitic, sericitic and potassic alteration. Mineralization consists of varying degrees of quartz, calcite, hematite, limonite, jarosite, pyrite, pyrrhotite, galena, sphalerite, chalcopyrite, or other sulphide minerals, present as individual and stockwork veinlets and veins, as disseminations, in the matrix and fragments of hydrothermal breccias, and as fracture coatings.

Table 8 shows a similar analysis to that of Table 6, and the mean and upper limit values of altered mineralized rocks are compared to the regional upper limit values of the unaltered unmineralized rocks and to global value ranges.

A brief description of statistical results (Table 8) for altered mineralized rocks is presented as follows.

Molybdenum. The only meaningful Mo anomaly is observed in rocks of the Patagonian Batholith, where the mean and upper limit value are well above the regional upper limit value and global mean value range. Weak positive anomalies are observed in felsic rocks of the Ibañez Formation and rocks of the Coihaique Group and Divisadero Formation, but are not worth further analysis. A very weak positive anomaly observed for rocks of the plateau basalts is well explained within a high background observed for these rocks in this region.

Copper. The highest positive anomalies appear associated with rocks of the Ibañez Formation, in both andesites and felsic rocks. Upper limit values for both rock types are well above regional and global values. Positive anomalies are also observed in rocks of the metamorphic basement and the Divisadero Formation. Rocks of the Patagonian Batholith present a local positive anomaly with respect to the regional upper limit value, but it is well within range with respect to global value ranges.

Lead. Extremely high positive anomalies are observed in rocks of the Ibañez and Divisadero formations, being higher in felsic rocks, and highest in rocks of the Divisadero Formation. A weak anomaly is observed for rocks of the Patagonian Batholith, only slightly higher than the regional background and global mean range.

Zinc. Similar to Pb, Zn shows extremely high positive anomalies in rocks of the Ibañez and Divisadero formations, being highest in felsic rocks. A high positive Zn anomaly is also observed in rocks of the Patagonian Batholith, and to a lesser extent, in rocks of the metamorphic basement.

Silver. Very high positive anomalies are present in rocks of the Ibañez and Divisadero formations, being highest in felsic rocks. Silver is also positively anomalous in rocks of the Patagonian Batholith, and only weakly anomalous in rocks of the metamorphic basement.

Arsenic. As shows very high positive anomalies in rocks of the Ibañez and Divisadero formations and of the metamorphic basement, being highest in felsic volcanic rocks of the Ibañez Formation. A positive anomaly is also observed in rocks of the Patagonian Batholith.

Gold. Very high positive anomalies are observed in rocks of the metamorphic basement and of the Ibañez and Divisadero formations, being highest in the metamorphic basement. Mean Au values for these rocks do not differ greatly, and are 9 to 10 times greater than global values. A weak positive Au anomaly is observed in rocks of the Patagonian Batholith, but this is not worth further analysis.

4.2.2. Analysis of element data

Values that are well above the regional upper limits and/or global mean values were taken for an additional population statistical analysis (Lepeltier, 1969) by use of the software PPLOT v. 1.01 (Stanley, 1987). Results are summarized in Table 9. Each population group was compared to mean and upper limit of the respective unaltered unmineralized rock types. Populations that are well above these regional and/or global upper limits were considered anomalous, and the recommended exploration threshold value for each case was taken as the upper limit of the population in which mean or upper limit value is within regional and/or global range. These exploration threshold values (Table 9) may be slightly overestimated, but certainly outline the highest potential targets for each lithologic unit in which altered and mineralized areas are observed.

In order to compare the inter-relation between el-

Table 8
Rock chip geochemical mean values for altered and mineralized rocks of the Aysén region, southern Chile. Also included are standard deviation values, standard deviation of mean values ($s/n^{0.5}$), mean values plus two standard deviation of mean values, regional upper limit values determined for unaltered rocks, and a compilation of global mean values here presented in ranges

Element (ppm)	*N*	% Samples < det. lim.	Mean value [a]	Std. dev.	Std. dev. of mean	Mean + 2 std. dev. of mean	Regional upper limit values [b]	Global mean values [c]
Metamorphic basement								
Mo	126	50	2.2	2.4	0.2	2.8	3.2	1–3
Cu	126	0	80	236	21	122	63.1	42–50
Pb	126	13.5	20.2	44.2	3.9	28	30.8	10–25
Zn	126	0	127.3	347.3	30.9	189.2	91.6	20–100
Ag	126	51.6	0.2	0.3	0.03	0.26	0.18	0.05–0.19
As	126	19.6	184	1126	100	384	24.9	2.5–15
Au [d]	126	53.1	154	1297	115.5	385	1.9	4–5
Andesites Ibañez Fm.								
Mo	201	48.2	2.9	5.4	0.4	3.9	6.7	1.0–1.5
Cu	201	2	247	1448	102	451	22.2	30–72
Pb	201	11.9	144	1287	91	326	17.7	4–15
Zn	201	0	606	7033	496	1598	57.4	60–94
Ag	201	49.8	0.8	2.9	0.2	1.2	0.11	0.07–0.10
As	201	34.3	48.4	181	12.8	74	13.4	1.5–2.0
Au [d]	201	44.2	47	248	17.5	283	1.4	3.2–4
Felsic volcanic rocks, Ibañes Fm.								
Mo	184	48.4	3	4.7	0.3	3.6	2.3	1.0–1.5
Cu	184	3.3	175	1339	99	373	11.9	30–72
Pb	184	5.4	400	2388	176	752	27.9	4–15
Zn	184	1.1	1382	9262	683	2748	117	60–94
Ag	184	51.1	2.1	22.3	1.6	5.3	0.37	0.07–0.10
As	184	24.5	387	4397	324	1035	19.1	1.5–2.0
Au [d]	184	44.6	34.8	280.7	20.7	76.2	2.5	3.2–4
Coihaique Group								
Mo	30	33.3	3.7	3.6	0.7	5.1	2.2	1–3
Cu	30	0	23.6	9.6	1.8	27.2	20.2	42–50
Pb	30	6.6	17.2	18.1	3.3	23.8	17.6	10–25
Zn	30	0	86.3	34.7	6.3	98.9	83.7	20–100
Ag	30	56.6	0.18	0.18	0.03	0.24	0.24	0.05–0.19
As	30	23.3	11.5	11.3	2.1	15.7	10.9	2.5–15
Au [d]	30	83.3	1.1	1.5	0.3	1.7	1.2	4–5
Divisadero Formation								
Mo	184	50.5	3.1	6.8	0.5	4.1	2.8	1.5–2.0
Cu	184	9.2	54.5	266	19.6	93.7	20	10–12
Pb	184	6.5	1425	5524	407	2239	15.1	18–20
Zn	184	0	1220	8809	649	2518	45	40–51
Ag	184	48.9	6.6	32.1	2.4	11.4	0.09	0.03–0.04
As	184	22.3	95.5	332	24.5	144.5	13.6	1.5–2.1
Au [d]	184	48.4	108	492	36	180	2.2	2.3–4.0
Plateau basalts								
Mo	14	0	4.6	3.6	1	6.6	6.3	1–1.5
Cu	14	0	11	10	2.7	16.4	17.4	72–100
Pb	14	0	6.5	2	0.5	7.5	9.4	4–5
Zn	14	0	35	15	4	43	40.6	94–100
Ag	14	85.7	0.08	0.07	0.02	0.12	0.19	0.1
As	14	57.1	5.1	9.1	2.4	9.9	26.2	1.5–2.0
Au [d]	14	57.1	2.8	4.7	1.3	5.4	5.2	3.2–4.0

Table 8 (continued)

Element (ppm)	N	% Samples < det. lim.	Mean value [a]	Std. dev.	Std. dev. of mean	Mean + 2 std. dev. of mean	Regional upper limit values [b]	Global mean values [c]
Patagonian Batholith								
Mo	193	33.7	10.1	51.3	3.7	17.5	2.4	1.0–1.5
Cu	193	1	60	123	9	78	31.3	30–72
Pb	193	24.9	26	118	8	42	18.3	4–15
Zn	193	0	182	1487	107	396	52.6	60–94
Ag	193	64.2	0.2	0.4	0.03	0.26	0.08	0.07–0.10
As	193	65.8	17.7	127	9.1	35.9	23.2	1.5–2.0
Au [d]	193	56	5.8	7	0.5	6.8	4.1	3.2–4

[a] Mean values were calculated including values below detection limit, considering those as half the detection limit.
[b] Regional upper limit values calculated from unaltered unmineralized rocks of previous section (see Table 3).
[c] Global mean value ranges were compiled from the following references: Turekian and Wedepohl (1961); Wedepohl (1969); Wedepohl (1969–1978); Levinson (1974); Turekian (1977); Saager et al. (1982). Values for the metamorphic basement rocks are obtained with respect to most probable protolith, shale and limestone. Ibañez Formation volcanic rocks are obtained with respect to granodioritic and mafic rock values. Divisadero Formation rocks are obtained with respect to granitic rock values.
[d] In ppb.

ements and mineralization, a correlation and factor analysis was done. A Pearson product–moment correlation matrix for logarithmically transformed data was calculated for each lithologic unit (Table 10). In addition, a factor analysis was done for each case, and the varimax rotated factor matrix, together with the communality values, is presented in Table 11.

Correlation results presented in Table 10 show statistically significant positive correlation coefficients for the following pairs: metamorphic basement (Cu–Ag; As–Au); andesites of the Ibañez Formation (Cu–Ag; Pb–Zn; Pb–Ag; Zn–Ag; Ag–As; Ag–Au); felsic rocks of the Ibañez Formation (Cu–Ag; Pb–Zn; Pb–Ag; Zn–Ag; Ag–As; Ag–Au; As–Au); sedimentary rocks of the Coihaque Group (Mo–As); rocks of the Divisadero Formation (all pairs excepting Mo); rocks of the plateau basalts (Mo–Cu; Mo–As; As–Au), and rocks of the Patagonian Batholith (Cu–Ag; Pb–Zn). These positive correlations are interpreted as representing metallic associations within sulphides (e.g. Ag in galena; Pb–Ag), or within sulphide mineral associations (e.g. sphalerite–galena; Pb–Zn).

The results of the factor analysis reveal that a five-factor model accounts in general for over 82% of the total variance, with the exception of Ag in rocks of the Patagonian Batholith, in which only 77% of the total variance is accounted for. In most cases, the displayed communality values account for well over 90% of the total variance. Results are described as follows for each selected rock unit.

Metamorphic basement. Factor 1 has high loadings of Zn and As, and may be explained by the commonly observed sphalerite–arsenopyrite association. Factor 2 has high loadings of Au and lesser Ag, suggesting that Au appears mainly in its native form and also as electrum, independent from sulphide mineralization. Factor 3 possesses a high Mo loading, suggesting that Mo, when present, is devoid of other sulphide associations. Factor 4 has high Pb and lesser Ag loadings, suggesting that galena is fairly independent from other sulphide associations, and that Ag appears also as solid solution within galena. Factor 5 has high loadings of Cu and much lesser Ag, indicating that Cu sulphides are fairly independent from other sulphides, and that Ag may form also certain degrees of solid solution within Cu sulphides.

Andesites, Ibañez Formation. Factor 1 possesses high loadings of Cu, Ag and Au, suggesting a Cu sulphide, native Ag and/or Ag sulphide and native Au and/or electrum association. Factor 2 has high loadings of Pb, Zn and lesser Ag, suggesting a close association between sphalerite–galena mineralization and significant Ag in solid solution with galena. Factor 3 has a high Mo loading, suggesting that Mo, when present, is devoid of other sulphides. Factor 4 has a high As loading, suggesting that this

Table 9
Geochemical population statistics and recommended exploration threshold values, for selected altered and mineralized rocks (calculated after Lepeltier, 1969 and Stanley, 1987: PROBPLOT v 1.01)

Element (ppm)	Nr. of samples	Nr. of populations	Population mean	Lower threshold	Upper threshold	Population %	Rec. expl. threshold
Metamorphic basement							
Cu	126	3	8.3	4.5	15.1	18.76	
			29.4	10.9	79.1	59.96	79
			130.8	11.6	1478	21.27	
As	126	3	2.6	1	6.7	32.9	
			20.7	6.6	64.5	35.3	65
			77.6	2	2961	31.8	
Au [a]	126	4	1	0.8	1.2	52.07	
			3.9	1	15.3	39.00	15
			45.7	8.7	239.5	4.28	
			1041	100.4	10790	4.64	
Andesites, Ibañez Formation							
Cu	201	4	5.8	2.6	12.9	6.45	
			6.9	1.2	40	45.79	
			71.9	18.3	282	39.25	72
			394	6.6	23681	8.51	
Pb	201	4	2	1.6	2.6	12.54	
			9.1	2.8	29.3	65.55	29
			47.2	15	148	16.42	
			620	39.1	9831	5.5	
Zn	201	4	8	3	20	2.75	
			42	11	165	82.36	165
			256	72	910	12.48	
			1941	13	290128	2.41	
Ag	201	4	0.1	0.07	0.13	48.36	
			0.3	0.14	0.46	29.38	0.46
			0.9	0.2	3.7	20.07	
			19.2	7.7	47.6	2.19	
As	201	4	2	1.4	2.9	36.68	
			8.5	2.4	29.5	31.32	30
			42.6	11.8	154	26.61	
			405	94	1747	5.39	
Au	201	4	1.5	0.5	4.4	75.08	
			5.5	1.2	24	17.80	24
			115	35.6	371	4.16	
			1114	384	3236	2.95	
Felsic rocks, Ibañez Formation							
Cu	184	4	1	0.6	1.8	3.06	
			10.3	1.9	56.4	82.38	56
			123	38.4	399	9.95	
			2075	362	11897	4.61	
Pb	184	4	2.2	1.4	3.6	7.27	
			10.2	2.8	37.5	61.29	38
			68.7	3.7	1291	27.5	
			5468	675	44251	3.94	
Zn	184	4	9.5	1.4	66	21.36	
			38.3	9.6	153	62.74	153
			467	31.5	6926	12.05	
			24127	4879	119313	3.85	

Table 9 (continued)

Element (ppm)	Nr. of samples	Nr. of populations	Population mean	Lower threshold	Upper threshold	Population %	Rec. expl. threshold
Ag	184	4	0.1	0.06	0.15	53.84	
			0.4	0.1	1.6	39.66	1.6
			4.4	1.7	11	4.62	
			68.2	6.2	743	1.88	
As	184	5	2	1.6	2.4	23.15	
			8.1	2.4	27.8	29.15	28
			44.1	7.4	264	33.86	
			565	287	1112	5.59	
			608	12.6	29263	8.25	
Au [a]	184	5	1	0.6	1.5	45.01	
			3	1.3	7.2	33.37	
			15.9	7.6	33.1	11.83	33
			71.2	20.3	249	6.86	
			591	66.2	5288	2.93	
Divisadero Formation							
Cu	184	4	2.7	0.7	9.7	48.92	
			9.9	3.4	28.6	39.69	29
			99.6	17.6	564	8.7	
			1149	289	4573	2.68	
Pb	184	4	2.2	1.3	3.7	7.76	
			13	3	55.6	65.82	56
			231	4.1	12825	20.88	
			17313	6220	48189	5.54	
Zn	184	4	12.1	2.1	71	55.58	
			43.8	21.5	89.1	26.05	89
			233	38.1	1423	14.19	
			9259	317	270014	4.19	
Ag	184	4	0.1	0.07	0.15	47.63	
			0.4	0.07	2.3	40.55	2.3
			10.6	4.6	24.4	6.87	
			80	13.6	471	4.95	
As	184	4	2	1.7	2.4	22.13	
			7	2.7	17.9	35.82	
			55.3	9.7	314	30.93	55
			353	143	869	9.35	
Au [a]	184	5	1	0.7	1.6	68.49	
			2.4	1.4	4	25.79	
			6.4	4	10.2	3.25	10
			796	6.6	96458	0.97	
			1309	201	8522	1.5	
Patagonian Batholith							
Mo	193	4	1.5	0.6	3.6	67.35	
			4.5	1.8	11.3	17.78	11
			19.9	9.5	41.7	9.71	
			56.5	7.8	412	5.16	
Zn	193	4	10.9	5.8	20	4.6	
			42.8	14.1	130	87.35	130
			241	109	531	6.79	
			3578	78	164574	1.26	
Ag	193	4	0.1	0.08	0.12	64.35	
			0.2	0.15	0.3	19.03	0.3
			0.4	0.18	1	9.33	
			1.55	1	2.3	7.29	

Table 9 (continued)

Element (ppm)	Nr. of samples	Nr. of populations	Population mean	Lower threshold	Upper threshold	Population %	Rec. expl. threshold
As	193	4	2	1.6	2.5	64.93	
			3.9	1.8	8.5	25.52	
			16.5	3.6	74.9	6.86	75
			335	47.2	2384	2.69	
Au [a]	193	4	1	0.8	1.2	80.2	
			2.9	1.7	5	17.03	
			2.3	0.6	8	1.14	12
			78.2	12.3	496	1.63	

[a] In ppb.

element is independent from other sulphides and/or precious metals. Factor 5 has no loadings of importance and represents only 2.2% of the total variance.

Felsic rocks, Ibañez Formation. Factor 1 has high loadings of Pb, Zn and significant Ag, suggesting a close sphalerite–galena association and significant Ag in solid solution with galena or as associated mineralization. Factor 2 possesses high loadings of As and Au, suggesting a close association between native Au and arsenides or As-rich sulphides such as arsenopyrite. Factor 3 has high Mo loading, suggesting as in previous cases the independence of Mo mineralization. Factor 4 possesses high Cu loadings, suggesting that Cu sulphide mineralization is independent from other sulphides. Factor 5 has a medium high Ag loading, with lesser Pb, suggesting that Ag appears also as native and/or sulphide mineralization, associated with galena and/or other sulphosalts.

Coihaique Group. Factor 1 possesses high loadings of Pb and Au, with lesser Cu, Ag and As, suggesting a mixed sulphide–sulphosalt association together with Au and Ag. Factor 2 has high Mo and As loadings, suggesting a molybdenite–arsenopyrite association. Factor 3 has a high negative Zn loading, suggesting not only that sphalerite is independent from other sulphides, but also that it correlates negatively with respect to other base metals. Factor 4 possesses a high Ag loading, indicating that Ag may be present as independent sulphides or native. Factor 5 has a high Cu loading, suggesting that Cu appears as independent sulphides with respect to other base metal sulphides.

Divisadero Formation. Factor 1 has high Pb and Au loadings, with lesser Ag and Cu, suggesting a mixed sulphide–sulphosalt association together with Au and Ag. Factor 2 possesses high Cu and Zn loadings, suggesting a Cu sulphide–sphalerite association. Factor 3 has a high Mo loading, suggesting molybdenite as an independent sulphide phase. Factor 4 has a high As loading, suggesting As mineralization mostly independent from other sulphide mineralization. Factor 5 has a high Ag loading with lesser Au, suggesting native Ag–Au as an independent mineralization phase.

Plateau basalts. Factor 1 has high Au and As loadings, and lesser Mo, suggesting a native Au–arsenopyrite (molybdenite) association. Factor 2 has high Mo and Cu loadings, suggesting a Cu sulphide–molybdenite association. Factor 3 possesses a high negative Zn loading, with lesser negative Cu and Au, suggesting a sphalerite–Cu sulphide–native Au association. Factor 4 has a high Ag loading with lesser As, suggesting native Ag and/or silver sulphides associated with sulphosalts and arsenopyrite. Factor 5 has a high Pb loading, suggesting galena as an independent mineralization phase.

Patagonian Batholith. Factor 1 possesses high Cu and Ag loadings, suggesting a Cu sulphide–native Ag and/or Ag sulphide association. Factor 2 has high As and Au loadings, suggesting a native Au–arsenopyrite association. Factor 3 has a very high negative Mo loading, indicating not only that molybdenite appears as an independent mineral phase, but that it correlates negatively with all other sulphides or precious metals. Factor 4 has a high Pb loading with lesser Ag, suggesting galena as an independent mineralization phase, with lesser Ag in solid solution. Factor 5 has a high Zn loading with lesser Ag, suggesting sphalerite as an independent phase, with lesser Ag.

Table 10
Correlation matrixes for altered and mineralized samples of the Aysén region

Element	Mo	Cu	Pb	Zn	Ag	As	Au
Metamorphic basement — N = 126							
Mo	1						
Cu	0.063	1					
Pb	0.133	0.251	1				
Zn	−0.214	0.409	0.346	1			
Ag	0.157	0.524	0.448	0.266	1		
As	0.123	0.395	0.387	0.487	0.446	1	
Au	0.057	0.449	0.306	0.242	0.388	0.534	1
Andesite, Ibañez Formation — N = 201							
Mo	1						
Cu	0.074	1					
Pb	0.140	0.210	1				
Zn	−0.079	0.368	0.564	1			
Ag	0.232	0.548	0.605	0.507	1		
As	0.341	0.285	0.463	0.358	0.582	1	
Au	0.150	0.463	0.354	0.288	0.581	0.452	1
Felsic rocks, Ibañez Formation — N = 184							
Mo	1						
Cu	0.299	1					
Pb	0.200	0.427	1				
Zn	0.007	0.404	0.688	1			
Ag	0.235	0.577	0.748	0.526	1		
As	0.185	0.446	0.403	0.141	0.500	1	
Au	0.149	0.475	0.423	0.184	0.606	0.606	1
Coihaique Group — N = 30							
Mo	1						
Cu	0.425	1					
Pb	0.126	0.341	1				
Zn	0.309	0.218	−0.110	1			
Ag	0.296	0.154	−0.054	−0.037	1		
As	0.541	0.287	0.461	0.023	−0.008	1	
Au	0.070	0.294	0.294	−0.221	0.297	0.176	1
Divisadero Formation — N = 184							
Mo	1						
Cu	0.437	1					
Pb	0.412	0.688	1				
Zn	0.244	0.747	0.716	1			
Ag	0.482	0.720	0.842	0.656	1		
As	0.403	0.537	0.727	0.540	0.718	1	
Au	0.451	0.627	0.712	0.570	0.844	0.671	1
Plateau basalts — N = 14							
Mo	1						
Cu	0.605	1					
Pb	0.086	−0.276	1				
Zn	0.041	0.143	−0.352	1			
Ag	0.079	−0.183	0.357	−0.078	1		
As	0.641	−0.053	0.404	−0.067	0.491	1	
Au	0.454	−0.094	0.238	0.202	0.131	0.673	1

Table 10 (continued)

Element	Mo	Cu	Pb	Zn	Ag	As	Au
Patagonian Batholith — N = 193							
Mo	1						
Cu	0.019	1					
Pb	0.023	−0.008	1				
Zn	−0.081	0.302	0.544	1			
Ag	0.010	0.551	0.351	0.455	1		
As	−0.153	0.048	0.348	0.294	0.174	1	
Au	0.009	0.321	0.108	0.168	0.259	0.306	1

5. Discussion

The comparison between regional upper limits for unaltered unmineralized rocks of the Aysén region with global mean value ranges of similar lithological types (Table 6) shows that no single lithologic unit is greatly enriched in metals. Positive Zn and Ag anomalies are observed in Jurassic–Cretaceous felsic rocks of the Ibañez Formation, Cu and Ag in rocks of the Upper Cretaceous Divisadero Formation, Mo and Ag in rocks of the Paleogene–Neogene plateau basalts and Mo in andesites of the Upper Jurassic–Lower Cretaceous Ibañez Formation. A conspicuous As positive anomaly is observed in all studied rock units except for sedimentary rocks of the Coihaique Group. The highest As anomalies occur in rocks of the plateau basalts and the Patagonian Batholith (more than 10 times normal crust), followed by Cretaceous volcanic rocks (more than 5 times normal crust) and the metamorphic basement (only slight positive anomaly). The high As background in the region must be considered for geochemical exploration purposes, and proportionally higher anomaly threshold values should be used. In addition, use of As as a Au–Ag pathfinder is cautioned.

Correlations among base metals, Mo, Au and As, observed for volcanic rocks (andesites, felsic rocks and basalts), may be related to trace quantities present within crystal lattice in common silicate minerals, such as feldspars (Pb and Cu; Smith, 1981), amphiboles (Zn and Pb; Hawthorne, 1981; and Cu; Hendry et al., 1985) and pyroxenes (Zn; Cameron and Papike, 1980). In addition, amphiboles may hold large cations within holes in the ring chains, with coordinations 6-, 8-, 10- and 12- (Klein and Hurlbut, 1993). Good correlations observed among Cu, Pb

Table 11
Varimax rotated factor matrixes of rock units of the Aysén region

Rock unit	Element	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Metamorphic basement	Mo	−0.038	−0.017	0.995	0.013	0.064	0.996
	Cu	0.035	0.096	0.063	0.091	0.983	0.989
	Pb	0.228	−0.057	−0.037	0.944	0.017	0.948
	Zn	0.916	−0.021	−0.089	0.169	0.107	0.887
	Ag	−0.012	0.578	0.148	0.673	0.305	0.902
	As	0.945	0.057	0.034	0.069	−0.057	0.905
	Au	0.035	0.978	−0.047	−0.003	0.053	0.963
Sum of squares		1.788	1.308	1.028	1.385	1.081	
Explained variability		25.549	18.688	14.686	19.792	15.441	
Cumulative explained variability		25.549	44.237	58.923	78.715	94.156	
Andesites, Ibañez Formation	Mo	−0.007	−0.019	0.999	0.039	−0.002	0.999
	Cu	0.981	−0.049	0.029	0.001	−0.162	0.992
	Pb	0.107	0.978	0.017	0.164	0.010	0.995
	Zn	0.078	0.984	0.015	0.130	0.011	0.991
	Ag	0.816	0.536	−0.065	0.114	−0.132	0.988
	As	0.070	0.215	−0.042	0.973	0.005	0.999
	Au	0.935	0.096	0.019	0.070	0.334	1
Sum of squares		2.526	2.271	1.006	1.010	0.155	
Explained variability		36.084	32.442	14.368	14.435	2.220	
Cumulative explained variability		36.084	68.526	82.894	97.329	99.549	
Felsic rocks, Ibañez Formation	Mo	0.091	−0.008	0.990	0.106	0.001	0.991
	Cu	0.065	0.092	0.109	0.985	0.057	0.998
	Pb	0.909	0.029	0.039	0.028	0.210	0.873
	Zn	0.941	0.020	0.091	0.055	0.092	0.906
	Ag	0.619	0.097	0.001	0.100	0.765	0.988
	As	−0.008	0.967	0.038	−0.035	−0.077	0.944
	Au	0.075	0.929	−0.051	0.173	0.173	0.931
Sum of squares		2.114	1.818	1.005	1.026	0.678	
Explained variability		30.204	25.966	14.361	14.655	9.682	
Cumulative explained variability		30.204	56.17	70.531	85.186	94.868	
Coihaique Group	Mo	0.086	0.843	−0.254	0.241	0.289	0.924
	Cu	0.219	0.129	−0.132	0.165	0.941	0.995
	Pb	0.813	0.312	0.155	0.146	0.155	0.828
	Zn	−0.157	0.106	−0.970	−0.019	0.121	0.992
	Ag	0.273	0.138	0.020	0.934	0.168	0.994
	As	0.212	0.950	0.031	0.005	−0.024	0.949
	Au	0.902	0.046	0.068	0.198	0.134	0.877
Sum of squares		1.673	1.760	1.053	1.019	1.054	
Explained variability		23.899	25.140	15.050	14.559	15.053	
Cumulative explained variability		23.899	49.039	64.089	78.648	93.701	
Divisadero Formation	Mo	0.080	0.036	0.993	0.060	0.014	0.997
	Cu	0.217	0.915	0.047	0.074	−0.053	0.895
	Pb	0.885	0.284	0.130	0.086	0.102	0.898
	Zn	0.015	0.909	0.006	0.009	0.287	0.909
	Ag	0.333	0.187	0.020	0.023	0.903	0.962
	As	0.131	0.060	0.062	0.987	0.030	0.999
	Au	0.813	−0.038	−0.010	0.134	0.441	0.875

Table 11 (continued)

Rock unit	Element	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Sum of squares		1.625	1.785	1.010	1.008	1.107	
Explained variability		23.214	25.499	14.433	14.407	15.820	
Cumulative explained variability		23.214	48.713	63.146	77.553	93.373	
Plateau basalts	Mo	0.373	0.904	0.118	0.109	0.042	0.984
	Cu	−0.309	0.835	−0.361	−0.162	−0.077	0.860
	Pb	0.116	−0.008	0.206	0.189	0.951	0.996
	Zn	0.136	0.097	−0.927	−0.034	−0.211	0.933
	Ag	0.048	−0.025	0.031	0.973	0.174	0.981
	As	0.700	0.392	0.362	0.385	0.136	0.941
	Au	0.913	−0.046	−0.269	−0.042	0.083	0.917
Sum of squares		1.593	1.679	1.251	1.172	1.012	
Explained variability		22.754	23.990	17.873	16.738	14.461	
Cumulative explained variability		22.754	46.744	64.617	81.355	95.916	
Patagonian Batholith	Mo	−0.020	−0.011	−0.999	−0.005	−0.001	0.998
	Cu	0.880	0.126	−0.001	−0.085	0.173	0.827
	Pb	0.097	0.018	0.004	0.974	0.105	0.969
	Zn	0.343	0.033	0.001	0.128	0.927	0.994
	Ag	0.804	0.054	0.032	0.273	0.207	0.768
	As	0.005	0.949	0.012	0.057	0.117	0.918
	Au	0.177	0.935	0.004	−0.031	−0.074	0.812
Sum of squares		1.578	1.795	1	1.052	0.962	
Explained variability		22.543	25.647	14.291	15.023	13.749	
Cumulative explained variability		22.543	48.190	62.481	77.504	91.253	

and Zn in sedimentary rocks (limestones and shales) may be related to carbonate mineral chemistry in the case of limestones, and to sulphides present within bituminous shales.

Having established a baseline for unaltered unmineralized rocks in the region, results for hundreds of samples taken from altered and mineralized areas have also been separated according to the main lithological units studied in the region. Table 8 shows mean and standard deviation of the mean for the different units, and are compared to regional upper limits and to global mean value ranges. This comparison shows outstanding positive As, and base and precious metals anomalies for the Mesozoic volcanic rocks (Ibañez and Divisadero formations), and lesser positive anomalies for the metamorphic basement (Cu, As and Au) and the Patagonian Batholith (Mo, Zn, Ag and As). The highest Cu anomalies are observed in andesites and felsic rocks of the Upper Jurassic–Lower Cretaceous Ibañez Formation, whereas the highest Pb, Zn, Ag and As anomalies are observed in Cretaceous volcanic rocks of the Divisadero Formation. The highest Au anomalies are present in andesites of the Ibañez Formation and in rocks of the metamorphic basement. From these results, it is quite obvious that the most important altered and mineralized areas in the region are mostly restricted to Upper Jurassic–Cretaceous volcanic rocks, and to a lesser degree, in rocks of the metamorphic basement and the Patagonian Batholith. Sedimentary rocks of the Coihaique Group may serve mostly as host rock to mineralization (e.g. El Toqui Zn–Pb skarn), but do not show potential as ore deposit generators. This would suggest that most alteration–mineralization in this region is associated with the development of the Upper Jurassic–Cretaceous volcanic arc, with lesser mineralization hosted within associated intrusive rocks (Patagonian Batholith) and within basement rocks (metamorphic basement). Upper Cretaceous–Tertiary basalts have no important mineralization, suggesting that the changes in tectonic regime and environment at the end of the Cretaceous, that led to cessation of volcanic arc activity and initiation

Table 12
Calculated and estimated threshold values recommended for exploration in the Aysén region

Element (ppm)	Recommended threshold value	% of samples above threshold
Metamorphic basement		
Mo	3	19.84
Cu	79	16.67
Pb	31	14.28
Zn	100	19.84
Ag	0.26	29.36
As	65	17.46
Au [a]	15	14.28
Andesites, Ibañez Formation		
Mo	7	6.47
Cu	72	27.36
Pb	29	19.40
Zn	165	12.93
Ag	0.46	24.87
As	30	25.87
Au [a]	24	7.96
Felsic rocks, Ibañez Formation		
Mo	4	21.74
Cu	56	17.39
Pb	38	23.91
Zn	153	14.67
Ag	1.6	7.61
As	28	36.95
Au [a]	33	9.24
Coihaique Group		
Mo	5	20
Cu	50	3.33
Pb	25	10
Zn	100	26.67
Ag	0.24	26.67
As	16	23.33
Au [a]	5	3.33
Divisadero Formation		
Mo	4	16.85
Cu	29	10.87
Pb	56	24.46
Zn	89	19.02
Ag	2.3	13.04
As	55	25.54
Au [a]	10	22.83
Plateau basalts		
Mo	7	21.43
Cu	100	0
Pb	9	0
Zn	100	0
Ag	0.19	14.28
As	2.6	7.14
Au [a]	5	14.28
Patagonian Batholith		
Mo	11	13.99
Cu	78	17.10
Pb	42	4.14
Zn	130	9.84
Ag	0.3	13.99
As	75	3.11
Au [a]	12	4.66

[a] In ppb.

of intra-continental tholeiitic basaltic volcanism towards the east, also led to the end of mineralization. Despite the fact that sedimentary units of Tertiary age were not sampled, these units do not report any important known mineralization, and also cover a very small percentage of total area within the region.

These geochemical data allow estimation of exploration threshold values for this region, which were calculated according to the following criteria: (1) elements within rock units which show similar upper limit values for altered and mineralized rocks to those of unaltered unmineralized rocks, and/or to global mean value range, were considered to have an upper exploration threshold value equal to or higher than the highest of the three upper limits considered (altered and mineralized upper limit, regional upper limit or global upper limit); and (2) elements in altered and mineralized rocks that are positively anomalous with respect to their unaltered unmineralized equivalent were processed by statistical population analysis (Table 9), and threshold values were calculated as the upper limit or mean value of the population that falls within the upper limit range of the unaltered unmineralized equivalent, or global value range equivalent, whichever is highest (Table 9). The estimated exploration threshold values are presented in a summary table (Table 12) which also includes the percentage of altered and mineralized samples that are above threshold limit. This table shows that, for mineralized and altered rocks, the Mesozoic volcanic rocks hold the largest potential for exploration targets, followed by rocks of the metamorphic basement and rocks of the Patagonian Batholith. Altered and mineralized sedimentary rocks of the Cretaceous Coihaique Group, despite not showing any obvious anomaly, do have a considerable percentage of samples containing Zn, Ag and As above estimated thresholds, and this may reflect good host rock conditions to passing hydrothermal fluids.

Correlation and factor analysis of altered and mineralized rock data show the best associations in the volcanic Mesozoic rocks, the best and most abundant in Cretaceous volcanic rocks of the Divisadero Formation, and similar correlations for andesites and felsic rocks of the Ibañez Formation. These good correlations reflect the frequent polymetallic character of mineralization present in this region, associated with epithermal and skarn type mineralization. For exploration purposes, in these volcanic rocks, factor analysis shows the following element associations:

(1) Andesites of the Ibañez Formation, Cu–Ag–Au and Pb–Zn–(Ag). Mo and As have individual loadings, not being recommended as pathfinder elements.

(2) Felsic rocks of the Ibañez Formation, Pb–Zn–Ag, As–Au, Ag–(Pb). Mo and Cu have individual loadings, not being recommended as pathfinder elements.

(3) Rocks of the Divisadero Formation, Pb–Au–(Ag), Cu–Zn–(Pb), Ag–(Au). Mo and As have individual loadings, not being recommended as pathfinder elements.

Rocks of the metamorphic basement show good correlations only for Cu–Ag and As–Au, and factor analysis indicates the following element associations: Zn–As, Au–(Ag), Pb–(Ag) and Cu–(Ag). Mo has an individual loading. Rocks of the Patagonian Batholith show good correlations for Cu–Ag and Pb–Zn, and factor analysis indicates the following associations: Cu–Ag, As–Au, Zn–(Ag). Mo and Pb have individual loadings.

6. Conclusions

Base and precious metal contents of rocks of the Aysén region are comparable to global contents for similar rocks. Arsenic is the only element within this study that shows a conspicuous positive anomaly for most rock types when compared to global contents. These regional backgrounds calculated for unaltered unmineralized rocks set the baseline values for base and precious metals exploration.

Based on the geochemical study of altered and mineralized rocks and relating it to the geotectonic evolution of the region, mineralization seems to have been constrained to the Late Jurassic–Cretaceous time period, preferentially linked to the evolution of the volcanic arc–back-arc system. Mineralization occurs preferentially hosted by the more felsic volcanic and subvolcanic rocks of the Ibañez and Divisadero formations.

Exploration threshold values are recommended for the various rock units in the region, the most prospective being the Upper Jurassic–Cretaceous Ibañez Formation and the Cretaceous Divisadero Formation. Factor analysis for geochemical data of these units indicates potential for polymetallic deposits, reflecting epithermal and skarn type mineralization characteristic of this region. Arsenic, despite having strong positive anomalies with respect to global and regional values, is widespread and not necessarily associated with base or precious metal mineralization, and may not be an indicator.

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References

Ahrens, H.L., 1957. Lognormal type distributions III. Geochim. Cosmochim. Acta 27, 333–343.

Baker, P.E., Rea, W.J., Skarmeta, J., 1981. Igneous history of the Andean Cordillera and Patagonian Plateau around latitude 46ºS. Philos. Trans. R. Soc. London A 303, 105–149.

Bartholomew, D.S., Tarney, J., 1984. Geochemical characteristics of magmatism in the southern Andes (45º–46º S). In: Harmon, R.S., Barreiro, B.A. (Eds.), Andean Magmatism: Chemical Isotopic Constraints, Shiva Publications, Cheshire, U.K., pp. 220–229.

Bertens, A., 1993. Antecedentes Geoquímicos y de Inclusiones Fluidas del Yacimiento El Toqui, XI region, Chile. Unpubl. Thesis, Departamento de Geología, Universidad de Chile, Santiago, 159 pp.

Cameron, M., Papike, J., 1980. Crystal chemistry of silicate pyroxenes. In: Prewitt, P.T. (Ed.), Pyroxenes. Reviews in Mineralogy V7, Ch. 2, Mineralogical Society of America, Washington, DC, pp. 5–92.

De Wit, M., Stern, C., 1981. Variations in the degree of crustal extension during formation of a back arc basin. Tectonophysics 72, 229–260.

Hawthorne, F.C., 1981. Crystal chemistry of the amphiboles. In: Veblen, D.R. (Ed.), Amphiboles and other Hydrous Pyriboles — Mineralogy. Reviews in Mineralogy V9A, Ch. 1, Mineralogical Society of America, Washington, DC, pp. 1–102.

Hendry, D., Chivas, A., Long, J., Reed, S., 1985. Chemical differences between minerals from mineralizing and barren intrusions from some North American porphyry copper deposits. Contrib. Mineral. Petrol. 89, 317–329.

Klein, C., Hurlbut, C. Jr., 1993. Manual of Mineralogy (21st ed.). Wiley, New York, 681 pp.

Lepeltier, C., 1969. A simplified statistical treatment of geochemical data by graphical representation. Econ. Geol. 64, 538–550.

Levinson, A.A., 1974. Introduction to Exploration Geochemistry (2nd ed.). Applied Publishing Ltd., Willmette, IL, 924 pp.

Miller, H., 1984. Orogenic development of the Argentinean/Chilean Andes during the Paleozoic. J. Geol. Soc. London 141, 885–892.

Palacios, C.M., Bertens, A., Ruz, L., 1994. Polymetallic skarn mineralization at El Toqui, Aysén province, southern Chile. Zbl. Geol. Palaeontol. 1 (7–8), 723–737.

Saager, R., Meyer, M., Muff, R., 1982. Gold distribution in supracrustal rocks from Archean greenstone belts of southern Africa and from Paleozoic ultramafic complexes of the European alps: metallogenic and geochemical implications. Econ. Geol. 7, 1–24.

Smith, J.V., 1981. Some chemical properties of feldspars. In: Ribbe, P.H. (Ed.), Feldspar Mineralogy. Reviews in Mineralogy V2, Ch. 12, Mineralogical Society of America, Washington, DC, pp. 281–297.

Stanley, C.R., 1987. PROBPLOT: an interactive computer program to fit mixtures of normal (or log-normal) distributions with maximum likelihood optimization procedures (version 1.01E7). Assoc. Explor. Geochemist, Spec. Vol. 14, 42 pp.

Tippet, M.C., Cruzat, A., Nasi, C., 1991. The Fachinal district, Aysén province, Chile. 93rd Annual Meeting of CIM-1991, Vancouver, 23 pp.

Toloza, R.B., 1987. Geología y Génesis del Manto de Cinc Rosillo, Basamento Metamórfico de Aysén, Lago General Carrera, XI región, Chile. Unpubl. Thesis, Departamento de Geología, Universidad de Chile, Santiago, 183 pp.

Townley, B.K., 1997. Ore Deposits, Tectonics and Metallogenesis of the Continental Aysén Region, Chile. Unpubl. Ph.D. Thesis, Queen's University at Kingston, ON, 254 pp.

Turekian, K.K., 1977. Geochemical distribution of elements. In: Encyclopedia of Science and Technology (4th ed.). McGraw-Hill, New York, pp. 627–630.

Turekian, K.K., Wedepohl, K.H., 1961. Distribution of the elements in some major units of the earth's crust. Bull. Geol. Soc. Am. 72, 175–192.

Wedepohl, K.H. (Ed.), 1969. Handbook of Geochemistry, Vol. 1. Springer, Berlin.

Wedepohl, K.H. (Ed.), 1969–1978. Handbook of Geochemistry, Vols. 2–4. Springer, Berlin.