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THE PRODUCTORA PROSPECT IN NORTH-CENTRAL CHILE: AN EXAMPLE OF AN INTRUSION-RELATED, CANDELARIA TYPE Fe-Cu-Au HYDROTHERMAL SYSTEM

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Abstract - The Productora prospect is situated 15 km SSW of the town of Vallenar in the Third Region, north-central Chile. It lies within the “Chilean Iron Belt” close to the north-trending Atacama Fault system. The belt contains a variety of Fe oxide ±Cu ±Au-bearing deposits including Candelaria (366 million tonnes averaging 1.08 % Cu, 0.26 g/t Au) which is situated in the Punta del Cobre region approximately 150 km north of Productora. The age, structural setting, alteration assemblages and styles of mineralisation in the Productora area resemble those present at Candelaria, but Productora differs in its spatial association with intrusive rocks and its lack of skarn assemblages.

Productora includes a north-trending zone of hydrothermal alteration (Fe oxide-albite-K spar-tourmaline-sericite-silica) that exceeds 8 km in strike length and 3 km in width. This zone contains 13 small former mines, 8 of which were worked for magnetite and the remaining 5 for Cu-Au. In addition, there are over 80 shallow pits and surface occurrences containing some Fe oxide ±Cu ±Au ±U ±REE ± apatite mineralisation.

The mineralisation and alteration are structurally and stratigraphically controlled. They are preferentially developed in more permeable tuffaceous units of a presumed Cretaceous package but also follow NW-striking and, to a lesser extent, N-trending structures related to the Atacama Fault system.

Hydrothermal alteration is mainly centred around two Early Cretaceous (c. 130 Ma) felsic intrusions, the Cachiyuyito and El Molle stocks. Six proximal to distal alteration zones are recognised. Zone I alteration assemblages in the stocks comprise pervasive albite with veins of actinolite, magnetite and epidote. The immediately adjacent country rocks are overprinted by Zone II alteration dominated by albite, chlorite, actinolite, magnetite, apatite and coarse calcite veins. More distal still is Zone III with widespread K-spar and tourmaline, as well as magnetite, hematite, secondary biotite and silica. This passes out to Zone IV in which the volcaniclastics are strongly replaced by albite and silica ± epidote and hematite. Zones V and VI represent the uppermost and lowest temperature alteration. The former is largely preserved in an elongate, 1.5 km-wide down-faulted block and is characterised by massive silica, specular hematite, sericite and dumortierite, whilst the outermost Zone VI has pervasive propylitic and albitic alteration with rare jasper veins.

Three styles of Fe-oxide dominant mineralisation are identified, each of which tends to occur within a specific alteration zone. The most proximal and common of these is magnetite ± apatite veins and replacements hosted by Zone II alteration assemblages. This style seldom contains significant Cu or Au and is represented by the Mariposa, La Bandera, La Chulula, La Negrita and the El Molle magnetite mines.

The second and most economically important style of mineralisation is typified by the Cu-Au ± REE ± U ± Mo ± Co mineralisation at the Productora and Santa Innes mines. It is more commonly associated with Zone III alteration (K-spar-silica and tourmaline) but in the case of the Monseratt Mine and Remolina pit it is hosted by Zone II mineral assemblages. Hypogene mineralisation includes magnetite, chalcopyrite, pyrite and native gold. Surface leaching has resulted in the development of irregular leached caps containing Cu-oxide and phosphate mineralisation at surface and secondary Cu enrichment locally at depth. Both the hypogene and secondary Cu mineralisation is Au-rich (100 to 9700 ppb) and they contain anomalous REE’s (50 to 560 ppm La). Trace quantities of the U oxide mineral, torbernite, are also present. Sulphur isotope ratios for chalcopyrite, pyrite and chalcocite collected from Style 2-type mineralisation show $\delta^{34}S$ values ranging from -8.2 to +1.2 which are lower than those recorded in the Punta del Cobre region further north.

The third style of mineralisation is developed in the outermost parts of the Productora hydrothermal system (Zone VI). Here, small veins and mantos of magnetite and/or hematite are associated with epidote, albite and silica alteration. This distal mineralisation may be geochemically anomalous in Cu, Au, Zn, As, Co, Pb and Mn.

Introduction

The Productora property is located approximately 625 km north of Santiago and 15 km SSW of Vallenar in Region III, north-central Chile (Figure 1). It lies less than 4 km west of the Pan American Highway (Ruta 5) and is geographically centred around the Productora Valley (Figure 2) which comprises several talus-filled basins. The basins are surrounded by, and lie on strike with, a north-trending zone of hydrothermal alteration (Fe oxide-albite-K-spar-biotite-tourmaline-sericite-silica) that is discontinuously traceable over an 8 km length. This zone reaches 3 km in outcrop width and contains five small, shallow former mines (Productora, Santa Innes, Monseratt, Remolina and Fortuna; Figure 3) that were worked for Cu oxides and Au, as well as eight magnetite mines and more than 80 pits and occurrences with Fe oxides ±Cu ±Au ±U ±REE ±apatite mineralisation.

The Productora area lies within the "Chilean Iron Belt" which is associated with the long-lived, north-trending Atacama Fault Zone (Figure 1). This brittle-ductile structure has been active since the Early Cretaceous and has involved recurrent sinistral strike-slip displacements (Brown et al., 1993). The belt contains a large number of Fe oxide-rich occurrences as well as several large deposits. The occurrences and deposits can be separated into two types (Figure 1), namely magnetite-dominant ± actinolite ± apatite systems that generally lack Cu sulphides (eg. El Romeral, El Tofo, Algarrobo and Iman) and those where the magnetite or hematite is associated with significant amounts of Cu and Au (eg. Candelaria, Manto Verde; Bookstrom, 1977; Ryan et al., 1995; Vila et al., 1996; Marschik et al., 1996). The Productora prospect and the lesser known Pajaritos occurrences north of Vallenar (Ray, 1997b; Figure 1) represent examples of the latter type. In particular, the structural setting, Na, K and Si alteration zoning and Cu-Au-Co-REE geochemical signature of the mineralisation at Productora show strong similarities to the Cretaceous-age Candelaria deposit (c. 366 Mt grading 1.08 % Cu, 0.26 g/t Au and 4.5 g/t Ag; Marschik et al., 1996; Jenkins et al., 1998), situated approximately 150 km further north (Figure 1). Unlike Candelaria, however, the Productora alteration is spatially related to a suite of elongate, albitised felsic intrusions that have yielded a U-Pb zircon date of 129.8 Ma (Fox, 2000).

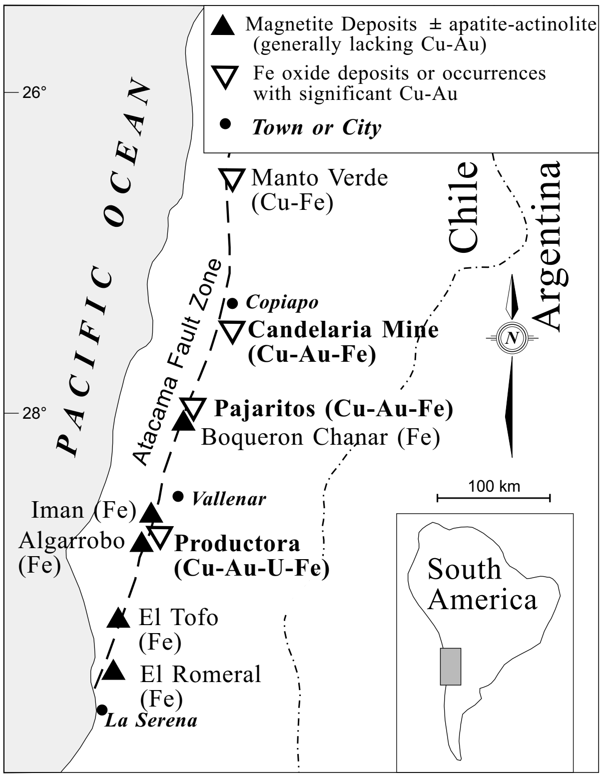


Figure 1: The Atacama Fault Zone, north-central Chile, showing locations of various Fe oxide deposits including the Productora Prospect and the Candelaria Deposit.

Previous Work

Despite the long history of sporadic mining and exploration in the Productora area, the only published report is a brief description by Dick and Ray (2000). Maus (1997a and b) completed reconnaissance mapping and also noted the earlier exploration by Noranda and Newcrest Mining. At least 10 short (35 m to 101 m long) holes were drilled during the 1980's by the Commission Chilena Energia Nuclear (CCEN). This drilling was targeting uranium mineralisation, but later assaying revealed significant intersections with Cu-Au mineralisation (Maus, 1997a). Later, General Minerals Corporation (GMC) completed an initial phase of eight percussion drill holes close to the Productora and Santa Innes mines. This totalled 1607 m of drilling along an 800 m strike length. The intersected mineralisation was typically 30 to 70 m thick and averaged 0.3 to 0.6 % Cu with elevated quantities of Au, Mo, Co, U, and REE's.

Descriptions of reflected light and scanning electron microprobe studies of rock chips collected from the GMC percussion drilling at Productora were presented by Osterman (1997, 1998), who also noted the presence of the uranium oxide mineral torbernite as well as some tourmaline breccias and stockworks. Later, 1:10 000 and 1:5000 geological mapping and sampling was completed over a 40 km^2 area (Ray, 1997a, 1998 a and b, 2001; Arcos, 1998). In addition, more detailed work was undertaken in the field and at the Colorado School of Mines (Fox, 2000). The latter work included U-Pb and K-Ar radiometric dating of the intrusions and the potassic alteration, as well as some sulphur isotope studies.

Regional Setting

The geology of the region includes a generally poorly exposed Paleozoic basement overlain by Mesozoic and Cenozoic volcanic and sedimentary sequences. Jurassic and younger deposition comprised mainly calc-alkaline andesitic lavas and flow breccias with some continental clastic sediments (Aguirre et al., 1974; Clarke et al., 1976), laid down in a continental margin, back-arc environment (Coira et al., 1982). The Andean Orogeny commenced during the early Jurassic (Clark et al., 1976), and the subsequent volcanism and plutonism moved progressively eastwards with time. Jurassic plutons occur along the coast, whereas Cretaceous and younger plutons outcrop further east. Compressional deformation in the region resulted in large amplitude folds, but it was generally subordinate to extensional movements that resulted in abundant normal faulting, accompanied by doming and the emplacement of some plutons (Jordan et al., 1983). The four main geological elements of Cretaceous age in the Productora-Candelaria region include the Chanarcillo back-arc basin marine carbonates in the east, the Bandurrias volcanic arc in the central part of the region, and the Coastal batholith and Atacama Fault Zone to the west (Marschik, 1996; Fox, 2000).

Geology of the Productora Area

Introduction

Most of the mapped area illustrated in Figure 3 is underlain by a gentle to moderately inclined stratigraphic package of andesitic to dacitic tuffs that are interpreted to have been deposited in a sub-aerial to shallow aqueous environment. In addition, there are some mafic volcanic flows, bedded tuffaceous siltstone, volcanic sandstone, and very rare examples of thin (<15 m thick) impure limestones. The precise age of the Productora rocks is unknown due to a lack of fossil and radiometric data. Fox (2000) suggests they may belong to the Jurassic-Lower Cretaceous age Bandurrias Formation; an alternative possibility is that the package at Productora represents part of the pre-late Valanginian Punta del Cobre Formation which hosts the Candelaria deposit further north (Marschik et al., 2000; Figure 1).

A north to south facies change is recognised along the Productora belt. In the northern part of the area and north of the Productora Fault (Figure 3), volcanic flows are rare and the sequence mainly comprises ash and lapilli tuffs with minor volcanic breccias. South of the fault, however, the tuff package includes an extensive flow unit of massive andesite-basalt. The unit is economically important because it forms a comparatively impermeable cap whose base, together with the immediately underlying tuffaceous rocks, have been the locus of intense hydrothermal alteration with the local development of Fe oxide-Cu-Au mineralisation.

The following bottom-to-top stratigraphic succession is recognised south of the Productora Fault (Figure 3):

1. a lower unit of ash flows and lapilli tuffs of andesitic to dacitic composition (Dick and Ray, 2000; Fox, 2000) which is estimated to be >500 m thick.
2. a middle unit of widespread basaltic to andesitic flows that reaches 220 m in thickness (Ray, 2001).
3. a thin upper tuffaceous unit that generally occurs as minor erosional remnants along the Eastern Ridge (Figures 2 and 3).

Lower Tuffs

The lowest part of the sequence comprises dacitic and andesitic ash and lapilli tuffs, some volcaniclastic debris flows and a 100 m thick unit of devitrified welded tuff (Fox, 2000). These lower permeable rocks host most of the magnetite and Cu-Au mineralisation in the belt, including that present at the Productora, Monseratt and Santa Innes mines and the Remolina pit (Figure 3). Most tuffs are massive, poorly to moderately sorted and lack grading. Rounded, water-worn lapilli are present but layering and sedimentary bedding are uncommon except in the finer grained ash tuffs or in the tuffaceous siltstones. In some lapilli tuffs the elongated clasts possess an alignment that records a crude layering. Many tuffaceous outcrops also display a well marked sub horizontal to gently dipping parting that may mimic original depositional layering in the tuffs. This parting is widespread and is well developed, for example, at the Productora Mine. Most tuffs display some degree of hydrothermal or thermal alteration. The fine grained ground mass contains crystals of K-feldspar and albite-oligoclase plagioclase with lesser amounts of glassy quartz, highly altered amphibole and minor pyroxene. In the dacitic tuffs, rounded to broken crystals of glassy quartz are a variable but widespread feature. The quartz crystals reach 5 mm in diameter and contain prominent bands of fluid inclusions and delicately embayed margins. The quartz crystals in many of the more silicified tuffs are characterised by ragged and thin overgrowths of secondary silica.

The heterolithic lapilli tuffs contain angular to well rounded clasts of volcanic and tuffaceous rocks. The lapilli include dark coloured feldspar porphyritic basalts and andesites, pale flow banded rhyodacites, and fragments of either mafic or quartz-bearing felsic tuffs. Also present are rare fragments of massive silica, bedded sediments and felsic intrusive rocks. Some mafic tuffs contain up to 10% amphibole and lesser augite that are extensively replaced by epidote and pale to dark green chlorite. Accessory minerals include zircon, zoisite, sericite and traces of apatite.

Middle Unit of Mafic Flows

The lower tuffs are overlain by the widespread unit of dark, mafic andesite-basalt that predominates in the southern part of the area (Figure 3). To the west, underlying the Silica Ridges (Figures 2 and 3) there is an extensive, thin unit of hydrothermally altered, Fe-rich basalts that may be part of the same flow unit. This generally massive volcanic unit includes equigranular and porphyritic types. The latter contain plagioclase phenocrysts up to 0.5 cm in length with smaller crystals of hornblende, pyroxene and olivine (Fox, 2000) in a highly chloritised and epidotised groundmass. Close to some presumed original volcanic feeder fissures, there are flow breccias containing clasts of intrusive felsic quartz diorite and monzonite up to 0.3 m in diameter (Ray, 1998b). Analyses indicate the volcanic flow rocks are sub-alkaline and calc-alkaline, being of basalt-andesite composition (Dick and Ray, 2000).

Upper Tuffs

These represent the uppermost sequence seen in the area. Along the Eastern Ridge (Figures 2 and 3) they occur as small remnants on the hilltops where they comprises fine grained ash tuffs and tuffaceous sediments. South and west of the Quebrada Escondido Fault, however, they pass laterally into heterolithic lapilli tuffs and very coarse grained volcanic breccias.

Intrusive Rocks

Two major intrusive phases are recognised. The youngest and least altered of these is the Ruta 5 Batholith, a small portion of which outcrops in the south-east part of the area

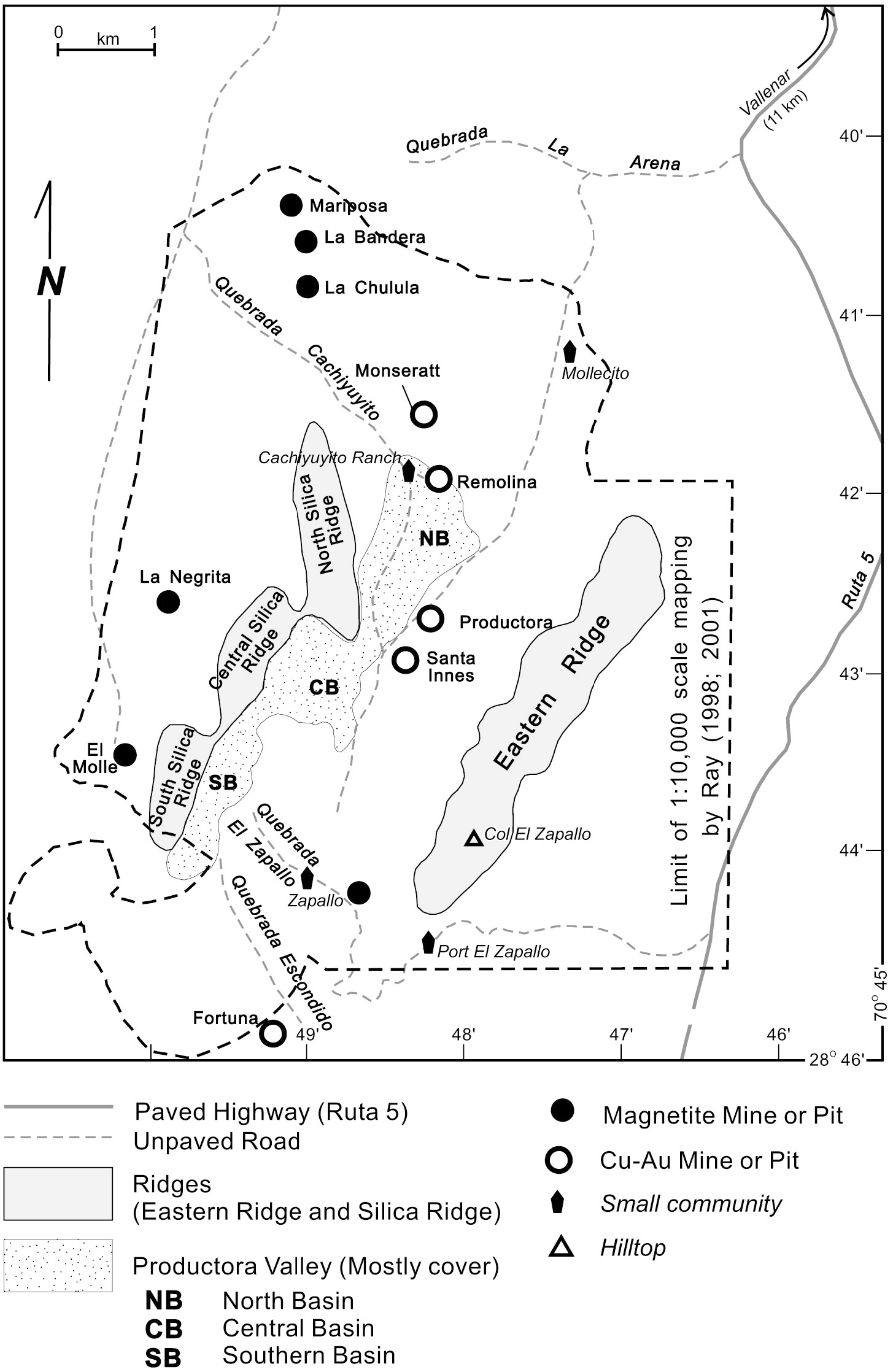


Figure 2: Location of mines, roads and main topographic features in the Productora area, Chile.

(Figure 3). It is medium to coarse grained, equigranular and leucocratic body with a biotite-dominant granodiorite-quartz monzonite core and a mafic, hornblende-rich border phase. The batholith has been dated by U-Pb zircon methods at 96.1 Ma (Fox, 2000). It is cut by swarms of Au-bearing quartz ± barite veins. These veins trend NNW to NW and some are still being mined on a small scale for their Au. Locally, the batholith is strongly supergene kaolin-altered but it post-dates the Productora Fe oxide-Cu-Au-REE-U mineralisation and the associated Na-K-Si alteration. The contact aureole includes a biotite ± garnet ± cordierite hornfels, a wide zone of epidote alteration (Figure 4), and several small Cu-bearing skarn occurrences (Ray, 1998b).

The older intrusive phase was responsible for the El Molle, Zapallo and Cachiyuyito stocks (Figure 3). It pre-dates the Fe oxide-Cu-Au-U-REE mineralisation and Na-K-Si alteration but is believed to be genetically related to the Productora hydrothermal system. Fox (2000) reports a U-Pb zircon age of 129.8 Ma for the Cachiyuyito Stock which is somewhat older than the 114-116 Ma ages determined for the Candelaria Fe-oxide mineralisation further north (Marschik et al., 2000).

Chemical analyses and various plots for the Cachiyuyito Stock are shown in Table 1 and Figure 5. The stock is sub-alkaline, meta-aluminous and calc-alkaline and its Rb, Y and Nb contents indicate it represents a "volcanic arc" granitoid as defined by Pearce et al (1984). Plots also suggest a tonalite-quartz diorite composition although this conclusion must be treated with caution due to the intense secondary albitisation and local silicification. The stocks are leucocratic, equigranular to weakly porphyritic and medium to coarse grained. Primary and secondary plagioclase totals between 60 and 90% of the rock, with hornblende, pyroxene and quartz generally comprising < 10%. Accessory minerals include zircon, apatite, carbonate, zoisite, ilmenite and late K-spar.

Intense hydrothermal alteration in these older stocks is ubiquitous, both as pervasive albitisation and veins of actinolite, epidote, chlorite and magnetite (Figure 6C and I). Rarely, veins of tourmaline or quartz are seen. The adjacent country rocks are overprinted by pervasive actinolite-chlorite-albite alteration with numerous magnetite ± apatite veins but no contact metamorphic hornfels aureole is recognised.

Geological and structural history

The geological history for the Productora area is believed to be:

1. Deposition of Early Cretaceous flows and tuffs in a shallow aqueous to subaerial, volcanic back-arc environment. Locally, the volcanism and sedimentation was controlled by intersecting sets of N and NW-trending structures related to the Atacama Fault system.
2. Early Cretaceous (c. 130 Ma) emplacement of the Cachiyuyito, El Molle and Zapallo stocks, closely followed by
3. Formation of the Productora Fe oxide-Cu-Au-U-REE-apatite hydrothermal system which was controlled on an outcrop scale by NW and N-trending structures (Figure 6A, B and J), as well as stratigraphic host-rock permeability.
4. Ductile movements resulting in the formation of several narrow N-striking quartz-sericite schist zones followed by normal down-faulting (Figure 3).
5. Late Cretaceous (c. 96 Ma) intrusion of the Ruta 5 Batholith and subsequent development of NW trending Au-bearing quartz ± barite veins.
6. Multiphase brittle minor movement along the sets of N and NW trending structures. This late movement along the cross-faults resulted in right lateral offset of the original lithologies and mineralisation.

No major folds have been identified in the area apart from drag structures adjacent to some major faults. However, the stratigraphy is complicated by abrupt volcanic facies changes and later brittle faulting. Two sets of fractures are recognised, a generally N to NNE-striking set and a more dominant NW trending cross-set (Figure 7). On a local scale, both sets have controlled the veins of Fe oxide-Cu-Au, feldspar, silica, actinolite and tourmaline, although the NW-trending fractures are more abundant (Figure 7).

The north-trending, steeply dipping structures, including the Quebrada Verde and Quebrada Mollecito faults (Figure 3), are probably related to the main Atacama Fault Zone which is believed to lie 10 km further west. These older faults have undergone both vertical and sinistral sub-horizontal recurrent movements, and have controlled the intrusion of the elongate Cachiyuyito and El Molle stocks and some of the Fe oxide-Cu-Au-REE mineralisation.

The area is also cut by swarms of NW-trending, steep-dipping cross structures, including the Rancho and Productora faults (Figures 3 and 6A and B). Offset of the stratigraphy, the stocks and the hydrothermal alteration, together with sub-horizontal slickensides show that the latest movements along these cross structures were right lateral. However, these faults have had a long history and locally have had important controls on the Fe oxide-Cu-Au mineralisation and its associated alteration (Figure 7). Mapping (Ray, 1998a and b) also suggests that the Productora Fault was a precursor fissure for some of the extrusive volcanism in the area. Thus, some of the older cross structures are probably Cretaceous in age.

The El Molle Stock is thought to be a SSW strike extension of the Cachiyuyito body (Dick and Ray, 2000). However, the stocks have been separated from each other by an elongate, 1.5 km wide down-faulted block of intensely silicified ± kaolin ± specular hematite ± dumortierite-bearing rocks (Figures 3 and 4; Dick and Ray, 2000). Two narrow (< 70 m), north-trending zones of quartz-sericite schist mark the eastern and western margins of the block. Most movement along the schist zones postdates the hydrothermal silicification in the adjacent rocks, and the eastern schist obliquely truncates the Cachiyuyito Stock and the Quebrada Verde Fault (Figures 3 and 4).

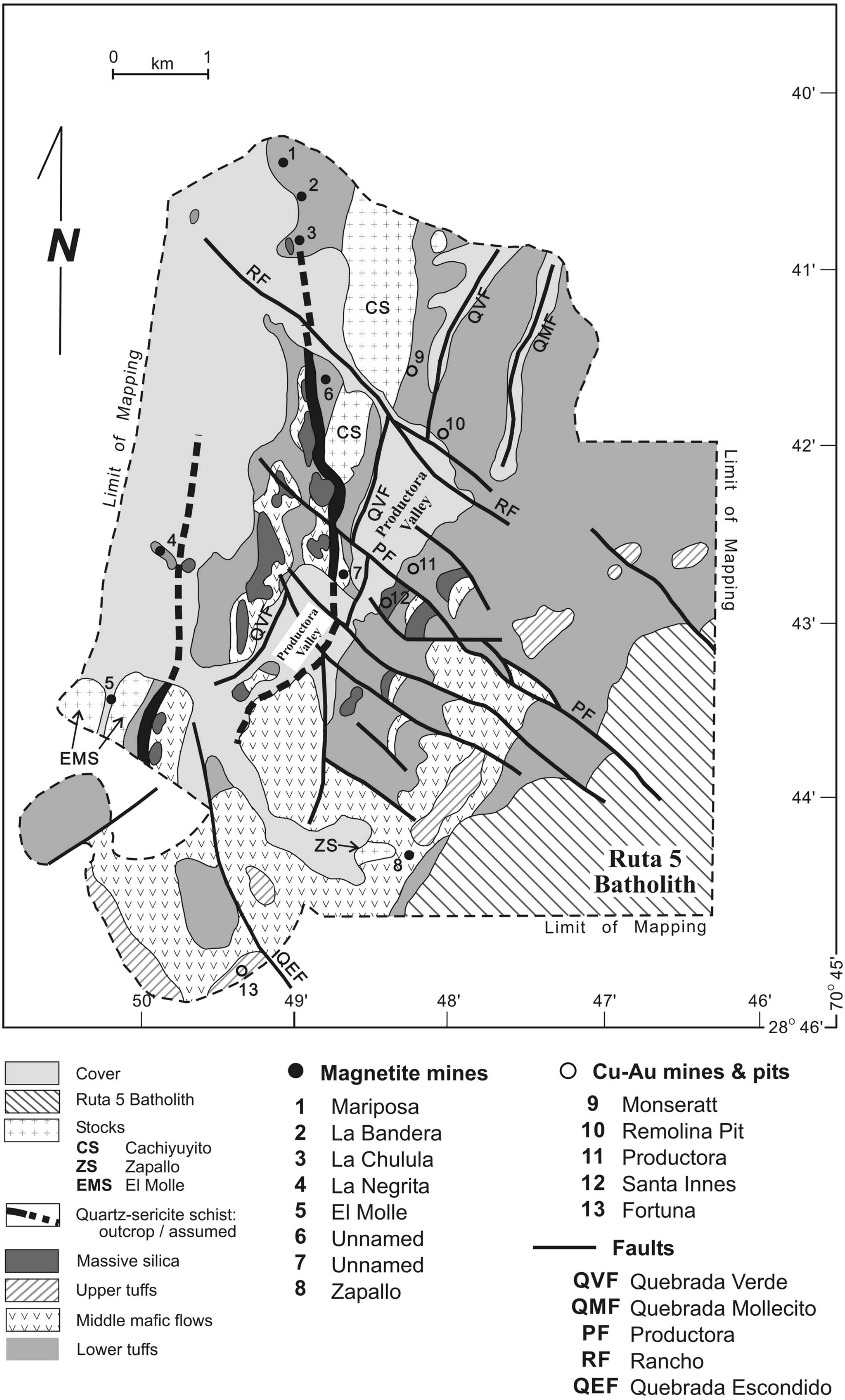


Figure 3: Geology of the Productora Prospect and location of the principal Fe oxide and Cu-Au workings.

Economic Geology

Introduction

Past small-scale metal mining in the Productora area has mainly been carried out on:

1. Gold in late quartz ± barite veins that cut the 96 Ma Ruta 5 Batholith and its adjoining hornfelsed country rocks.
2. Placer Au derived from the above quartz veins.
3. Magnetite in lenses, pods or veins, commonly associated with actinolite ± apatite, as seen at the Mariposa, La Bandera, La Chulula, La Negrita and El Molle Fe mines (Figure 3).
4. Copper-gold mining from Fe oxide-Cu ±Au ±U ±REE mineralisation. Most of this was extracted from secondary Cu oxide ore (Figure 6J) with lesser amounts of hypogene Cu-sulfide material. This mineralisation occurs along vertical structures or, less commonly, as small stratiform replacements and is seen at the Monseratt, Productora, Fortuna and Santa Innes mines and the Remolina pit (Figure 3).

Numbers 1 and 2 above are probably directly or indirectly related to the Ruta 5 Batholith whereas numbers 3 and 4 belong to the older Productora hydrothermal system.

Alteration

The Productora area is marked by an elongate zone of hydrothermal alteration that is > 3 km wide and > 8 km in semi-continuous strike length (Figure 4). Virtually all the tuffs and many of the volcanic flows along the belt show varying degrees of alteration that involved the introduction of large volumes of Fe, Si, Na and K. Alteration occurs either in veins, disseminations or as pervasive, selective replacements, and is locally so intense that the nature of the original lithology is uncertain. Where alteration is less strong, lapilli in the tuffs may be rimmed by halos of either albite, silica or K-feldspar (Figure 6O), and the lapilli fragments partially or totally replaced by various silicates (including tourmaline) or Fe-oxides (Figure 6E and G).
The alteration mineral assemblages include albite, K-feldspar, specular and non-specular hematite, tourmaline, chlorite, actinolite, magnetite and apatite, together with extensive developments of massive silica and numerous Cu-Au ± REE ± U occurrences. Dumortierite (Figure 6H) and secondary biotite are sporadically developed, as well as some minor jasper veining. In addition, REE-enriched allanite has been identified with some of the Cu-Au mineralisation (Osterman, 1997). Adjacent to some massive silica zones, the alteration is characterised by veins, up to 5 cm wide, of massive bright green sericite-muscovite. Areas with strong supergene alteration include abundant disseminated kaolin (some of which has been mined) and rare veins of alunite.

Various paragenetic sequences of mineral alteration occur in different parts of the area which reflect the diachronous development of the Productora hydrothermal system. However, the overall mineral paragenesis suggests the system involved the early introduction of Na, followed in turn by K, Si, Fe and B. It ended with widespread Fe and Si metasomatism. The general mineral paragenesis is:

(1) albite, (2) K-spar (3) pervasive silica (4) tourmaline (5) magnetite and/or actinolite (6) specular hematite (7) chlorite and/or epidote (8) jasper veins, and (9) late hematite veins.

The Cu-Au-REE mineralisation was either syn or immediately post the chlorite event (No. 7 above). It postdates the magnetite which accounts for the poor spatial relationship between magnetite and Cu-Au throughout the area.

Alteration Zoning

The hydrothermal alteration along the belt can be broadly separated into extensive zones of higher temperature, prograde assemblages (albite, K-spar, tourmaline and some early magnetite), and more restricted areas with lower temperature retrograde assemblages marked by actinolite, chlorite, epidote, hydrothermal biotite, sericite and some late magnetite-hematite. Development of massive silica was protracted and took place as prograde and retrograde events. The pyrite-chalcopyrite mineralisation is temporally and often spatially associated with the retrograde Fe-Mg assemblages.

The prograde alteration appears to be centred and zoned around the Cachiyuyito-age stocks (Figure 4), which suggests that these intrusions and the Productora hydrothermal system are related. However, while some of the retrograde alteration (eg. actinolite, chlorite and late magnetite) is centred around the stocks, most of the better Cu sulphides mineralisation found to date is not. Copper mineralisation appears to be best associated with K-spar ± tourmaline prograde alteration and mainly lies along a N-trending zone that can be discontinuously traced along the east side of the Productora valley (Figure 4).

The intensity and nature of the prograde and retrograde alteration assemblages throughout the belt were strongly influenced by a number of factors including:

1. the presence of controlling NW and, to a lesser extent, N to NNE-trending faults,
2. distance from either the structural conduits or the stocks, and
3. the composition and permeability of the original host-rocks. Mafic volcanics and tuffs, tend to produce epidote-chlorite-actinolite-rich assemblages while the Fe-poor dacitic tuffs tend to be more readily overprinted by albite, K-spar and silica alteration.

Most of the prograde and retrograde alteration along the belt appears to follow the original, gently dipping stratigraphy, which suggests that rock permeability was an overall important controlling factor. This is seen, for example, along the Silica Ridges (Figure 2) where fluids have passed selectively along certain permeable tuffaceous horizons to produce thick, gently dipping zones of massive silica. Elsewhere, however, alteration crosscuts the stratigraphy at a high angle, probably due to the influence of steeply dipping structural conduits.

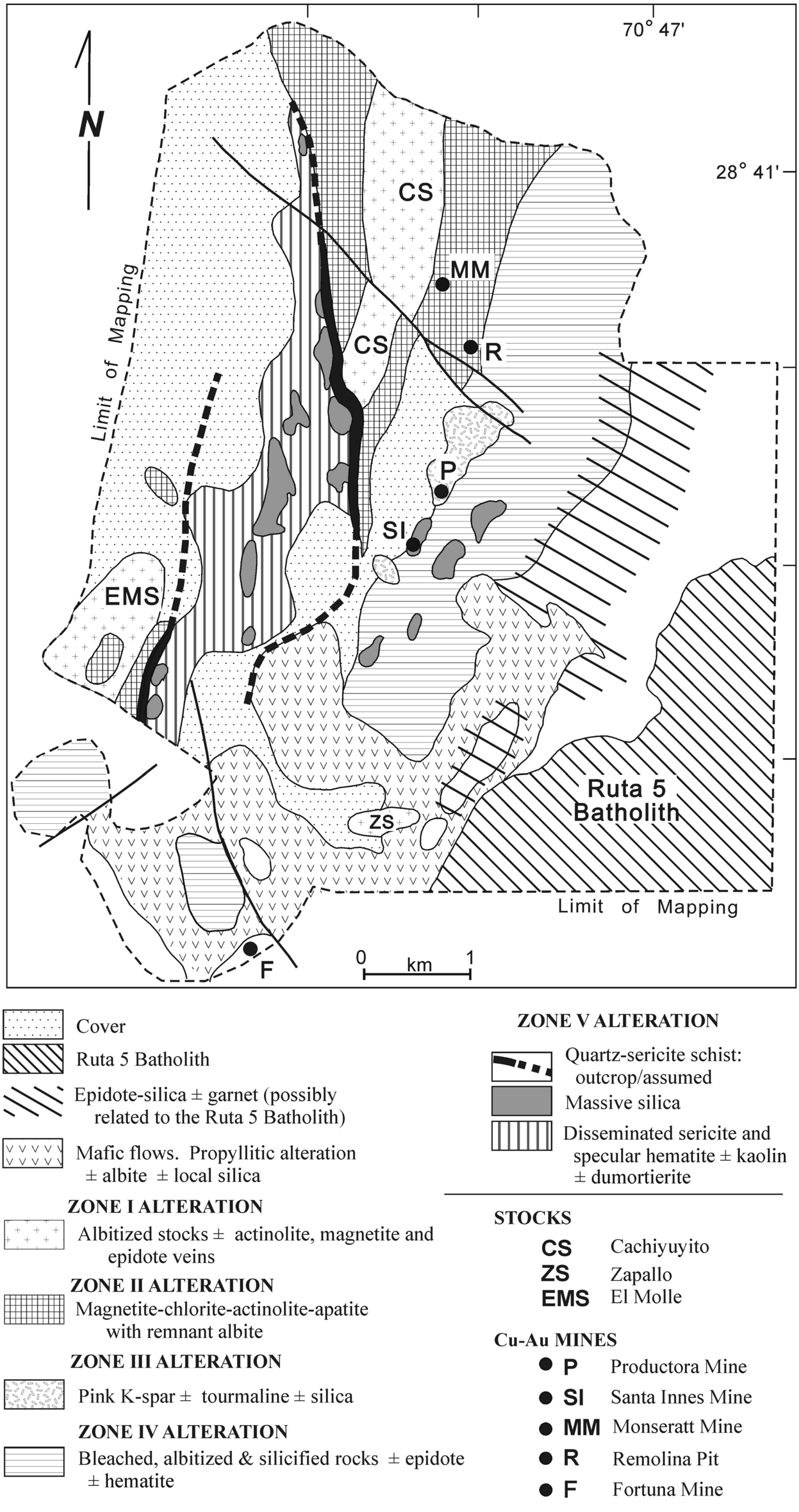


Figure 4: Distribution of hydrothermal alteration on the Productora Prospect

Table 1: Major and trace element data of altered plutonic & tuffaceous rocks, Productora

	CACHIYUYITO STOCK (Zone I-type alteration)						Zone III-type alteration				Zone IV-type alteration					
Sample No.	GR 15	GR102	GR103	GR105	GR106	GR123	71416	71417	71421	71422	GR159	GR 232	GR244	71411	71414	71415
SiO_2	59.04	71.04	73.83	66.98	60.74	64.47	69.29	66.84	69.02	65.34	74.43	68.89	74.54	70.15	75.64	74.75
$Al2O_3$	17.32	15.27	13.99	18.19	15.61	17.23	12.87	12.85	12.03	12.38	13.69	17.46	13.80	13.81	13.29	13.37
$Fe2O_3$	3.34	1.51	1.70	2.03	4.35	3.45	2.12	4.11	2.91	5.25	1.72	1.13	1.19	1.07	0.55	0.95
MgO	3.50	0.79	0.57	0.27	2.90	2.22	0.73	0.67	0.57	3.08	0.53	0.30	0.25	0.19	0.19	0.18
CaO	7.06	2.85	1.48	3.52	7.41	2.23	0.54	0.28	1.9	2.24	0.34	0.65	0.50	2.34	0.37	0.43
Na_2O	5.61	5.81	6.66	5.49	4.09	7.39	0.41	0.34	2.25	2.41	7.06	9.13	6.88	8.02	7.52	7.7
K_2O	1.34	0.82	0.26	1.04	2.56	0.97	11.51	12.9	7.9	5.64	0.37	0.60	0.45	0.54	0.89	0.37
TiO_2	1.14	0.67	0.35	1.23	1.03	0.53	0.32	0.34	0.37	0.54	0.29	0.41	0.29	0.51	0.29	0.51
P_2O_5	0.04	0.05	0.06	0.01	0.17	0.02	0.21	< .01	0.07	0.14	0.12	0.12	0.12	0.13	0.05	0.05
MnO	0.14	0.04	0.02	0.07	0.11	0.10	0.02	0.02	0.03	0.06	0.02	0.01	0.01	0.1	0.01	0.02
LOI	1.80	1.20	1.00	1.40	1.20	1.60	1.40	1.10	2.30	2.30	1.30	1.30	1.60	2.60	1.10	1.60
S	0.15	0.08	0.01	0.04	0.02	0.03	0.04	0.02	0.86	0.08	0.01	0.01	0.01	< .01	< .01	0.04
Sum	100.48	100.13	99.93	100.27	100.19	100.24	99.46	99.47	100.21	99.46	99.88	100.01	99.64	99.46	99.90	99.97
Total alk	6.95	6.63	6.92	6.53	6.65	8.36	11.92	13.24	10.15	8.05	7.43	9.73	7.33	8.56	8.41	8.07
Na/K	4.19	7.09	25.62	5.28	1.60	7.62	0.04	0.03	0.28	0.43	19.08	15.22	15.29	14.85	8.45	20.81
Ba	117	59	15	144	527	71	1260	1279	1537	805	47	45	157	45	112	86
Ni	20	25	28	24	25	22	NA	NA	NA	NA	24	20	34	NA	NA	NA
Zr	126	275	139	261	173	123	125	106	103	121	117	178	127	168	131	115
Y	20	12	13	10	27	10	11	6	16	28	10	12	17	39	11	16
Sc	22	12	10	10	16	10	10	4	5	9	10	10	10	8	6	7
Nb	2	4	3	6	5	2	3	5	6	6	3	4	5	10	5	4
Rb	30	10	1	12	46	14	NA	NA	NA	NA	8	10	10	NA	NA	NA
La	4	6	12	2	3	3	NA	NA	NA	NA	23	1	11	NA	NA	NA
Cr	31	71	51	34	65	24	NA	NA	NA	NA	116	61	127	NA	NA	NA
V	18	29	32	15	77	23	NA	NA	NA	NA	17	10	11	NA	NA	NA
Th	2	26	20	2	10	6	NA	NA	NA	NA	5	7	6	NA	NA	NA
Sr	33	21	16	24	36	10	64	65	70	79	5	6	13	29	23	27

	CACHIYUYITO STOCK (Zone I-type alteration)
GR 15	Porphyritic tonalite with actinolite veins
GR102	Feldspathic & silicified diorite-tonalite
GR103	Feldspathic & silicified hornblende tonalite
GR105	Feldspathic hornblende-quartz bearing tonalite
GR106	Hornblende-quartz bearing diorite with minor late K-spar
GR123	Feldpathic, hornblende bearing tonalite
	Zone III-type alteration (K spar-silica-tourmaline)
71416	K spar-silica-tourmaline altered tuff, NNE of Productora Mine, UTM 323975; 6823035
71417	K spar-silica-tourmaline altered tuff, NNE of Productora Mine, UTM 323958; 6823071
71421	K spar altered tuffs, hole PR 24 @ 210-212m, UTM 323887; 6823105
71422	K spar altered tuffs, hole PR 24 @ 138-140m, UTM 323887; 6823105
	Zone IV-type alteration (albite-silica)
GR159	White, albitized & silicified tuffs, north Productora Basin
GR 232	Albitized dacitic tuff west of Cachiyuyito Ranch
GR 244	Silicified & albitized dacitic tuff, Productora Mine trench
71411	Silicified & albitized tuff, NNW of Zapallo, UTM 334055; 6900566
71414	Albite-silica altered dacitic lapilli tuff, NNE of Productora Mine, UTM 324144; 6822956
71415	Albite-silica altered dacitic lapilli tuff, NNE of Productora Mine, UTM 323983; 6822844

Analyses at ACME Analytical Laboratories, Santiago, Chile.
Major elements by XRF, minor elements by ICP.
Major elements in percent; trace elements in ppm.
NA = elements not determined.

Six proximal to distal zones of mineral alteration are recognised together with at least three different styles of mineralisation (Figure 8). The mineralogy and width of individual alteration zones reflect depth and proximity to the Cachiyuyito-type stocks as well as the composition and pervasive character of the original host-rocks. The mineral zoning is as follows (Figures 4 and 8):

Zone I is represented by the pervasively albitised Cachiyuyito-type stocks with veins of actinolite, quartz, epidote and magnetite (Figure 6C and I).

Zone II includes pervasive early albitisation, overprinted by actinolite-rich alteration with magnetite ± apatite ± actinolite veins and breccias (Figure 6K and L), together with abundant retrograde epidote, chlorite and coarse crystalline calcite veining. This is best seen adjacent to the Cachiyuyito and El Molle stocks. It hosts a number of magnetite occurrences, including the La Negrita, La Mariposa, La Bandera and La Chulula magnetite mines (Figure 3).

Zone III is characterised by pervasive pink K-feldspar and tourmaline ± pervasive silica ± veins of magnetite-hematite. This alteration occurs with local retrograde epidote-chlorite, secondary biotite and Fe and Cu sulphides. It outcrops as a belt along the east side of the Productora valley (Figure 4), and is characterised by low Na/K ratios (<0.43; Table 1), numerous Cu ± Au ± U ± REE occurrences, and hosts the Productora and Santa Innes mines mineralisation. Although

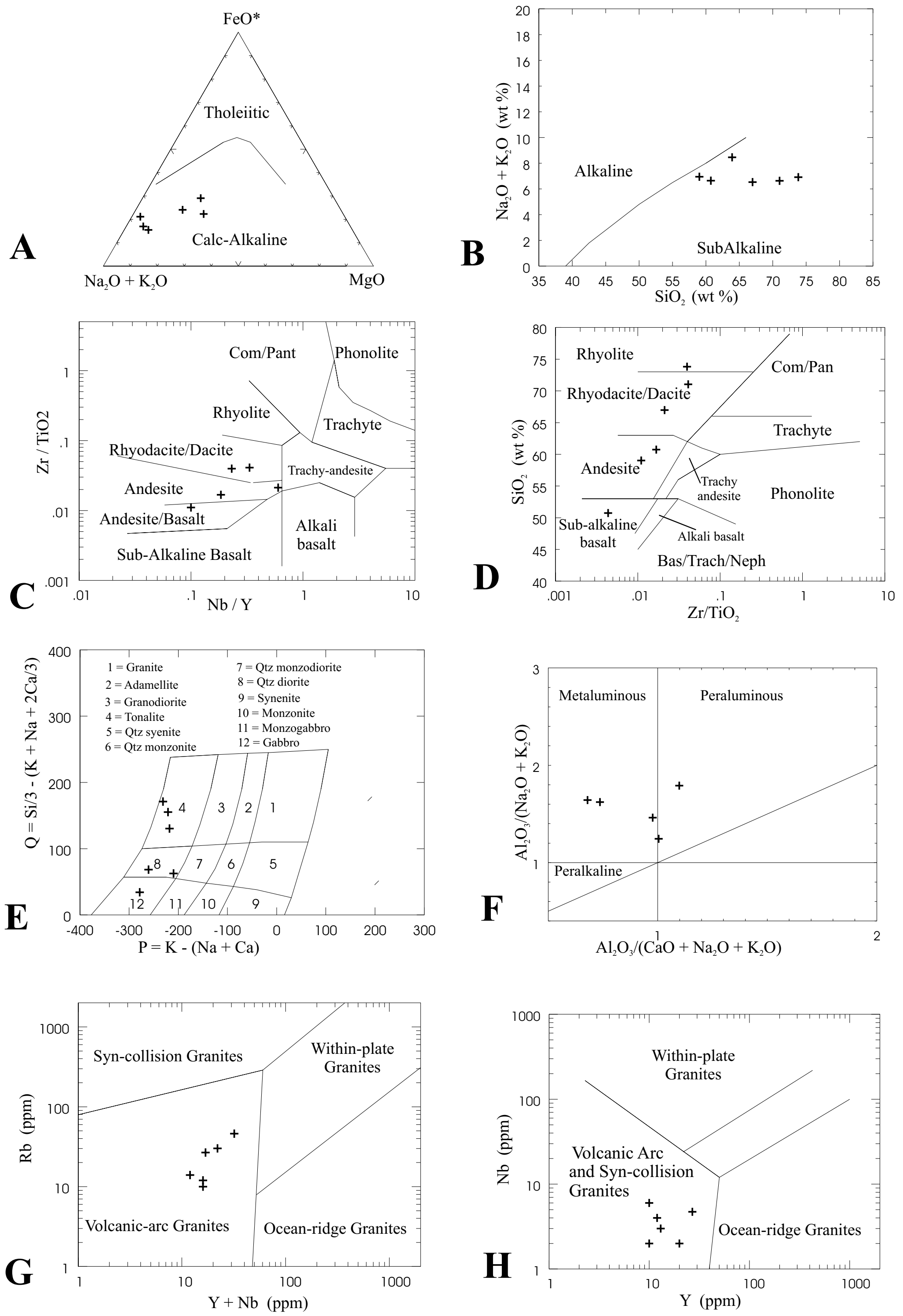


Figure 5: Major and trace element plots of the Cachiyuyito Stock (data from Table 1)

A & B: AFM & alkali-silica plot (after Irvine and Baragar 1971).
C: Zr/TiO_2 versus Nb/Y discrimination plot (after Winchester & Floyd, 1977).
D: SiO_2 versus Zr/TiO_2 discrimination plot (after Winchester & Floyd, 1977).
E: Q - P plot (after Debon and Le Fort, 1983).
F: Aluminium saturation plot (after Maniar and Piccolli, 1989).
G: Log Rb versus Log Y+Nb tectonic discrimination plot (after Pearce et al., 1984).
H: Log Nb versus Log Y tectonic discrimination plot (after Pearce et al., 1984).

isolated and widespread veins of black tourmaline occur in Zones I and II, in Zone III assemblages the mineral may locally form > 50 % of the rock. Tourmaline occurs mostly in veins (Figure 6D and F), many of which are controlled by fractures related to the north and NW-trending fault sets. However, in Zone III tourmaline also occurs as disseminations, as selective replacements of lapilli and in breccias where fragments of silicified pink K-spar are enclosed in a matrix of massive black tourmaline (Figure 6E and F). Intense tourmaline alteration is always spatially associated with abundant pink K-spar, although the latter mineral is invariably older. There is also a tendency for Cu oxide showings to be more common in areas with intense tourmaline and K-spar alteration.

Zone IV is marked by intense bleaching because virtually all the primary mafic minerals have been removed and replaced by albite and silica ± epidote ± specular hematite (Figure 6G). The amount of epidote present depends on the original host-rocks; epidote is abundant (up to 10%) in the bleached middle unit basalts but is generally absent in the altered dacitic tuffs. This extensive alteration is seen on the slopes east of the Productora and Santa Innes mine, as well as in the south part of the belt (Figure 4). It is marked by high Na/K ratios (8-20; Table 1).

Zone V is characterised by replacement zones of massive pale coloured silica ± disseminated white sericite ± specular hematite ± pyrite ± green sericite-muscovite veins. Generally, the silicification is so strong that no original tuffaceous or sedimentary textures are recognisable, although in rare cases remnant bedding or layering are seen (Figure 6M). Where the narrow, N-trending quartz-sericite schist zones cut the silica alteration, sporadic veins of dumortierite and alunite are developed (Figure 6H). This higher-level alteration, which includes that present along the Silica Ridges, is best displayed in the 1.5 km-wide, down-faulted block that separates the El Molle and Cachiyuyito stocks (Figures 3 and 4). In surface outcrops, most of the original disseminated pyrite (Figure 6N) has been leached and replaced by hematite-jarosite.

Zone VI. Rocks in the very highest or most distal parts of the system are weakly to moderately bleached and propylitically altered with epidote, chlorite and sporadic silica, minor albite and rare veins of jasper. Lapilli in the tuffs may be haloed by pale rims of silica or albite alteration (Figure 6O). This outer propylitic zone hosts veins and small irregular mantos of massive magnetite and/or hematite (Figure 8) some of which contain anomalous amounts of Cu, Au, Zn, Pb, Ag, Co and Mn (Table 2).

Mineralisation

The following three styles of Fe-oxide dominant mineralisation are identified in the Productora area, each of which tends to occur in a specific alteration zone (Figure 8):

Style 1, which is the most proximal and common, is represented by magnetite veins and replacements associated with Zone II-type actinolite-chlorite-epidote ± apatite assemblages, as well as thin veins of coarse calcite. This style of mineralisation seldom contains significant Cu or Au values and examples include the Mariposa, La Bandera, La Chulula, La Negrita and the El Molle mines (Figure 3). Apatite may occur in fine disseminations, in pegmatite-like veins where it is intergrown with coarse grained actinolite, or in irregular breccia bodies where it forms brecciated fragments enclosed in a magnetite-actinolite matrix (Figure 6K and L).

Style 2 mineralisation is typified by the Cu-Au ± REE ± U occurrences seen at the Productora and Santa Innes mines (Figure 3). It appears to be more commonly associated with Zone III alteration (K-spar, silica and tourmaline) but in the case of the Monseratt Mine and Remolina pit it is hosted by Zone II mineral assemblages. It is dominated by secondary Cu minerals; malachite, chalcocite, chrysocolla, brochantite, tenorite and turquoise have been tentatively identified, and rare native Cu is reported. Hypogene mineralisation in the deeper pits and mines comprises disseminations and veinlets of chalcopyrite, some of which cut and post-date the pyrite (Fox, 2000). Microprobe studies (Osterman, 1997) recognised an association between chalcopyrite and allanite; the latter mineral contains up to several percent combined REE's (Ce, La, Nd, Pr, Sm, Yb and Gd). This study also noted that the chalcopyrite and chalcocite occur with variable amounts of pyrite, covellite, apatite and minute grains of molybdenite.

Chalcocite is common at the Monseratt and Productora mines; at the latter property it appears to form a blanket beneath a leached, argillised horizon that contains Cu and U oxides. Some chalcocite grains contain up to 5% Co but no cobalt minerals have been identified (Osterman, 1997). There are several generations of Au, including a very late supergene phase which overgrows coatings of black Cu-Mn oxides at the Productora Mine. Most of the near surface supergene and hypogene Cu mineralisation is fracture controlled, although in the deeper parts of the Productora and Monseratt mines some mineralisation is disseminated and stratiform.

The assay results of Style 2 mineralised grab samples from some of the Cu mines and pits in the area and examples of the Cu mineralisation intercepted by drilling are shown in Tables 2 and 3 respectively. Most of the Cu mineralisation contains between 200 and 600 ppb Au, although Au values up to 9.7 g/t Au are present locally. In the hypogene mineralisation a good correlation exists between Cu:Au, Cu:Co and Co:V. However, no positive relationship between Au and Cu is seen in the oxide ore. The Cu ±Au mineralisation is sporadically anomalous in Mo, Co, Zn, U, La and P (Table 2). The highest REE values occur in hypogene and supergene mineralisation at the Productora and Monseratt mines where samples containing up to 563 ppm La are recorded. There is also a good positive correlation between La:P, indicating that some of the REE's are held in the apatite. The U oxide, torbernite, occurs in veinlets but the low Th content of the mineralised rocks sampled (maximum 12 ppm) suggests that no primary U minerals are present.

Sulphur isotope ratios were determined for chalcopyrite, pyrite and chalcocite collected from Style 2-type mineralisation along the eastern margin of the Productora valley (Fox, 2000). The isotopic ratios for these minerals show a range of $\delta^{34}S$ values from -8.2 to +1.2 which is lower than values recorded for the Punta del Cobre region where they range from -0.7 to +1.1 (Marschik, 1996). At Productora, pyrite and chalcopyrite average -3.5 and -1.8 respectively, and Fox (2000) notes that the absence of isotopically heavy values suggests that the sulphur was not derived from an evaporitic source, as modelled for some other worldwide Fe oxide deposits (Barton and Johnson, 1996).

Style 3 mineralisation is developed in the propylitically altered, upper and outermost parts of the Productora hydrothermal system (Figure 8). It consists of generally small veins, irregular replacements and mantos dominated by massive magnetite and/or hematite that is commonly associated with epidote, albite and silica

Figure 6: Photographs showing various aspects of the Productora Prospect:

A: View looking south down the northern basin of the Productora valley. Note the locations of the Productora Mine and the north-trending Quebrada Verde Fault. This structure separates the basin from the Silica Ridge further west. The northwest-trending cross-structure, the Rancho Fault, is in foreground.

B: View looking north from the Productora Mine. The northern basin is bounded to the north and west respectively by the Rancho and Quebrada Verde faults. Note the ridge underlain by the Cachiyuyito Stock (CS) and the location of the Monseratt Mine (MM).

C: Zone I alteration. Magnetite veinlets cutting the altered Cachiyuyito Stock, 1.75 km north-northwest of the Productora Mine.

D: Zone III alteration. Narrow veins of black tourmaline cutting pink K-spar and silica altered tuffs. Located on the eastern edge of the northern Productora basin, approximately 800 m southeast of the Cachiyuyito Ranch (Figure 2).

E: Zone III alteration. Black tourmaline selectively replacing lapilli fragments in a K-spar and silicified lapilli tuff. Length of photo represents 45 cm. Located 330 m south-southwest of the Santa Innes Mine.

F: Zone III alteration. Intensely K-spar-altered and silicified pink tuffs, brecciated and cut by a black tourmaline vein. Located 330 m southwest of the Santa Innes Mine.

G: Zone IV alteration. Bleached, silicified and strongly albitized dacitic tuff with some lapilli selectively replaced by specular hematite. Located 950 m east of the Santa Innes Mine at UTM 324540E; 6822150N.

H: Zone V alteration. Massive silica cut by veins of blue dumortierite. Located on the south segment of Silica Ridge at UTM 321030E; 6821190N.

I: Zone I alteration. Albitized Cachiyuyito Stock cut by intersecting sets of dark actinolite veins, 1.75 km north-northwest of the Productora Mine.

J: Small-scale surface mining of Cu-oxides and phosphates along northwest-trending fractures that cut albitized and silicified tuffs. Note the seated figure in trench for scale. Workings lie south of the El Molle magnetite Mine at UTM 320785E-6820026N.

K: Zone II alteration. Apatite-magnetite breccia with rounded to angular clasts of pale apatite in a dark matrix of magnetite and minor hematite. Float from a small pit located north of the Rancho Fault at UTM 323994E-6824599N.

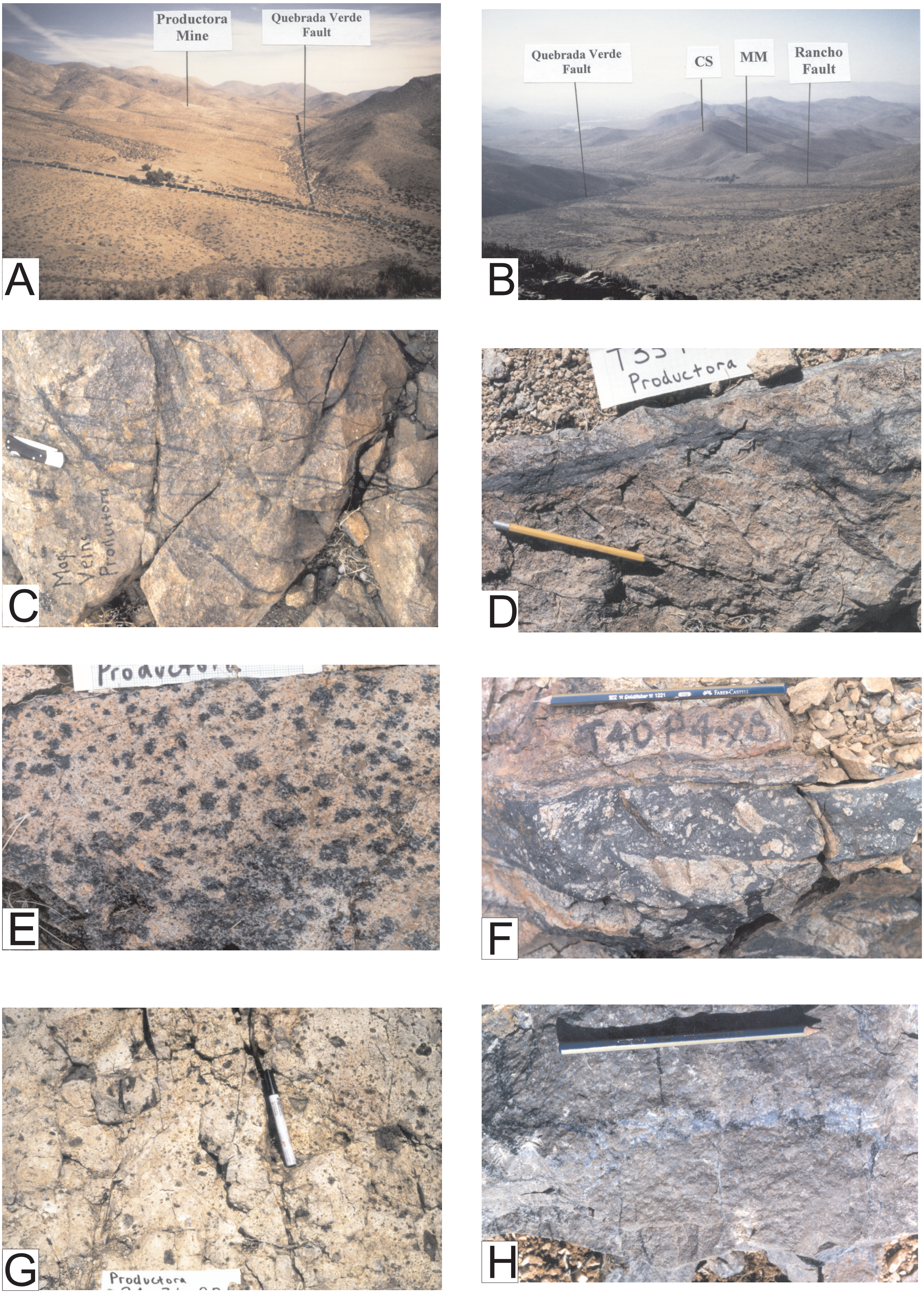
L: Zone II alteration. East-striking pegmatitic vein containing elongate crystals of dark actinolite and pale apatite that have grown normal to the vein margins. The 2 m-wide vein is located 950 m northeast of the Cachiyuyito Ranch (*see* Figure 2).

M: Zone V alteration. Massive pale silica showing remnant tuffaceous layering. Boulder float near the central segment of the Silica Ridge, UTM 322211E-6823137N.

N: Zone V alteration. Euhedral, coarse-grained crystals of pyrite in massive silica. Located on the north segment of Silica Ridge, 1.6 km NW of the Santa Innes Mine.

O: Zone VI alteration. Hydrothermally altered andesitic lapilli tuff and tuff breccia. Dark, angular to sub-angular clasts of andesite with pale alteration halos of silica and albite. Located on ridge southwest of Quebrada Escondido at UTM 321031E- 6818271N (*see* Figure 2).

P: Hematitic breccia containing pale silica-albite-altered clasts cemented by a dark, earthy hematite with sulphide boxwork. Located west of the Quebrada Escondido at UTM 320016E-6819354N (*see* Figure 2).



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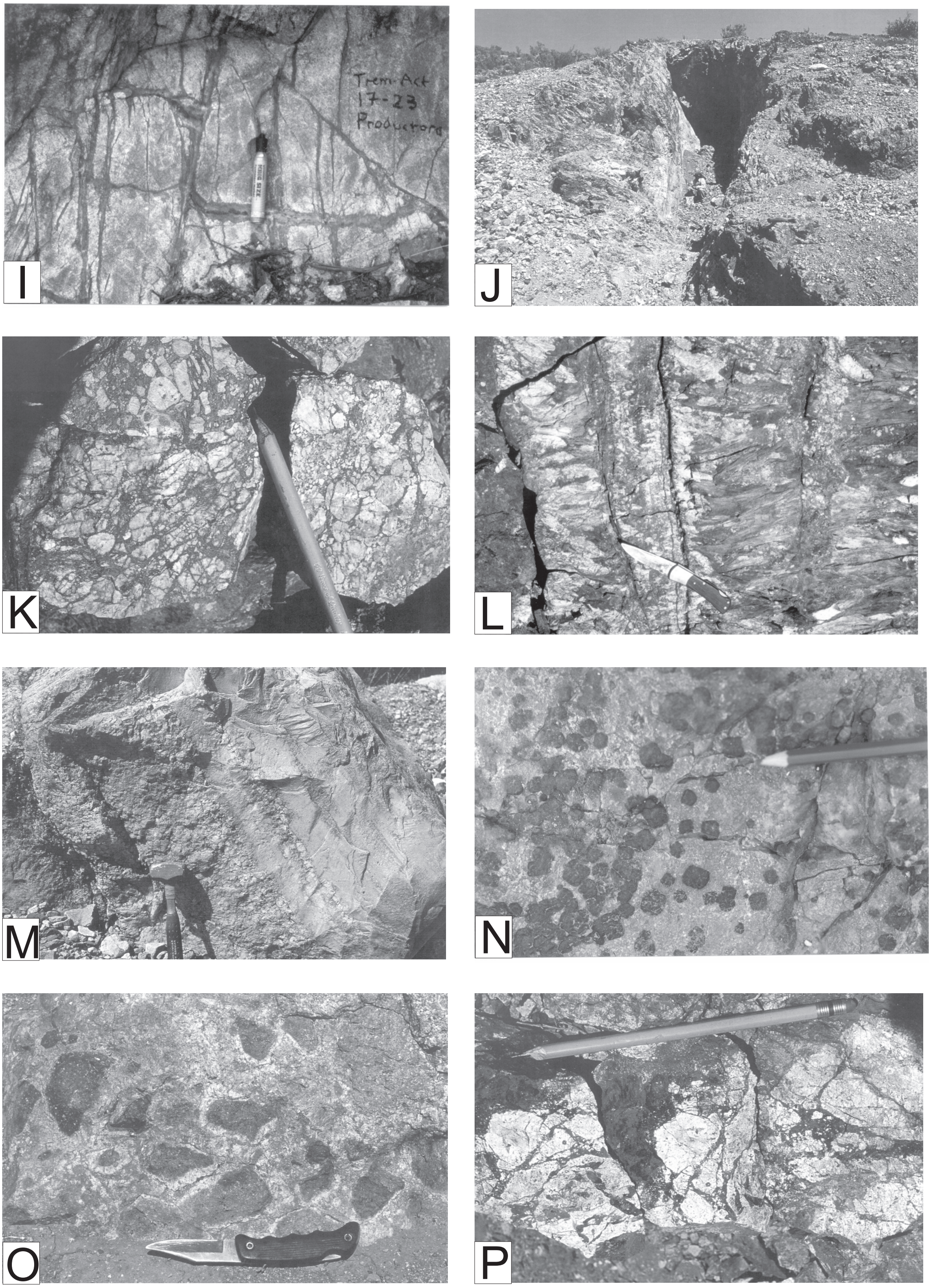

Figure 6: Continued from page 143. See caption on p. 142.

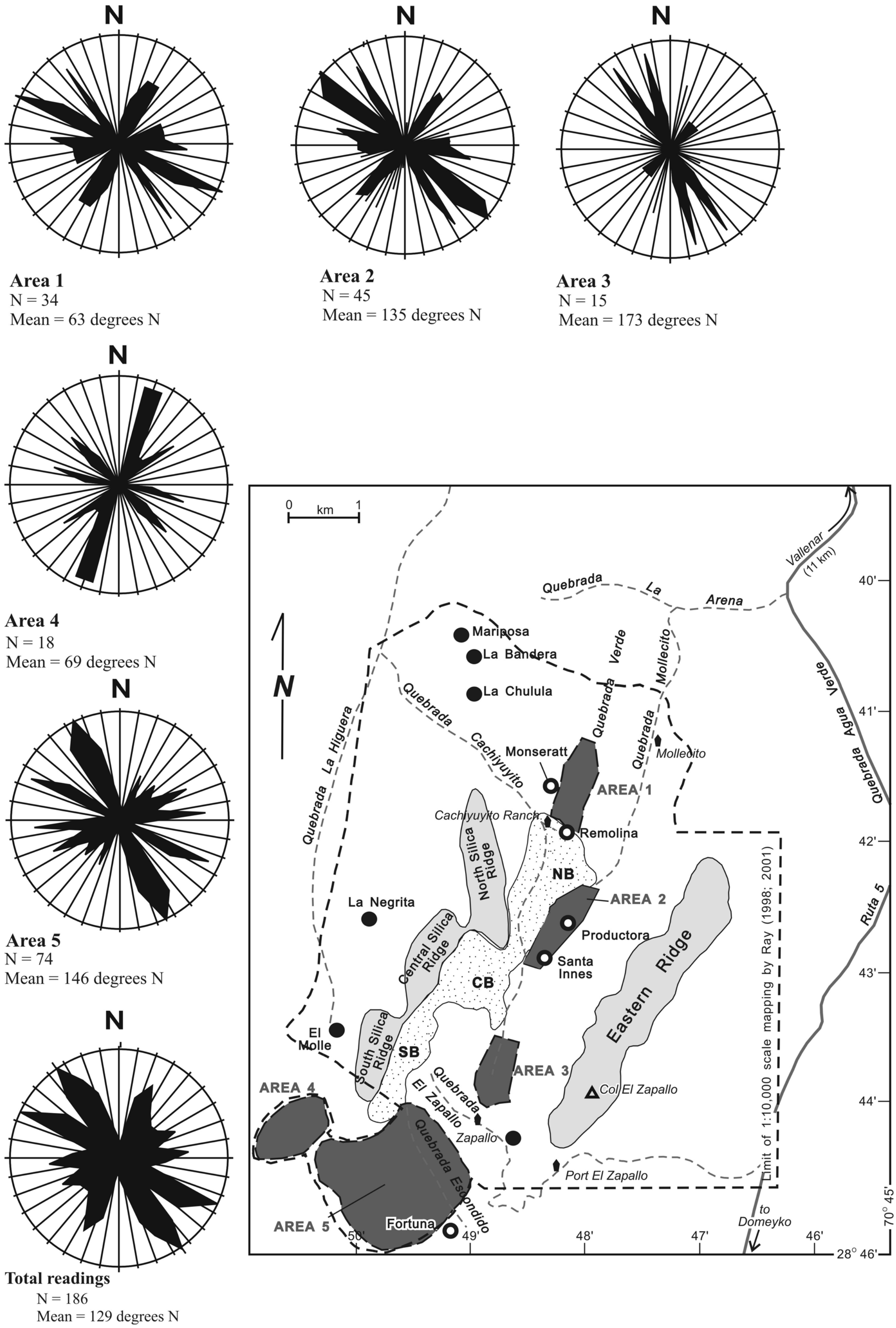

Figure 7: Rose diagrams showing the main strike of fractures controlling the Fe and/or Cu oxides, K spar, silica, actinolite or tourmaline veins in five parts of the Productora Prospect. Note the variations in vein orientation throughout the prospect and the abundance of the NW-trending vein set. See Figure 2 for map legend.

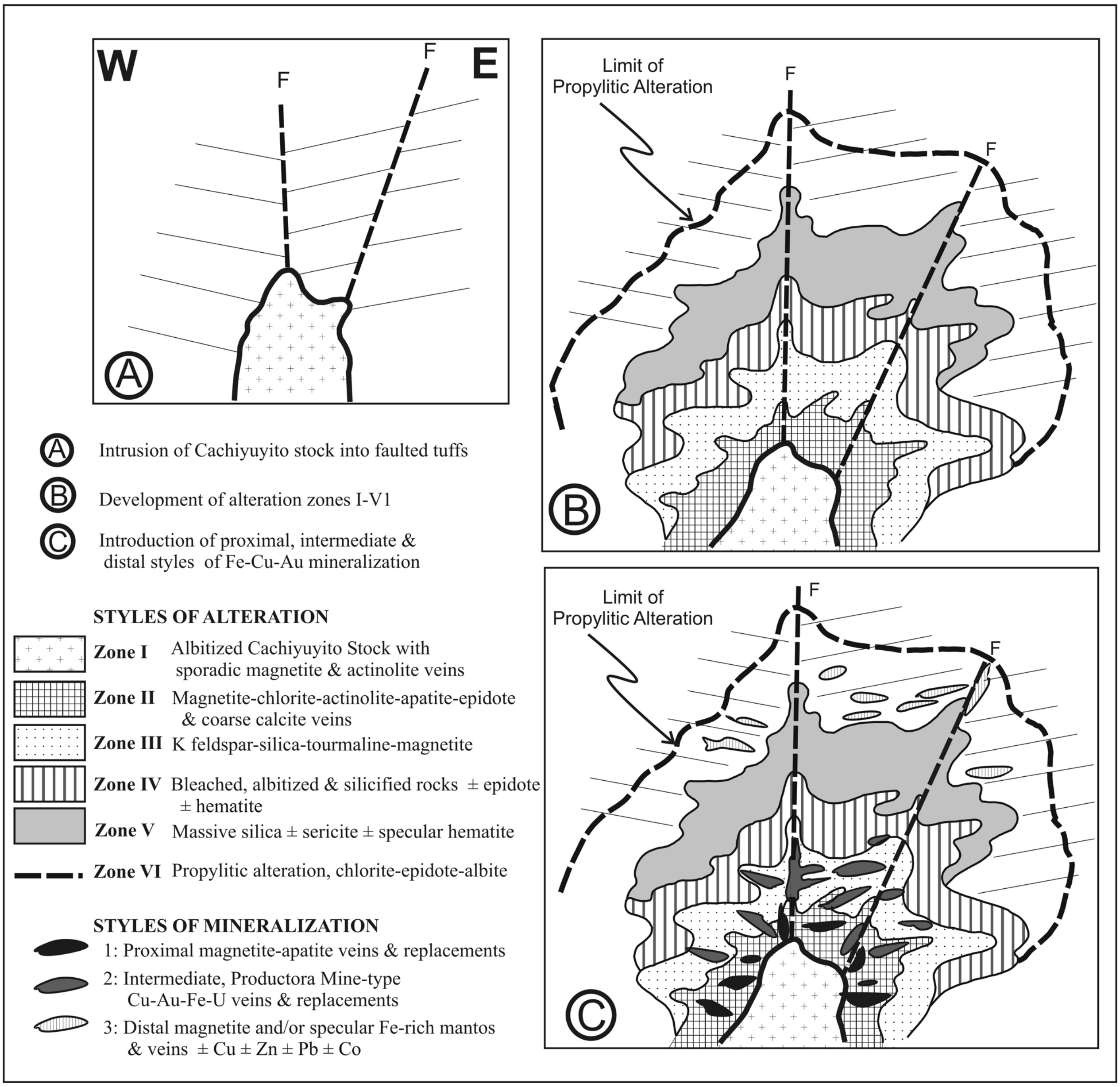

Figure 8: Model showing the distribution of the alteration zones at Productora and location of various styles of Fe oxide ± Cu ± Au mineralization.

alteration together with minor jasper veining. Locally, these Style 3 occurrences contain minor pyrite and trace chalcopyrite together with Cu oxides and phosphates. Assays indicate that this distal type of mineralisation may contain anomalous quantities of Cu, Au, Zn, As, Co, Pb and Mn (Table 2).

Discussion and Conclusions

The age, structural setting, alteration assemblages and varied styles of mineralisation in the Productora area are similar to those present at the Pajaritos property (Ray, 1997b), the Candelaria Cu-Au deposit and other Fe oxide-Cu-Au occurrences in the Punta del Cobre belt further north (Figure 1; Ryan et al., 1995; Marschik and Fontboté, 1996, Marschik et al., 1996, 2000). However, the alteration and Fe oxide mineralisation at Productora differ from Candelaria in their clear spatial association with intrusive rocks and their lack of garnet-pyroxene-scapolite skarn assemblages; these differences may reflect deeper erosion at Productora and the absence of calcareous host-rocks.

Certain aspects of the alteration at Productora (eg. K-spar, secondary biotite, tourmaline, dumortierite and green sericite-muscovite veins) resemble those present in certain Au and magnetite-rich Cu porphyry systems, such as the Highland Valley and Island Copper deposits in British Columbia, and the Los Pelambres porphyry in Chile (Perello et al., 1995; Casselman et al., 1995: Atkinson et al., 1996). However, other features such as the presence of abundant Fe oxides, together with apatite, allanite, anomalous Au, REE's and U, are similar to those described in deposits of the Fe oxide-Cu-Au family (Williams, 1998).

Studies by workers such as Oreskes and Einaudi (1990), Einaudi and Oreskes (1990), Vidal et al. (1990), Hitzman et al. (1992), Oreskes and Hitzman (1993) and Williams

Table 2: Analytical data of mineralized samples, Productora.

Sample	GR-36	GR-84	GR-124	GR-155	GR-209	GR-257	GR-258	GR-260	46510	46519	46520
Au	609	16	203	3061	9730	23	303	218	161	402	137
Mo	10	2	128	9	9	4	180	571	128	52	27
Cu	16279	2734	42592	22904	26659	15274	14772	37753	11981	4447	2316
Ag	0.9	0.3	0.3	1.1	2.0	0.3	1.1	1.5	0.3	0.5	0.3
Ni	148	437	327	19	114	16	60	340	7	18	12
Co	88	497	832	17	97	23	149	660	33	118	30
As	63	18	77	13	27	7	56	93	7	10	8
U	10	8	8	30	8	8	8	8	8	8	8
Th	3	5	2	2	12	6	3	2	8	5	5
Sr	15	19	166	22	11	11	11	15	17	21	16
V	1297	329	304	194	1033	154	176	271	6	58	44
P	0.98	0.18	0.39	0.07	0.54	0.16	0.12	0.13	0.02	0.07	0.06
La	2	28	498	26	37	219	25	52	5	347	563
Cr	25	56	51	48	13	112	66	27	47	11	18
Ba	12	21	8	33	12	8	7	9	130	140	145
Ti	0.08	0.16	0.02	0.12	0.01	0.01	0.01	0.01	0.01	0.02	0.02
B	3	45	3	11	3	12	9	6	71	6	8
Pb	9	3	7	11	33	3	3	12	NA	NA	NA
Zn	27	76	13	57	126	27	67	19	NA	NA	NA

Sample	71326	71350	71314	71348	71404	71408	71410	71412	71413	71418	71420
Au	1105	350	594	20	989	195	173	10	43	134	3440
Mo	21	42	< 1	3	69	2	11	3	52	130	6
Cu	32246	56771	26070	14731	22072	21864	19537	9644	27029	6527	26318
Ag	2	0.5	5.1	1.6	2.7	3.5	0.8	1.2	< .3	0.4	2
Ni	81	95	24	9	29	227	1173	19	83	16	4
Co	265	125	72	44	391	246	1240	160	904	46	7
As	489	575	< 2	25	95	73	23	8	7	13	13
U	< 8	< 8	< 8	< 8	< 8	40	< 8	< 8	< 8	< 8	< 8
Th	< 2	3	< 2	< 2	5	9	6	< 2	< 2	8	2
Sr	11	31	6	63	24	29	18	5	8	13	23
V	416	93	75	110	284	679	520	70	169	54	59
P	0.02	0.06	< .001	0.02	0.04	0.94	0.25	0.13	0.02	0.09	0.07
La	3	< 1	3	3	26	23	30	4	3	76	3
Cr	29	15	17	81	40	43	38	17	18	39	45
Ba	3	2	23	1	10	6	29	3	7	77	17
Ti	0.04	< .01	0.01	0.12	0.1	0.05	0.07	0.07	0.06	0.05	0.05
B	3	7	35	3	14	11	8	< 3	4	3	< 3
Pb	87	48	1237	73	13	56	4	8	4	4	< 3
Zn	47	21	7803	1193	48	88	197	81	83	17	12

Au in ppb; Ti & P in %; All other elements in ppm: Analytical methods: Au by MIBK; other elements by ICP
Analyses by ACME Analytical Laboratories, Santaigo, Chile
Sample descriptions:

GR-36 Altered tuff with magnetite & apatite veins & Cu oxides; 300m north of Productora Mine.
GR-84 Highly altered tuff with minor tourmaline & Cu oxides; adjacent to the Zapallo Stock.
GR-124 Hematite-magnetite-Cu oxide ore, Monseratt Mine.
GR-155 Altered tuff with Cu oxides; 400m NE of Productora Mine.
GR-209 Chalcopyrite-cuprite-magnetite ore: pit 900m NE of Monseratt Mine.
GR-257 Albite-actinolite-altered tuff with Cu oxides; Remolina Pit.
GR-258 Albite-actinolite-altered tuff with magnetite & Cu oxides; small pit 700m south of Monseratt Mine.
GR-260 Chalcopyrite-chalcocite-magnetite ore; Monseratt Mine.
46510 Altered, tourmaline-bearing tuff with Cu oxides, trench at Productora Mine.
46519 Altered tuff with Cu oxides; trench at Productora Mine.
46520 Altered tuff with Cu oxides; trench at Productora Mine.
71326 Cu oxides with epidote & chlorite. South of El Molle Mine, UTM 320557; 6819626
71350 Cu oxides from pit. South of El Molle Mine, UTM 320459; 6819783
71314 Massive magnetite float with Cu oxides, west of Quebrada Escondido, UTM 321506; 6819229
71348 Cu oxides with epidote, calcite & magnetite, SW of Zapallo, UTM 322156; 6819863
71404 Massive specular hematite-magnetite with Cu oxides. West of Quebrada Escondido, UTM 321094; 6818208
71408 Hematite-magnetite with Cu oxides. NE of Zapallo, UTM 322893; 6820344
71410 Albite with hematite-magnetite & Cu oxides. NE of Zapallo, UTM 323002; 6820251
71412 Magnetite-hematite with actinolite, Cu oxides & pyrite. North of the Rancho Fault, UTM 323905; 6824821
71413 Actinolite-chlorite with magnetite & Cu oxides. North of the Rancho Fault, UTM 323867; 6824772
71418 K spar-silica alteration with pyrite & Cu oxides. North of Productora Mine, UTM 323952; 6823111
71420 Cu-oxides with specular hematite. Fortuna Mine, UTM 322241; 6817884

(1998), and summarised by Ray and Lefebure (2000), suggest that this Fe oxide family is worldwide and includes the Olympic Dam and Ernest Henry deposits in Australia, Kiruna in Sweden, and those in the Chilean and Peruvian Iron belts such as Candelaria, El Romeral, Manto Verde, Productora, Condestable, Raul and Eliana. The idea that these varied deposits share any family link is controversial, which is hardly surprising given the wide variation in their ages, tectonic settings and non-ferrous metal contents. However, there is now increasing evidence that the ideas presented by early workers such as Hitzman et al. (1992) are valid and that the Fe oxide-Cu-Au family represents a spectrum of hydrothermal deposits that varies from magnetite ± apatite systems which are barren of economic Cu and Au (eg. Kirunavaara; El Romeral) to more sulfide-rich Fe oxide-Cu ± U ± Au ± REE ± apatite-bearing examples as seen at Olympic Dam and Candelaria. Candelaria, Productora and Pajaritos (Figure 1) probably represent a subtype of this family; they differ notably from the better known Proterozoic examples by their younger ages, the presence of B-rich alteration, and their development in a volcanic back-arc rather than a continental crustal environment.

Acknowledgements

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Table 3: Examples of mineralised drill intersections at the Productora property.

Hole	From (metres)	To (metres)	Length (metres)	Average Cu (%)
S1-7	27.5	48	20.5	1.01
S1-11	31.5	44.5	13	1.13
PR-2	68	140	72	0.60
including	68	92	24	0.93
PR-5	52	96	44	0.72
including	84	96	12	1.23
PR-7	96	140	44	0.41
S8-4	0	25	25	0.75
S8-5	7	40	33	0.97
including	21	36.5	15.5	1.44
PR-9	102	214	112	0.65
including	102	130	28	1.00
PR-13	200	316	116	0.41

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