Trabajos de Geología, Universidad de Oviedo, 29 : 78-83 (2009)

Compressional deformation along the Chañarcillo basin west margin: North Chilean Late Jurassic-Early Cretaceous back-arc basin

A. AMILIBIA*

Centre Mixt d'Investigació GEOMODELS. Departament de Geodinàmica i Geofísica, Universitat de Barcelona, Zona Universitaria de Pedralbes s/n, 08018 Barcelona, Spain.

**e-mail: aamilibiac@ub.edu*

Abstract: The study area is located at the boundary between the Central Andes Coastal Cordillera and Precordillera morphostructural units (CCPB) that corresponds to the west margin of the mainly volcanic, subduction related, Late Jurassic-Early Cretaceous back-arc basin of northern Chile. Around Copiapó, this margin describes an E-verging NNE-SSW-trending regional scale anticline, result of the basin inversion under transpressional regime at Albian times. The anticline involves volcanic Punta del Cobre formation and marine Chañarcillo group syn-extensional sequences. Overlying Cerrillos formation conglomerates, deposited synchronously to the basin inversion, has been interpreted as the distal part of a fan-delta system located at the western border of the basin.

Keywords: Central Andes, back-arc basin, inversion tectonics, syn-tectonic sediments.

Copiapó region of central northern Chile hosts a number of world class iron oxide-rich Cu-Au deposits (IOCG) including the giant Candelaria deposit (Fig. 1). Paleogeographic resconstructions for the Late Jurassic-Early Cretaceous times locate the Copiapó region at the eastern margin of a subduction related volcanic arc, paired with a back-arc basin located immediately to the east (Coira *et al*., 1982; Morata and Aguirre, 2003) (Fig. 2). Back-arc basin syn-extensional sequence is mainly represented by the upper part of the Late Jurassic volcanic Punta del Cobre formation and the marine rocks of the Early Cretaceous Chañarcillo group. The majority of the mineral deposits occurs in the lower part of the Punta del Cobre formation, and are located east of the Atacama Fault System (AFS) main trace, largely active during the Jurassic (Fig. 1B). Emplacement of the easternmost Copiapó Plutonic Complex intrusions occurred between 119 and 97 Ma, along the basin west margin, under a contractional regime that resulted in the back-arc basin inversion during Albian times. The age of mineralization seems to be in the range of 116 to 114 Ma (Marschik *et al*., 2003) synchronous with the plutons emplacement. Resulting dominant contractional structures strike NNE-SSW. A set of NW to NNW sub-vertical strike-slip faults are also present, and seem to control the ascent of mineralization and associated intrusives. The structural geology of the region is poorly understood with various authors proposing both major components of strike-slip deformation (Arévalo, 1999; Grocott and Taylor, 2002) as well as widespread extensional deformation (Mpodozis and Allmendinger, 1993; Grocott and Wilson, 1997) during the evolution of the basin. Previous cross-sections were essentially schematic and are not well constrained. In order to understand the

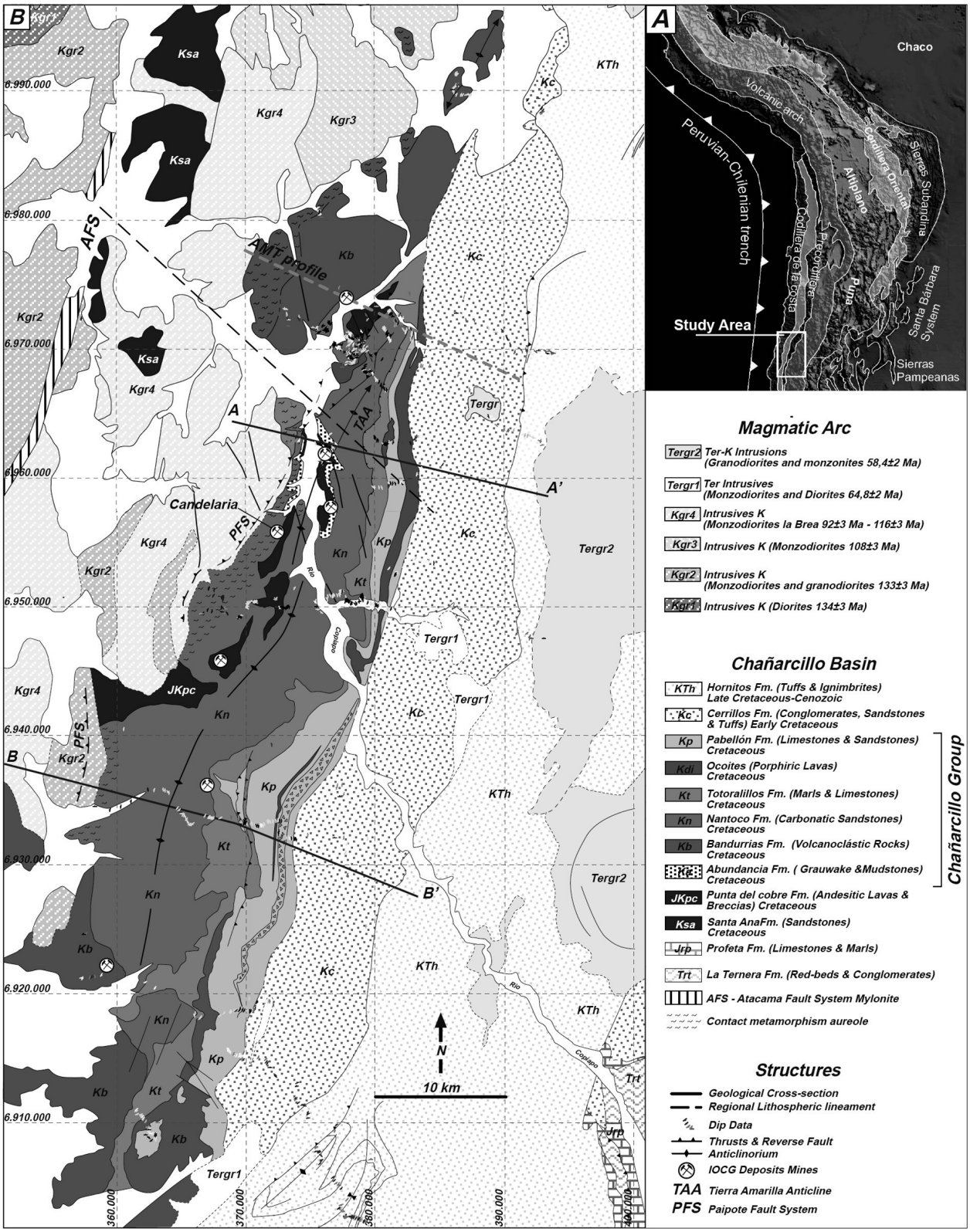

Figure 1. (A) Central Andes DEM and main morphostructural units with location of the study area, (B) simplified geological map of the Tierra Amarilla anticline and surrounding areas. Geological sections produced during this study are located. (UTM coordinates Fuse nº: -19). From Arévalo (2005).

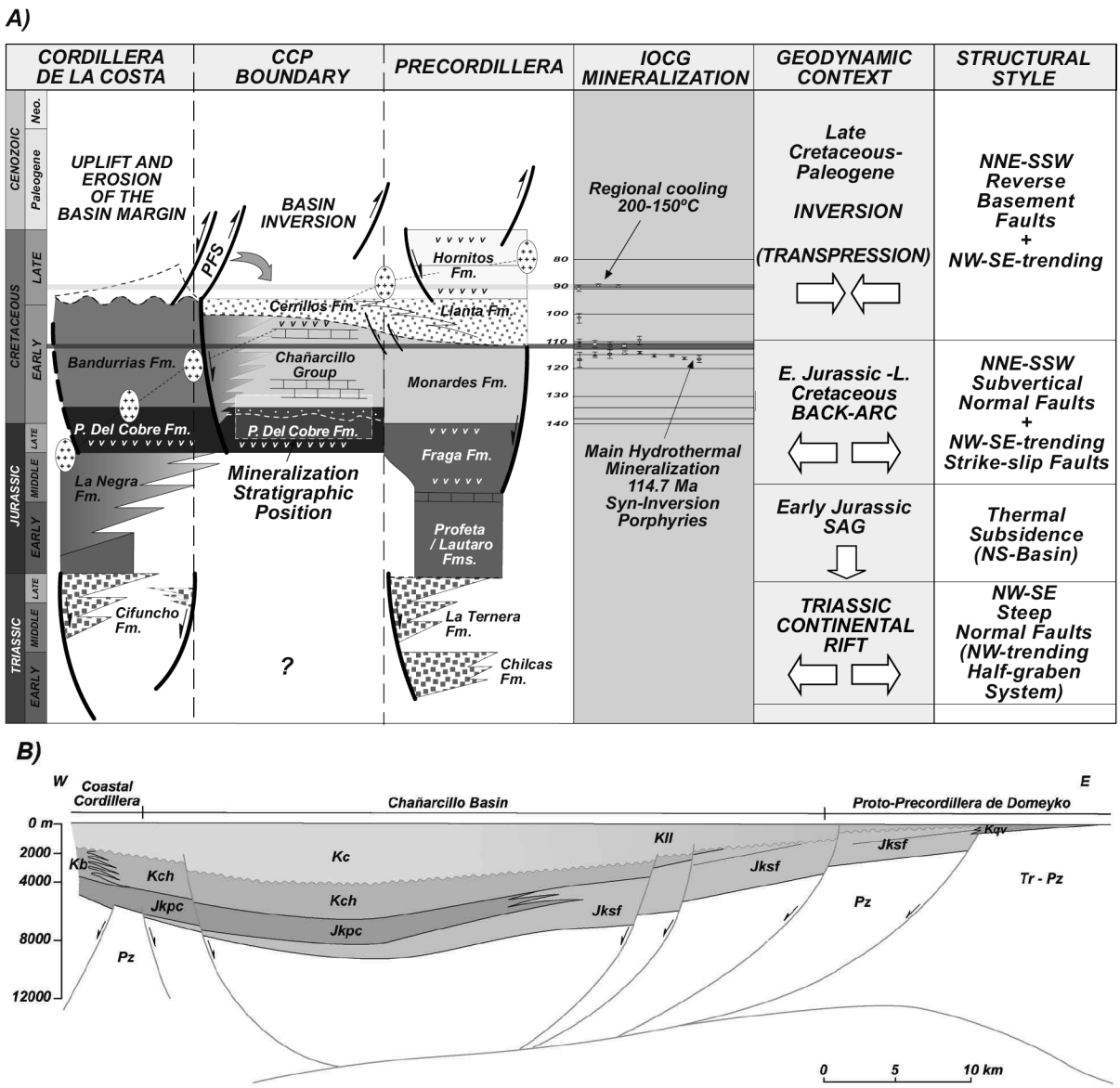

Figure 2. (A) Chañarcillo basin Tectono-stratigraphic chart. The Chañarcillo basin is located in the Coastal Cordillera-Precordillera Bounday (CCPB) morphostructural unit. Main mineralization events of the area as well as geodynamic context and structural styles are also represented. Notice the magmatic arc and deformation migration towards the east since Early Cretaceous time coeval with the beginning of a contractional regime in the South American plate, (B) Chañarcillo basin synoptic W-E cross-section. (Kc: Cerrillos Fm; Kll: Llanta Fm; Kb: Bandurrias Fm; Kch: Chañarcillo Group; Kqv: Quebrada Marquesa Fm; Jkpc: Punta del Cobre Fm; Jksf: Sierra Fraga Fm; Tr: Triassic; Pz: Paleozoic Basement).

structural evolution related to the development of these important IOGC deposits, a deep structural analysis is required not only for the mineralizing systems but also for the regional structures.

Methodology

The regional study is based on surface data (approximately 1000 data sites) mainly distributed along seven W-E transects (Fig. 1B) perpendicular to the regional trend of the compressional structures, as well as on Landsat-7TM and regional aeromagnetic (RTP) map interpretation. One W-E trending AMT profile was the only subsurface data available (Fig. 1). To construct restorable cross-sections, 2DMove software (Midland Valley Exploration©) has been used. Rock samples for dating purposes were also collected.

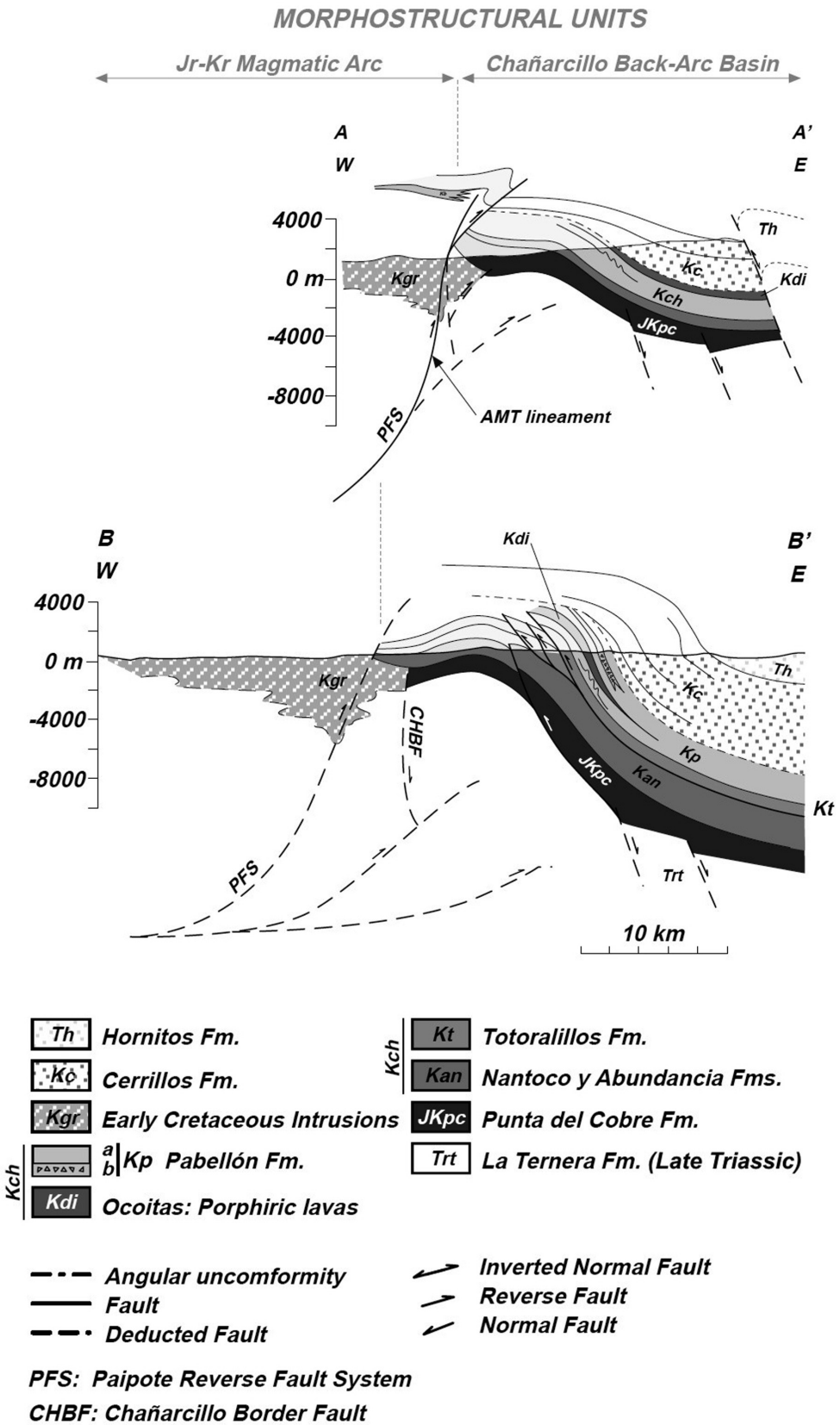

Figure 3. Geological cross-section across the CCPB at Copiapó - Tierra Amarilla area. Section A-A' runs along the Quebrada Meléndez and Section B-B' runs along the Quebrada Carrizalillo. Both cross sections cut across the regional east-verging Tierra Amarilla Anticline.

Results and discussion

Style and age of the deformation

An en echelon set of NNE-SSW-trending basement-involved reverse faults (e.g. Paipote Thrust) and associated E-verging anticlines are the observed dominant structures in the area (Figs. 1 and 3). They could be interpreted as the westernmost west dipping steep basement reverse faults that uplift the western margin of the back-arc basin (Fig. 3). A steep W-dipping conductor observed in the western sector of the AMT profile, sub-parallel to A-A' cross-section, corroborates this interpretation. These structures were interpreted as en echelon flower structures, developed under left-lateral transpression (Arévalo, 1999; Arévalo *et al.*, 2006). On the contrary, we postulate that the geometry and distribution of the structures could be inherited from the Mesozoic back-arc tectono-sedimentary architecture, being coherent with an inversion model instead of a strike-slip one. During this basin inversion its steep west boundary fault could not be reactivated and has been transported towards the east via the new developed Paipote short-cut reverse faults system (PFS). Minor thrusting and chevron folding developed internally in the well stratified Chañarcillo group accommodating part of the deformation in the steep eastern frontal limb (Fig. 3). This work suggests that NW-SE sinistral strike-slip faults as well as the dominant NNE-SSW contractional structures could be generated under the same tectonic regime, that is, W-E compression. NW-SE faults accommodate oblique displacement between anticline sectors with different cylindricity. These faults seem to be in tune with some of the lithospheric scale lineaments described in the Central Andes. These oblique lineaments could be clearly observed on the aeromagnetic resistivity (RTP) map, were the high anomaly located to the west of Copiapó is off-set by a NW-SE lineament coherent with the off-set observed in the Copiapó Plutonic complex and associated hematite alteration (Fig. 1B).

Marschik and Fontbote (2001), from geochemical and isotopic observations, placed the age of the main mineralization in 114.7 Ma, just before the beginning of the basin inversion marked by the hiatus between the Chañarcillo group and Cerrillos formation. Sedimentation of shallow marine rocks of Pabellón formation (Upper Chañarcillo group) ended around Late Aptian times (Corvalan, 1973; Pérez *et al.*, 1990). This marked the beginning of the contractional deformation that resulted in the inversion of the Jurassic-Early Cretaceous back-arc basin at the end of Aptian times. This evolution is coherent with our sedimentary and structural field observations. Continental deposits of Cerrillos formation show metamorphosed limestone clasts from Nantoco formation (Chañarcillo group), as well as reworked marine fossils of Hauterivian to Barremian age on their conglomeratic bodies. The source area of these clasts should be the Chañarcillo basin west margin, where the marine succession of Nantoco formation was metamorphosed during the emplacement of the Copiapó plutonic complex around Aptian times. This observation corroborates the hypothesis of Albian inversion as uplift and exhumation of the Chañarcillo basin western margin is needed in order to have a source area from where obtain the clasts observed in the Cerrillos formation conglomerates (Fig. 2A). Then, the continental detrital and volcanic deposits of Cerrillos formation could be interpreted as syn-inversion deposits. Growth-strata angular unconformities would be located in the eroded part of the western margin of the Chañarcillo basin. Today expression of this syn-inversion sequence is clearly an unconformable series of continental conglomerates that filled the basin towards the east. The mentioned unconformity is visible on figure 1B map, where Cerrillos formation conglomerates sits progressively on top of older rocks from Chañarcillo group formations as we move towards the NNE.

New insights for the Chañarcillo basin evolution

Two new contributions to the evolution of the Chañarcillo basin could be derived from this work. The first one is the location of Chañarcillo basin depocentre to the east of the studied area between the Cretaceous volcanic arc to the west, and the Proto-Precordillera to the east. This could be deduced by: 1) the observed inter-fingering of the Bandurrias formation volcanic deposits to the west with the marine Chañarcillo group carbonates to the east (Fig. 2B) and 2) the east-verging slumps and debris flows observed in the Chañarcillo group carbonates at Tierra Amarilla anticline, that clearly mark a deepening of the basin towards the east.

The second contribution, coherent with Marschik and Fontbote (2001) conclusions, suggests that the deposition of the Cerrillos formation continental sediments is synchronous with the beginning of the contraction at the continental margin that inverted the Late Jurassic-Early Cretaceous back-arc basin. Since that moment, magmatic activity as well as deformation front migrates eastwards (Fig. 2). The Inversion of the Late Jurassic-Early Cretaceous Andean back-arc basin ends with the

uplift of its eastern margin during Early Cenozoic that results in the basement-involved thick-skinned Cordillera de Domeyko Andean Proto-precordillera.

Conclusions

1) Observed NE-SW contractional structures and NW-SE steep strike-slip faults are coherent with an E-W shortening across the Chañarcillo basin west-margin.

2) Cerrillos formation was possibly deposited coeval to the contractional episode that uplifted the Chañarcillo western margin in Albian time.

3) Paipote Fault System could be interpreted as steep reverse faults that transported towards the east the footwall of the Chañarcillo basin border fault, due to the incapability of the steep normal fault to reactivate.

Acknowledgements

Thanks to the CODELCO-EMSA for funding this project as well as to provide me with the field logistics. Part of this work has been developed in collaboration with the Grup de Geodinàmica i Anàlisi de Conques (GGAC – UB) and funded by the project MODES 4D (CGL2007-66431-C02-01/BTE).

References

Arévalo, C. (1999): *The Coastal Cordillera-Precordillera boundary in the Copiapó area, northern Chile, and the structural setting of the Candelaria Cu-Au ore deposit*. PhD Thesis. Kingston University, Kingston-upon-Thames, UK, 244 pp.

Arévalo, C. (2005): *Carta Copiapó, Región de Atacama. Servicio Nacional de Geología y Minería, Carta Geológica de Chile, Serie Geológica Básica, 1 mapa escala 1:100 000*. Santiago, Chile.

Arévalo, C., Grocott, J., Martin, W., Pringle, M. and Graeme, T. (2006): Structural Setting of the Candelaria Fe Oxide Cu-Au Deposit, Chilean Andes (27º30'S). *Econ. Geol.*, 101: 819-841.

Coira, B., Davidson, J., Mpodozis, C. and Ramos, V. (1982): Tectonic and magmatic evolution of Northern Argentina and Chile. *Earth Sci. Rev.*, 18: 303-332.

Corvalan, J. (1973): Estratigrafía del Neocomiano marino de la región al sur de Copiapó, provincia de Atacama. *Rev. Geol. Chile*, 1: 13-36.

Grocott, J. and Wilson, J. (1997): Ascent and emplacement of granitic plutonic complexes in subduction-related extensional environments. In: M.B. Holness (ed): *Deformation-enhanced fluid transport in the Earth's crust and mantle*. Chapman & Hall, London, 173-195.

Grocott, J. and Taylor, G. K. (2002): Magmatic arc fault systems, deformation partitioning and emplacement of granitic complexes in the Coastal Cordillera, north Chilean Andes (25º30'S to 27º00'S). *J. Geol. Soc. London*, 159: 425-442.

Marschik, R., Fontignie, D., Chiaradia, M. and Voldet, P. (2003): Geochemical and Sr-Nd-Pb-O isotope composition of granitoids of the Early Cretaceous Copiapó plutonic complex (27º30'S), Chile. *J. S. Am. Earth Sci.*, 16: 381-398.

Marschik, R. and Fontboté, L. (2001): The Candelaria-Punta del Cobre Iron Oxide Cu-Au (-Zn-Ag) Deposits, Chile. *Econ. Geol.*, 96: 1799-1826.

Morata, D. and Aguirre, L. (2003): Extensional Lower Cretaceous volcanism in the Coastal Range (29º30'–30ºS), Chile: geochemistry and petrogenesis. *J. S. Am. Earth Sci.*, 16: 459-476.

Mpodozis, C. and Allmendinger, R. W. (1993): Extensional tectonics, Cretaceous Andes, northern Chile (27ºS). *Geol. Soc. Am. Bull.*, 105: 1462-1477.

Pérez, E., Cooper, M. R. and Covacevich, V. (1990): Aptian ammonite-based age for the Pabellon Formation, Atacama region, northern Chile. *Rev. Geol. Chile*, 17, 2: 181-185.