UNIVERSIDAD CATOLICA DEL NORTE
Departamento de Ciencias Geológicas
VIII Congreso Geológico Chileno
1997

ACTAS • VOL III
Nuevos Antecedentes de la Geología del Distrito de Chuquicamata, Período 1994 • 1995 • Sesión 1: Geología Regional
Páginas 1873 • 1877

STRUCTURAL EVOLUTION AND DISPLACEMENT HISTORY OF THE WEST FAULT SYSTEM, PRECORDILLERA, CHILE: PART 1, SYNMINERAL HISTORY

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INTRODUCTION

The West Fault (West Fissure) System (WFS) is the northernmost segment of the Domeyko Fault System of northern Chile, and is best known for its exposure in the Chuquicamata Mine. Primarily because of studies in and around Chuquicamata, the WFS is considered important as both a synmineral fault system controlling the emplacement and mineralization of porphyry-copper-related intrusions, and a postmineral system displacing and concealing potential exploration targets. Over decades of investigation the sense of displacement has been debated and few estimates of its offset have been made. Recently, the multistage history of the WFS has been documented and data advanced on the order, sense, and timing of slip events (1, 2, 3). Still, there are unresolved problems concerning the time of origin of the WFS, its structural evolution, magnitude of offset, tectonic framework and relation to porphyry copper deposits. In this paper we present data on these matters in relation to its early, synmineral history. In an accompanying paper (4) the postmineral history of the WFS is discussed.

In this and the companion paper we use West Fault (WF) to refer to the master throughgoing fault(s) which has taken up >90% of the strike-slip displacement of the system and the West Fault System (WFS) to refer to the master and peripheral faults that compose the system.

REGIONAL SETTING AND PRE-WEST FAULT DEFORMATION

The WFS extends from Calama to Copaquiri where it runs the length of the Sierra del Medio (Fig. 1a). The current elevation of the Precordillera, north of Calama, is largely a function of late Miocene and Pliocene tectonics, but the structure of pre-middle Miocene rocks and differential elevations within the Precordillera is largely a product of Late Cretaceous and Eocene shortening, and Eocene to early Miocene transcurrent tectonics along the WFS (Fig. 1b). Approximately 37 km of net postmineral sinistral displacement on the WFS is documented by (4). In order to understand early Oligocene and older structures this displacement must first be restored (Fig. 1b).

In the Sierra de Moreno, basement blocks were uplifted along high-angle reverse faults in the Cretaceous, while the Sierra del Medio remained undeformed (5). The first post-Paleozoic deformation in the Sierra del Medio involved Eocene shortening, which began at ~44 Ma as constrained by a 45.4±1.2 Ma K-Ar biotite age on a dacitic-andesitic volcanic breccia cut by a reverse fault west of Cerro Yocas (Fig. 1b), and a K-Ar biotite age of 42.9 ± 1.2 Ma on a granodiorite intruding the same fault. Shortening continued at least until 38.5 Ma (40Ar-39Ar dating of an unconformity west of Co. Jaspe (2)) and was contemporaneous with emplacement of the El Abra plutonic complex (39-37 Ma (6)) as evidenced by a flattening foliation in meta-clastic rocks in the contact aureole having an orientation consistent with E-W regional shortening. ~44 to 37 Ma is similar to the time span for regional shortening associated with sinistral transpression in the El Salvador-Potrerillos area (26-27°S), where syntectonic intrusions and domes constrain shortening as spanning 42 to 36 Ma (7).

MIDDLE TO LATE EOCENE HISTORY OF THE WEST FAULT SYSTEM

North of Cerros de Paqui

The first evidence for approximately N-S directed transcurrent activity is recorded in the development of a series of soft-linked (not directly interconnected) N to NNE striking faults with dextral kinematic indicators (fault plane stria and steps, contemporaneous vein sets, associated thrusts and folds). Between Copaquiri and Qda. Puno, three of these faults form an en echelon array, similar to Riedel shears in model experiments, and have associated quartz-sericitic alteration (north of Co. Yocas) and gold mineralization (Mina Choja, Fig. 1b). Further south, another isolated dextral fault zone, the Pastos Largos, has sericitic alteration that yield a 39.3±1.4 Ma K-Ar age.

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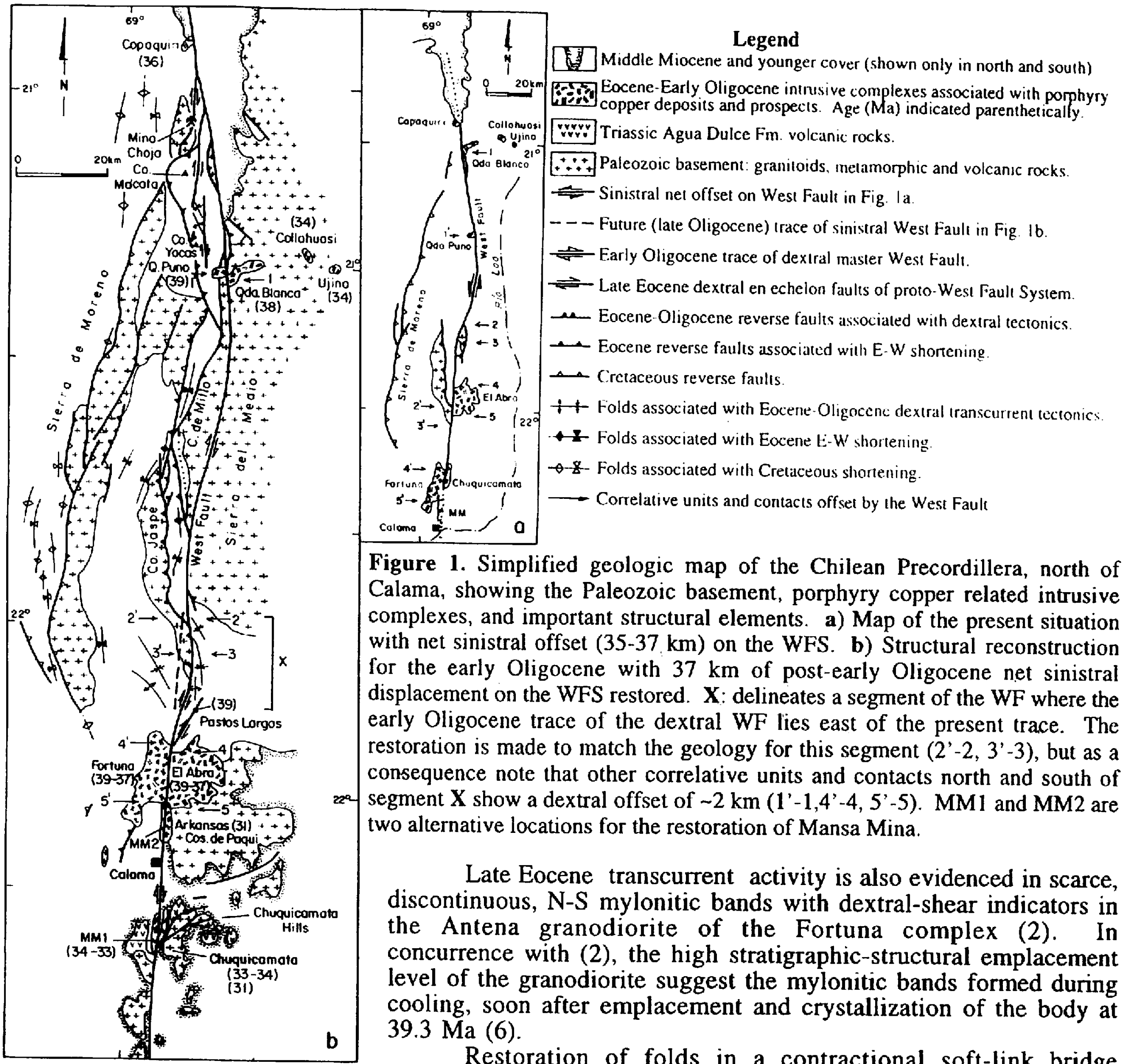


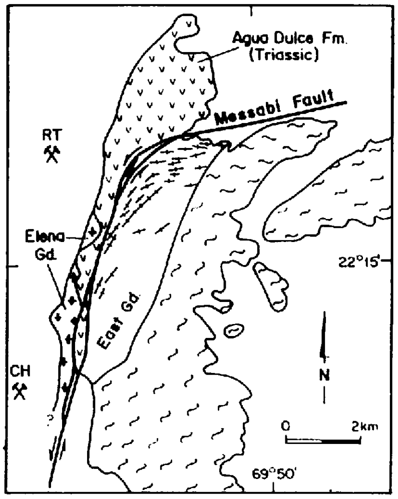
Figure 1. Simplified geologic map of the Chilean Precordillera, north of Calama, showing the Paleozoic basement, porphyry copper related intrusive complexes, and important structural elements. **a**) Map of the present situation with net sinistral offset (35-37 km) on the WFS. **b**) Structural reconstruction for the early Oligocene with 37 km of post-early Oligocene net sinistral displacement on the WFS restored. **X**: delineates a segment of the WF where the early Oligocene trace of the dextral WF lies east of the present trace. The restoration is made to match the geology for this segment (2'-2, 3'-3), but as a consequence note that other correlative units and contacts north and south of segment **X** show a dextral offset of ~2 km (1'-1,4'-4, 5'-5). MM1 and MM2 are two alternative locations for the restoration of Mansa Mina.

Late Eocene transcurrent activity is also evidenced in scarce, discontinuous, N-S mylonitic bands with dextral-shear indicators in the Antena granodiorite of the Fortuna complex (2). In concurrence with (2), the high stratigraphic-structural emplacement level of the granodiorite suggest the mylonitic bands formed during cooling, soon after emplacement and crystallization of the body at 39.3 Ma (6).

Restoration of folds in a contractional soft-link bridge between two of these en echelon faults, north of Cerro Yocas, suggests that dextral shear is < 2 km on this system (8). Crosscutting relations in the same area indicate that at least locally dextral faults postdate Eocene reverse faults, but the geochronological data suggest that regionally they overlap in time.

South of Cerros de Paqui

The structure of the Chuquicamata Hills (Fig. 2) differs markedly from the rest of the Sierra del Medio but has strong similarities to the structure south of Limón Verde (9) where structural and radiometric data indicate that in the Eocene (~45-40 Ma) a series of Paleozoic basement blocks were translated northward and rotated clockwise about curved faults (Fig. 3). In the Chuquicamata Hills, steeply dipping foliations in Paleozoic meta-plutonic rocks and dikes cutting the undeformed East granodiorite change in strike orientation concordant with the change in orientation of the curved Messabi fault (Fig. 2) suggesting the block is bent (folded) about a vertical axis. Since Mesozoic volcanic rocks north of the Messabi fault are not folded, it is inferred the folding of the basement block occurred as a result of movement about an originally curved Messabi fault. Furthermore since Paleozoic foliations in adjacent areas are N-S striking it suggests the block translated sinistrally and were rotated into their present E-W orientations.



—+— Subvertical dikes cutting the Triassic East Granodiorite.

~ ~ Strike of steeply dipping foliation in Upper Paleozoic meta-diorites and -granites.

Figure 2. Simplified geologic map of the Chuquicamata Hills for the late Eocene, with displacement on the Estanques Blancos Fault zone restored. Ch: Chuquicamata, RT: Radomiro Tomic.

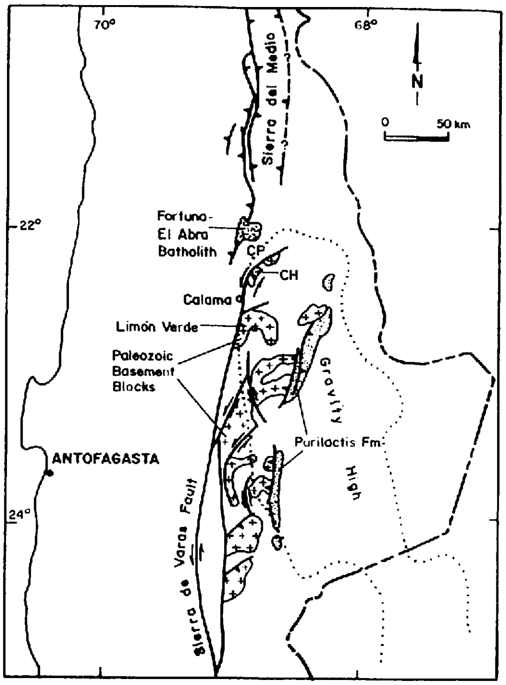


Figure 3. Simplified map of Chilean Precordillera for the Eocene (~44-35 Ma) showing a close correspondence between along strike change in the Eocene structural character of the Precordillera and the area of anomalous high gravity (13) and position of the Purilactis Basin. CH: Chuquicamata Hills, CP: Cerros de Paqui.

The only sinistral kinematic indicators on the Messabi fault have been attributed to a younger sinistral WF event (2). Most shear indicators in the Messabi fault zone are dextral (2, 8, 10), but a metamorphic upgrade of shear fabrics as the Chuquicamata porphyry is approached and presence of dextral mylonitic shears in the porphyry suggest the dextral Messabi was active at about 34-33 Ma (10, 11). This is significantly younger than the age of sinistral activity south of Limón Verde. Considering the similarities to the geology south of Limón Verde, we propose that the kinematic data of (9) can be extrapolated to the area and support the interpretation made above of an older sinistral displacement along the Messabi fault. The dextral fabrics require a reversal of the system by 34-33 Ma (see below).

The geology of the Chuquicamata Hills require a revision of the models of (9) and (12). Those authors interpreted the Limón Verde block to be a rigid buttress obstructing northward translation of basement blocks and interpreted the Cretaceous-Eocene Purilactis rift basin to act as a free face allowing the blocks to "escape" to the east. Our mapping indicates the buttress is located north of the Chuquicamata Hills, where it is represented by the Sierra del Medio, which underwent E-W shortening contemporaneous with the sinistral displacements farther south. This is in accordance with the distribution of the Purilactis Formation and has a close correspondence with the "gravity terrane" of (13) (Fig. 3) which appears to delineate an area of the crust with anomalous geophysical and geologic characteristics that has been maintained as a long-lived basin. South of where the gravity high intersects the Precordillera (south of 24°S) the structure is characterized by transpression with basement blocks bound by reverse faults on their NW margins. Where the gravity high intersects the Precordillera (22°-24°S), basement blocks are limited by left-lateral faults, and north of the gravity high (north of 22°S), E-W shortening and minor dextral faulting dominate. The close correspondence of the Eocene structure with the gravity high supports the proposition of (9) and (12) that a mechanically heterogeneous continental lithosphere controlled the deformational style.

Dynamic model for northern Chile in the middle to late Eocene

Figure 4a is a conceptual model to explain how simultaneous sinistral and dextral orogen-parallel slip may have been produced. Following plate reconstructions, the Farallon plate is shown converging with the continental margin rapidly and in a dextral-oblique sense. The rapid-oblique convergence produces deformation north of 22°S which is partitioned into E-W shortening and orogen-parallel dextral shear, in agreement with classical trench-linked models. Normally in such models the traction at the plate interface dominates the dynamics of the system and would translate the forearc sliver northward, however, in the presence of an ancestral Arica bend, and a thickening crust, the forearc is buttressed against northward translation. In this case, other forces such as asthenospheric corner flow may be more important in driving deformation (12). Following (12), it is considered that the obliquity of the convergence produces a trench-parallel component to the corner flow, which in conserving momentum, produces a return flow directed to the NW across the base of the lithosphere. This basal shear drives the

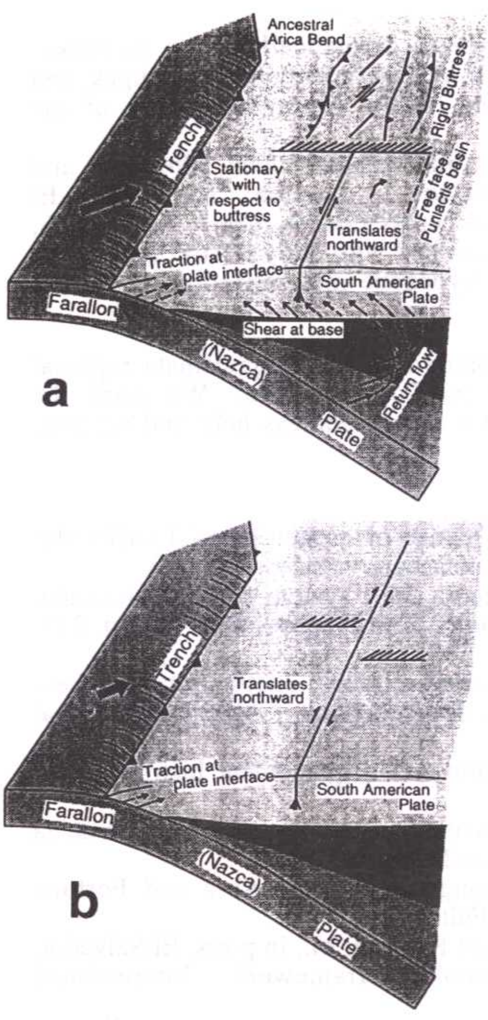


Figure 4. Dynamic model for northern Chile: **a**) in the middle to late Eocene, **b**) in the early Oligocene. Modified from (12).

sinistral transpression. A thinned area of lithosphere, represented by the Purilactis rift basin, provided a mechanical "free face" and allowed translation of blocks northward.

OLIGOCENE HISTORY OF THE WFS

Development of the WF must postdate 37 Ma since E-W and WNW striking faults and associated pyritic veins correlate between the Fortuna and El Abra complexes, suggesting their development at ~37 Ma was not interrupted by a throughgoing N-S fault (6). By 31 Ma the WF was likely developed, as N-S faulting in the Chuquicamata porphyry exerted an important control on the 31 Ma sericitic alteration (10). Furthermore, the emplacement of several N-S elongate, porphyry-copper-related, intrusive complexes along the present trace of the WF (MM, Arkansas and Chuquicamata, Fig. 1b) and their radiometric ages (11, 14, R. Pardo pers. commun.) suggest development of a master WF by 34-33 Ma. The dextral mylonitic shears in the Chuquicamata porphyry (3) indicate that this system was dextral at 34-33 Ma. This deformation can likely be extended to 31 Ma, the age of sericitic alteration in Chuquicamata (3, 11). The data indicate a reversal of the earlier sinistral system at the latitude of Chuquicamata. Recent studies completed in the Domeyko Fault System in the El Salvador-Exploradora area (26°S) indicate a similar sinistral to dextral reversal at ~35 Ma (15). North of El Abra, N-S elongate sericitic alteration zones along the present trace of the WF suggest that a throughgoing WF propagated through the area, probably contacting (hard-linking) the earlier dextral system of en echelon faults but also locally utilizing steeply dipping, extinct?, Eocene reverse faults (Fig. 1b, 8).

Structural relations described by (4) suggest that north of El Abra (segment "X" in Fig. 1b) a dextral master WF lies east of the present trace of the WF, such that the present trace of the WF at segment "X" shows only the net postmineral displacement of the WF (mid-Oligocene-early Miocene sinistral and late Miocene-Pliocene dextral displacement), whereas the WF segments north and south of "X" show the postmineral displacements and early Oligocene dextral synmineral displacement. Correlations and structural restorations of numerous unit contacts across the WF along segment "X" indicate a net postmineral sinistral displacement of 37.1 ± 0.4 km (4). This is close to, but greater than the 35 ± 1.0 km of displacement determined for the Fortuna-El Abra complex (6) and apparently greater than the less precise estimate of 35.5 ± 2.5 km offset on the Qda. Puno-Qda Blanca complexes (8). The displacement differences support the structural interpretations in segment "X" and suggest that the early Oligocene dextral movement was on the order of 2 ± 1 km.

Dynamic model for northern Chile in the early Oligocene

Early development of the Eocene en echelon dextral faults and later interlinking to form the throughgoing early Oligocene master WF is similar to the different evolutionary stages of strike-slip systems observed in model experiments and could indicate that the change is a result of the progressive evolution of the system as displacement increases (an internal cause). However, the timing of development of the throughgoing WF (between 37 and 34 Ma) corresponds with the cessation of Eocene shortening, and the sinistral to dextral kinematic reversal on the system south of the Cerros de Paqui, suggesting an external cause, which may be the return to lower plate-convergence rates in the Oligocene. The cessation of Incaic shortening appears to have allowed propagation (or more likely coalescence) of the Domeyko Fault System through the former rigid buttress (Fig. 4b) and permitted the forearc sliver to translate northward in accordance with the dextral-oblique convergence. The slower convergence in the Oligocene would also decrease the importance of the corner flow-induced shear at the base of the lithosphere, as the velocity of the corner flow is proportional to the convergence rate.

CONCLUSIONS

The Eocene-Oligocene geology of the Domeyko Fault System changes dramatically along its strike-length and suggests a complex history wherein external causes, such as plate convergence changes, and the mechanical heterogeneity of the lithosphere, exerted controls on the timing and style of the deformation.

Mapping indicates that all the various types of faults controlled emplacement, alteration and mineralization patterns of the many Eocene-Oligocene porphyry systems in the area. The Fortuna-El Abra and Qda. Puno-Qda. Blanca complexes were emplaced along or across Eocene reverse faults (6, 8, Fig. 1b), quartz-sericitic alteration and gold mineralization occur associated with early dextral faults, and the Oligocene master West Fault controlled the emplacement and hypogene mineralization of various Oligocene porphyries (MM, Arkansas, and Chuquicamata).

Acknowledgments: This work is part of the results of the Quebrada Blanca-Chuquicamata regional mapping project conducted by the SERNAGEOMIN and funded by Codelco-Chile. We thank the geologic staffs of Codelco-Calama, Chuquicamata and Exploration for their endless help and support. This abstract is supported by the National Subdirection of Geology.

REFERENCES

1.-Reutter, K., Scheuber, E., and Helmcke, D., 1991, Structural evidence of orogen-parallel strike slip displacements in the Precordillera of northern Chile: Geologische Rundschau, v. 80, p. 135-153.

2.-Reutter, K., Scheuber, E., and Chong, G., 1996, The Precordilleran fault system of Chuquicamata, northern Chile: evidence for reversals along arc-parallel strike-slip faults: Tectonophysics, v. 259, p. 213-228.

3.-Lindsay, D., Zentilli, M., and Rojas de la Rivera, J., 1995, Evolution of an active ductile to brittle shear system controlling mineralization at the Chuquicamata porphyry copper deposit, Chile: International Geology Review, v. 37, p. 945-958.

4.-Tomlinson, A., and Blanco, N., this congress, Structural evolution and displacement history of the West Fault System: Part 2, postmineral history.

5.-Ladino, M., Tomlinson, A., and Blanco, N., this congress, Nuevos antecedentes para la edad de la deformación Cretácica en Sierra de Moreno, II Región de Antofagasta-Norte de Chile.

6.-Dilles, J., Tomlinson, A., Martin, M., and Blanco, N., this congress, The El Abra and Fortuna complexes: a porphyry copper batholith sinistrally displaced by the Falla Oeste.

7.-Cornejo, P., Tosdal, R., Mpodozis, C., Tomlinson, A., Rivera, O., and Fanning, M., in press, El Salvador, Chile, porphyry copper deposit revisisted: geologic and geochronologic framework: International Geology Review.

8.-Tomlinson et al., in prep., Estudio Geologíco de la franja entre Qda. Blanca y Chuquicamata. Servicio Nacional de Geología y Minería-CODELCO, Registered report.

9.-Mpodozis, C., Marinovic, N., and Smoje, I., 1993, Eocene left lateral strike-slip faulting and clockwise block rotations in the Cordillera de Domeyko, west of Salar de Atacama, northern Chile: in Second International Symposium Andean Geodynamics , p. 225-228, Oxford, UK.

10.-Lindsay, D., Zentilli, M., and Ossandon, G., 1996, Falla Oeste fault system: record of its regional significance as exposed in the Chuquicamata open pit, northern Chile: in Third International Symposium Andean Geodynamics, p. 427-430, St. Malo.

11.-Reynolds, P., Ravenhurst, C., Zentilli, M., and Lindsay, D., in press, High-precision 40Ar/39Ar dating of two consecutive hydrothermal events in the Chuquicamata porphyry copper, Chile: Chemical Geology-Isotope Geoscience.

12.-Yáñez, G., Mpodozis, C., and Tomlinson, A., 1994, Eocene dextral oblique convergence and sinistral shear along the Domeyko fault system: A thin viscous sheet approach with asthenospheric drag at the base of the crust: in 7° Congreso Geológico Chileno, v. 2, p. 1478-1482, Concepción.

13.-Götze, H., Lahmeyer, B., Schmidt, S., and Strunk, S., 1994, The lithospheric structure of the central Andes (20-26°S) as inferred from interpretation of regional gravity, in Tectonics of the Southern Central Andes, Reutter, K., Scheuber, E., and Wigger, P., eds, p. 7-21, Berlin.

14.-Sillitoe, R., Marquardt, J., Ramírez, F., Becerra, H., and Gómez, M., 1996, Geology of MM: a concealed porphyry copper deposit in the Chuquicamata district, northern Chile: Special Publication, Society of Economic Geologists

15.-Cornejo, P., and Mpodozis, C., 1996, Geologia de la región de Sierra Exploradora (25°-26°S): Servicio Nacional de Geología y Minería-CODELCO, Registered report IR-96-09, p. 330, Santiago.