STRUCTURAL GEOLOGY OF THE SIERRA CASTILLO - AGUA AMARGA FAULT SYSTEM, PRECORDILLERA OF CHILE, EL SALVADOR-POTRERILLOS

Andrew J. TOMLINSON(1), Constantino MPODOZIS(1), Paula C. CORNEJO(1), and Carlos F. RAMIREZ(1)

(1) Servicio Nacional de Geología y Minería, Avda. Santa María 0104, Santiago, Chile

RESUMEN: El sistema de la falla Sierra Castillo - Agua Amarga es parte de un sistema de fallas activas a lo largo del eje del arco magmático Eoceno-Oligoceno inferior, asociado al emplazamiento de pórfidos cupríferos del norte de Chile. Las estructuras y relaciones de edad en las zonas adyacentes al sistema de la falla Sierra Castillo - Agua Amarga indican un régimen transpresivo sinistral regional, durante a lo menos el rango de ~42-39 Ma. El sentido de movimiento sinistral en el margen continental es contradictorio con las reconstrucciones de movimiento de placas en el Eoceno, indicando que habría un error en las reconstrucciones o bien, una mayor complejidad cinemática para la deformación del margen continental.

Key Words: Structure, Northern Chile, Eocene, Copper porphyry, Transpression

INTRODUCTION

The Eocene-Lower Oligocene magmatic belt in northern Chile is anomalous for its numerous and large copper porphyry systems, and is closely associated with the Domeyko fault system, a system of strike-slip and reverse faults in the Chilean Precordillera. Increasingly, studies indicate the Domeyko fault system was active during the life span of the Eocene - Lower Oligocene copper porphyry magmatic arc, having both important strike-slip and shortening deformation associated with it (Maksaev, 1990; Reutter et al., 1991). However, there is still uncertainty concerning the sense of shear of the strike-slip movement, with evidence for both sinistral and dextral shear being found on the master fault system (Maksaev, 1990)

In the El Salvador - Potrerillos area, 26° - 27° S latitude, the Domeyko fault system is represented by the Sierra Castillo and Aqua Amarga faults (Figure 1). Although the timing and kinematics of these faults is poorly constrained, the deformation in their eastern borderland is well constrained and can be related to their movement. First the master fault system is described, and then the deformation in the eastern borderland, which contains in its northern part the Potrerillos fold-and-thrust belt and in its southern part a domain of NW-trending, sinistral strike-slip faults.

SIERRA CASTILLO - AGUA AMARGA FAULT SYSTEM

The Sierra Castillo fault is a subvertical fault, with considerable up-on-the-east throw, juxtaposing Paleozoic batholithic rocks on the east against Jurassic and Cretaceous volcanic sequences on the west (Figure 1). The Agua Amarga fault is a moderately to steeply west dipping fault with considerable up-on-the-west reverse throw, placing the same Jurassic and Cretaceous volcanic formations on the west over Paleocene-Lower Eocene volcanic units on the east. Despite the opposed senses of vertical separation, the Sierra Castillo and Agua Amarga faults are different segments of the same fault. Although separated for 6 kms by a cover of Miocene gravels at the town of Potrerillos, they appear to be contiguous, and each serve as the major fault in the area separating a Mesozoic platform sequence on the east from a coeval volcanic sequence on the west.

The timing of movement of the Sierra Castillo and Agua Amarga faults are poorly constrained. The Sierra Castillo fault cuts rocks as young as Cretaceous and is overlain by the Miocene Atacama Gravels. However, several faults subparallel to and apparently linked to the Sierra Castillo fault, cut intrusive rocks as young as 40-38 Ma (K-Ar whole rock and biotite ages). Similarly, the Aqua Amarga fault cuts Middle Eocene intrusive rocks (46.6 ± 1.5 and 44.2 ± 1.2 Ma) and is overlain by the Miocene Atacama Gravels.

POTRERILLOS FOLD-AND-THRUST BELT

The Potrerillos fold-and-thrust belt is an approximately 14 km wide and 45 km long (minimum) east-vergent belt (Figure 1) exhibiting two different styles of deformation in its eastern and western parts. The eastern part exhibits thin-skin, ramp-flat style folding and thrusting, and deforms primarily a Mesozoic platform carbonate and clastic sequence. The western part shows thick-skinned folding and thrusting, involving deformation of the underlying Paleozoic batholithic basement. In the southern part of the belt, near Potrerillos, the Lower Tertiary volcanic sequence is also involved in the deformation. A balanced cross section indicates a minimum of ~14.5 kilometers of shortening, or about 45%, across the belt.

Another prominent set of structures in the fold-and-thrust belt is a set of east-west trending subvertical strike-slip faults (Figure 1). The faults are more prevalent in the southern part of the belt, but are distributed throughout. Slickensides exhibit subhorizontal to shallowly plunging stria. The sense of offset of marker beds and sense of shear from secondary fractures on slickenside surfaces (Petit, 1987) indicate the majority of the faults have a dextral sense of slip, but that several faults have subhorizontal sinistral slip. The opposed senses of slip on faults of the same orientation require two kinematically separate deformations. Several of the larger east-west trending dextral faults are seen to be oblique ramps transfering slip between different thrusts. The relations indicate they are kinematically related to movement on the thrusts and on this basis are considered part of the deformation that formed the fold-and-thrust belt. The sinistral faulting probably represents a reactivation of the dextral faults at a younger time.

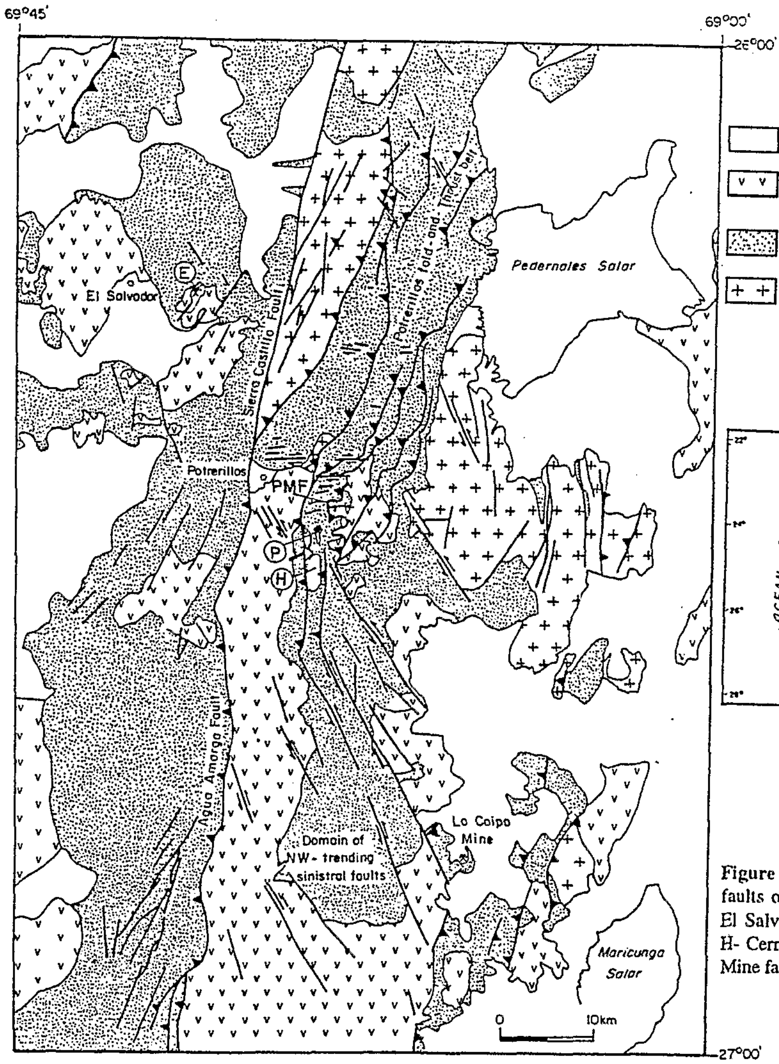
In the southern part of the fold-and-thrust belt, cross-cutting relations with radiometrically dated units provide tight constraints on the timing of deformation. Thrusts cut a ~42 Ma dacitic pyroclastic breccia unit and are cut by a dike swarm emanating from the 32 Ma Cerro El Hueso porphyry. Furthermore, several relations, including a cleavage which exhibits a textural-metamorphic up-grade towards the Potrerillos Copper Porphyry, indicate the ~39 Ma porphyry is a syntectonic intrusion.

DOMAIN OF NORTHWEST-TRENDING SINISTRAL STRIKE-SLIP FAULTS

To the south and to the east of, but also partially overlapping with, the Potrerillos fold-and-thrust belt, is a domain of northwest-trending subvertical faults (Figure 1). They have a mean strike of N25°-30°W, and have significant vertical and sinistral separations. Several similar faults also occur at the northern end of the Potrerillos fold-and-thrust belt. Stria on slickenside surfaces have subhorizontal to moderate plunges and invariably show sinistral senses of shear from secondary fractures and sinistral offsets on geologic markers. Several of the faults, occurring within the fold-and-thrust belt, also have a second set of steeply plunging, near dip-slip stria. Shear sense indicators indicate a reverse sense of movement on the dip-slip stria set. They are interpreted to indicate that those faults occurring within the fold-and-thrust belt also accommodated some shortening at some stage of their slip history.

The age of movement of the NW-trending faults is well constrained. A group of Eocene rhyolitic domes, porphyries, and dikes, and subvolcanic andesite and dacite porphyries occurs associated with, and follow several of these faults. They are localized along the faults for distances of 25-30 kilometers, at a significant angle to the overall trend of the Eocene-Oligocene magmatic arc. Furthermore, inconsistent cross cutting relations, with both dome rocks being cut by the faults and pyroclastic rocks derived from the domes overlying the faults, indicate the faults were existent and active at the time of emplacement of the domes. K-Ar whole rock ages indicate an ~42 Ma age for one of these rhyolitic domes, and a rhyodacitic dike, intruded along another of these faults, yield a 39.3 Ma. The relations indicate the faults were existent and active by ~42 Ma. One of the sinistral faults cuts the ~39 Ma Potrerillos Copper Porphyry, indicating their activity continued until sometime after ~39 Ma. These cross cutting relations are consistent with the age constraints in the fold-and-thrust belt.

Several of the thrusts, at the south end of the fold-and-thrust belt, terminate at the northern ends of NW-trending sinistral faults (Figure 1). The sinistral sense of displacement on the NW-trending faults is compatible with the sense of the movement on the adjacent thrusts. This, and their similarity in age, indicate the NW-trending faults and thrusts are kinematically related and part of the same deformation.



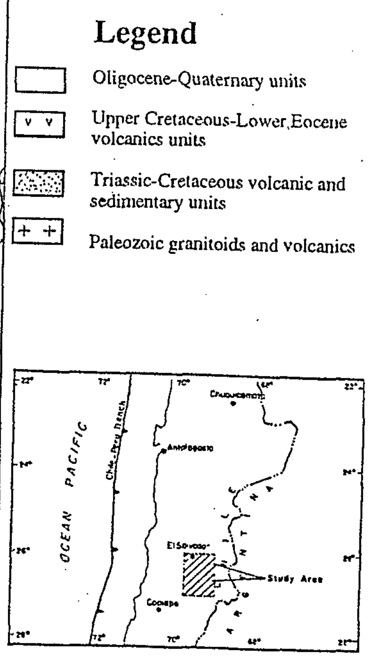


Figure 1. Simplified geological map showing faults of known or suspected Eocene age. E- El Salvador mine, P- Copper porphyry Mine, H- Cerro El Hueso porphyry, PMF- Potrerillos Mine fault.

RELATION OF FAULT SEPARATIONS ON THE SIERRA CASTILLO - AGUA AMARGA SYSTEM WITH DEFORMATION IN THE EASTERN BORDERLAND

The change in the bulk strain pattern, from the fold-and-thrust belt to the domain of sinistral strike-slip faults, is spatially associated with, and compatible with the change in the separation sense on the Sierra Castillo - Agua Amarga system. The horizontal shortening across the Potrerillos fold-and-thrust belt is accommodated by vertical thickening and uplift in its hinterland, adjacent to the Sierra Castillo fault, resulting in uplift on the eastern side of the fault. In contrast, in the domain of NW-trending sinistral faults, there are few folds and thrusts. Most of the strain is accomplished by subhorizontal or oblique sinistral movement on subvertical faults. Since there is negligible horizontal shortening, there is negligible thickening and uplift on the east side of the Agua Amarga fault, thereby more readily allowing the west side to be displaced over the east side. The relations indicate the borderland deformation and movement on the Sierra Castillo and Agua Amarga faults are related and therefore the Sierra Castillo - Agua Amarga system is also Middle-Late Eocene.

REGIONAL SINISTRAL TRANSPRESSION IN THE MIDDLE - LATE EOCENE

Sinistral transpression is indicated by two relations on the regional scale, and two independent observations on the local scale. On the regional scale, since the kinematic and age relations indicate the NW-trending sinistral faults and E-W-trending dextral faults are part of the same deformation, the two sets are interpreted to form a conjugate pair. This interpretation is further supported by the orientation of subvertical

Eocene dikes (~39 Ma), whose mean trend (~N55°W) approximately bisects the dihedral angle between the two fault sets. Latite dikes in the El Salvador Mine (42.0 ± 1.0 Ma K-Ar biotite, recalculated from Gustafson and Hunt, 1975) have the same orientation and are interpreted to have intruded under the same regional stress state.

The asymmetric development and domainal distribution of the conjugate set is interpreted to indicate formation during a noncoaxial strain history (Choukroune et al., 1987; Gapais et al., 1991), as occurs in major strike-slip fault systems. In this regard, the NW-trending sinistral faults are interpreted to be Riedel-shears and the dextral faults conjugate Riedel-shears. The orientation of the shortening direction given by the conjugate set and bisecting dikes, with respect to the Sierra Castillo - Agua Amarga system, indicates a sinistral sense of shear on the master fault system. Furthermore, the high angles of the structures to the master fault indicate regional transpression (Sanderson and Marchini, 1981). Likewise on the regional scale, the orientation of the Potrerillos fold-and-thrust belt indicates NW-SE shortening and implies sinistral displacement on the Sierra Castillo - Agua Amarga system.

Two features, in association with the Potrerillos Mine thrust fault, support the regional relations of sinistral transpression. One is the sense of slip on the fault, determined from the geometric relations of a cleavage with the thrust, giving a sinistral oblique thrust movement. The other is the clockwise sense of cleavage transection of a forced fold in the hangingwall of the fault, indicating sinistral shear.

The above observations indicate regional sinistral transpression with the Sierra Castillo and Agua Amarga faults as the master fault system. The vertical throws on the Sierra Castillo and Agua Amarga faults can be easily accomplished by even small pitches in the slip direction in a system having only 10's of kilometers of strike-slip motion.

Reviewing the timing, the data indicate the deformation started by ~42 Ma, age of the latite dikes at El Salvador and rhyolitic domes occurring along the NW-trending sinistral faults; was ongoing at ~39 Ma, age of the syntectonic Potrerillos Copper Porphyry; and over by 32 Ma, age of the Cerro El Hueso dikes.

PROBLEMS FOR LOWER TERTIARY PLATE TECTONIC FRAMEWORK

The Domeyko fault system has been previously interpreted to be a trench-linked strike-slip fault system (Mpodozis and Ramos, 1990; Maksaev, 1990; Reutter et al., 1991), but a sinistral sense of shear in the Middle - Late Eocene contradictions the plate reconstructions which predict dextral shear in the continental margin (Pilger, 1983, 1984; Pardo-Casas and Molnar, 1987). There are two possible solutions to this problem. One, the deformation in the continental margin is not related to the plate convergence in the simple fashion indicated by the "classic" trench-linked strike-slip fault models. Or two, another, now subducted plate, was converging with the continental margin in a sinistral sense in the Eocene.

Acknowledgements: This work is part of a proyect supported by the Servicio Nacional de Geología y Minería and Codelco Chile

REFERENCES

CHOUKROUNE, P., GAPAIS D., MERLE O., 1987, Shear criteria and structural symmetry: Journal of Structural Geology, v. 9, N° 5/6, p. 525-530.

GAPAIS D., FIQUET G., COBBOLD, P. R., 1991, Slip system domains, 3. New insights in fault kinematics from plane-strain sandbox experiments: Tectonophysics, v. 188, p.143-157.

MAKSAEV, V., 1990, Metallogeny, geological evolution, and thermochronolgy of the Chilean Andes between latitudes 21° and 26° south, and the origin of major porphyry copper deposits: PhD Thesis, p 1-554, Dalhousie University, Halifax, Nova Scotia, Canada.

MPODOZIS, C., ALLMENDINGER, R., JORDAN, T., 1991, La zona del Nevado de Jotabeche y Laguna del Negro Francisco: evolución tectónica y volcánica de la extremidad meridional del Altiplano Chileno: VI Congreso Geológico Chileno, Actas, p.91-95, Viña del Mar.

PARDO-CASAS, F., MOLNAR, P., 1987, Relative motion of the Nazca (Farallon) and South American plates since Late Cretaceous time: Tectonics, v. 6, p. 233-248.

PETIT, J. P., 1987, Criteria for the sense of movement on fault surfaces in brittle rocks: Journal of Structural Geology, v. 9 N° 5/6, p. 597-608.

PILGER, R. H., JR., 1983, Kinematics of the South American subduction zone from global plate reconstructions: American Geophysical Union, Geodynamics Series 9, p.113-125.

PILGER, R. H., JR., 1984, Cenozoic plate kinematics, subduction and magmatism: South American Andes: Journal of the Geological Society of London, v. 141, p. 793-802.

REUTTER, K. J., SCHEUBER, E., HELMCKE, D., 1991, Structural evidence of orogen-parallel strike slip displacements in the Precordillera of northern Chile: Geologische Rundschau, v. 80(1), p. 135-153.

SANDERSON, D. J.; MARCHINI, R. D., 1981, Transpression: Journal of Structural Geology, v. 6 (5), p. 449-458.