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Structural and magmatic responses to steepening of a flat subduction, southern Mendoza, Argentina

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The reconnaissance of typical volcanic arc products in the Chachahuén area of the southern Mendoza foothills (35°- 37°30'S) as far as 500 km from the continental margin led to the proposal of a period of flat subduction in Late Miocene times (Kay 2002). Further studies on the structure and magmatic distribution in time and space of the volcanic rocks of southern Mendoza led to the confirmation of this hypothesis and to improve the comprehension of the geologic history of this segment of the Andes.

Field work and observations made along the Principal Cordillera of Argentina and Chile and the adjacent foothills show that this segment of the Andes has a distinctive geologic evolution when compared to the northern and southern adjacent segments.

Main structural units

The Andes between 35° and 37°30'S are characterized by the following structural units that have been defined since the early XX century by Gerth (1931). From west to east they are:

Active Magmatic Arc: The magmatic arc at these latitudes is developed in the western slope of the cordillera and has been characterized by numerous petrologic and geologic studies (López Escobar 1984, Hildreth et al. 1999). Recent analyses have demonstrated a complex history of crustal erosion and consequent migration of the magmatic arc towards the foreland between 7 and 4 Ma (Kay et al. 2005).

Las Loicas Trough: A Plio-Quaternary basin has been recognized east of the present magmatic arc, associated with large silicic calderas controlled by extensional north-northwest trending faults such as the Planchón – Azufre and Calabozos calderas, Puelche volcanic field, Mary, Varvarco, Domuyito and Domuyo calderas (see location in Folguera et al. 2005, this volume). This depression coincides with the north-south course of the Río Grande valley, and has been filled by thick sequences of ignimbrites, lavas, and ash fall deposits of acidic composition.

Principal Cordillera: Miocene granitoids have been emplaced by Mesozoic deformed rocks and are unconformably covered by thick sequences of Late Miocene volcanic rocks (Gerth 1931, Ramos and Nullo 1993). As a result of important orogenic shortening and uplift, synorogenic conglomerates and sandstones have been deposited in the foreland. The age of the older deposits is constrained between of 15.1 Ma at the base and 6.7 Ma at the top of the sequence by K/Ar ages. The angular unconformity between this sequence and the next synorogenic deposits is bracketed between 6.7 and 5.04 Ma, age obtained at the base of these deposits (Kraemer 2000). This sequence is unconformably covered by Late Pliocene-Quaternary deposits. Pliocene lavas of andesitic and basaltic composition are not deformed in this segment.

Río Grande basin: This foreland basin accumulated more than 2,000 m of synorogenic deposits in two depocenters, north and south of the Río Atuel (Yrigoyen 1993). The two previous Tertiary sequences are covered by thick Late Pliocene to Quaternary deposits. This last sequence is characterized by thick coarse deposits with an east provenance (Kraemer and Zulliger 1997). Active subsidence is recorded in the Laguna Llancanelo depression located to the east of the basin. North of this lake the Tunuyán half-graben system developed in Quaternary times has been described by Polanski (1963) between San Carlos and Tunuyán. This tectonic depression is bounded to the east by north-south trending normal faults with throws of more than 700 m affecting Pliocene deposits (fig. 15, Polanski 1963). This tectonic depression continues to the south as the Valle Extenso del Campo Bajo, that matches Laguna de Llancanelo, and is located in the western margin of the basement uplifts of the San Rafael Block.

San Rafael Block: This basement uplift is composed by middle Proterozoic metamorphic rocks, late Paleozoic to Triassic volcanic products and granitoids assigned to the Choiyoi igneous province (Kay et al. 1989) emplaced in Paleozoic sedimentary rocks. The region has been uplifted in the latest Miocene, and still preserves the original peneplain, broken by normal faults of Pliocene to Quaternary age. The eastern margin of the block is being presently contracted by active basement faults, as recorded by recent seismic activity like the large Malvinas earthquake in 1929 (Bastías et al. 1993). The western border is bounded by west dipping normal faults like the Llancanelo fault.

Payenia: This large volcanic field defined by Polanski (1954) as a distinctive geological unit partially covers the San Rafael Block. The studies of González Díaz (1972) and Bermúdez et al. (1993) characterized the following volcanic episodes:

- Alkaline basaltic flows of Early to Middle Miocene age unconformably covering Miocene deposits, as preserved in El Cortaderal, south of Las Salinillas;
- Hornblende bearing andesites, rhyolites and dacites, in deeply exhumated volcanic fields that from north to south encompasses the Cerros Peceño (35°17'S) and de Afuera, Los Cerritos, Cerros Pelado and Plateado, Sierra Chorreada, Cerro El Puntudo, Volcán El Zaino and Sierra de Chachahuén (37°05'S). All these volcanic edifices are eroded and unconformably overlaid by more recent volcanics, defining a north south trending belt of more than 250 km. The ages obtained in Chachahuén by Kay (2002) indicate a peak between 7.2 and 4.8 Ma for this volcanism.
- Large alkaline basaltic fields, with several large stratovolcanoes like the Volcán Nevado (3,810 m a.s.l.), Cerro Payún (3,680 m) and Cerro Diamante (2,354 m), and important volcanic centers like the Payen Matru caldera, with basaltic flows with length over 200 km. These volcanic rocks are assigned to Pliocene and Quaternary times (Bermúdez et al. 1993).

Structural evolution

The Neogene evolution of this sector of the Andes started with an important compression in Middle to Late Miocene times, when the Malargüe fold and thrust belt was formed (Kozlowski et al. 1993). As a result of this contraction, a series of north-trending belts of granitoids were emplaced in the eastern slope of the Principal Cordillera (Gerth 1931). Large volcanic fields of andesitic composition and arc affinities of Miocene age are unconformably overlying previous Mesozoic deposits. These volcanic rocks are widely distributed along the Barrancas and Río Grande valleys and partially tilted by Late Miocene compression. The evolution of the synorogenic deposits as depicted by Kraemer and Zulliger (1997) in Castillos de Pincheira indicates two early stages of uplift and deformation along the western side that ends with a late deformation and contractional uplift of the eastern side. This evolution indicates that the east-verging basement thrust system that characterizes the Principal Cordillera (Ramos et al. 2004) began at about 15.1 Ma; it was reactivated at about 6 Ma with the same vergence, and the final deformation was related to the uplift of the San Rafael Block, in the latest Miocene.

After this period of contractional deformation a generalized extension took place in the foothills and adjacent foreland regions. The uplifted San Rafael block was affected by normal faulting that was controlled by the Paleozoic structures originating a series of blocks and half-graben systems with northwest and east-southeast trends (Narciso et al. 2001). The extensional faults are not so frequent in the foothills, but are clearly seen in the Río Salado valley where they were described by Kozlowski et al. (1993). These faults have a Quaternary reactivation as demonstrated by the location of the Infiernillo alkaline basaltic cones.

The Río Grande basin was affected by latest Pliocene and Quaternary extensional faults as the normal fault that is bounding the Huayquerías de San Carlos and the Tunuyán graben (Polanski 1963). This depression continues through the Valle Extenso del Campo Bajo until the Laguna Llancanelo half graben as indicated by Manceda (in Kozlowski et al. 1993).

Late Quaternary structures are characterized by important strike-slip displacement and contraction as seen in the present orogenic front in the northeastern margin of the San Rafael Block in Las Malvinas town (Bastías et al. 1993). This present contraction may be responsible of recent extension along east-west and northwest trending faults as observed in the adventive basaltic cones of the Payen Matru field.

Tectonic interpretation

The pulse of deformation that started about 15.1 Ma in the Principal Cordillera, migrated to the foreland until 5.05 Ma, and ended with the basement uplift of the San Rafael Block in the latest Pliocene. It coincides in space and time with the expansion and shifting of the volcanic activity from 11.7 to 4.8 Ma observed by Kay (2002). The geochemical and isotopic behavior of these rocks were interpreted by the development of a flat-slab subduction zone, that began to shallow in the Middle Miocene and reached the maximum development at 4.8 Ma, when the arc volcanism ends in the Chachahuén area (Kay 2002). This latest Miocene arc volcanism is widely developed along the San Rafael Block and partially covered by the Payenia more recent volcanics. The San Rafael block was a basement uplift with a similar structural setting than the Sierras Pampeanas further north (Ramos et al. 2002).

As a consequence of the steepening of the latest Miocene flat-slab subduction, important extensional faults are recorded, first affecting the San Rafael Block as depicted by Narciso et al. (2001), and later on shifted to the Río Grande basin where affected the synorogenic deposits. The presence of Quaternary half-grabens from Tunuyán (35°S) to Llancanelo (37°S) as the ones described by Polanski (1963) and Kozlowski et al. (1993) matches the same longitudinal area where arc volcanism was developed in Late Miocene times in the foreland. The alkaline basalts of Pliocene-Pleistocene age developed in Payenia are the expression of hot asthenosphere upwelling associated with steepening of the subducted slab. This hot asthenosphere underplated the thickest crust along the axis of the cordillera as proposed by Hildreth et al. (1999), producing extensive crustal melting and the silicic volcanic products of the Las Loicas trough. This trough is bounded to the east by west dipping normal faults

(Folguera et al. 2005). Subsequent steepening of the subducted slab produced the final migration toward the trench observed in the present active volcanic arc.

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