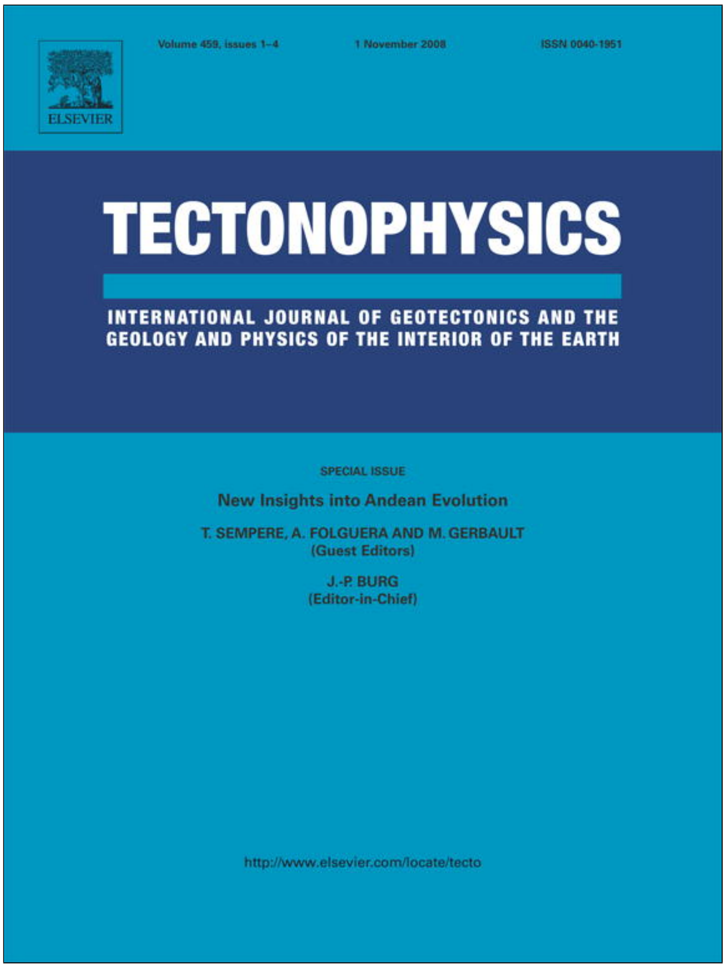
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# Crustal collapse in the Andean backarc since 2 Ma: Tromen volcanic plateau, Southern Central Andes (36°40′–37°30′S)

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ABSTRACT

Analysis of seismic lines and gravity data shows the existence of Quaternary extensional depocenters beneath thick covers of <1 Ma-old volcanic rocks in the Tromen volcanic plateau backarc region (36°40′–37°30′S). Dating and mapping of pre- and post-extensional volcanic units and structure in this area indicate that the main phase of crustal collapse developed during the 1.7–0.7 Ma time interval. However, Late Quaternary reactivations of the extensional structure show that this process is still going on, perhaps with decreasing intensity. Moreover, identification of "mechanical" rift zones and a potentially related main thermal anomaly leads to propose that an east-dipping detachment exists beneath the Late Cretaceous–Late Miocene fold and thrust belt, controlling the crustal collapse at these latitudes. The southernmost Central Andes (35°–37°30′S) have undergone a period of shallow subduction from ~13 to ~5 Ma, that led to expansion of the arc toward the foreland, generation of ductile–fragile crustal transitions, and subsequent foreland imbrications more than 550 km away from the trench. This framework shifted to a normal Andean subduction type after ~5 Ma, and the arc front re-established in the present western position. The consequences of this readjustment were: a) widespread volcanic eruptions of intra-plate melts in the eastern backarc (foreland plateau flows), and b) a major trough formed between the arc front and the foreland plateau basalts (Las Loicas trough). This extensional basin controlled the emplacement of crustal melts as well as primary mantle-derived products, well represented in the Tromen volcanic plateau.


## 1. Introduction

The Andean fold and thrust belt of Argentina and Chile was developed as a response of stacking of mainly east-verging crustal sheets. This process has acted intermittently since 120 Ma to the Present denuding ancient sequences that had been accumulated in retroarc and intra-arc basins buried by the products of erosion of the inner parts of the orogen. Most of the retroarc topography through the Central and Patagonian Andes is formed by folded and thrusted sedimentary and volcanic sequences, locally covered by Late Cretaceous to Tertiary syn-orogenic sediments (Ramos et al., 2004). However, and even more locally, particularly in the Southern Central and Patagonian Andes, discrete segments of the fold and thrust belt are unconformably overlain by Eocene to Quaternary thick sequences of basalts. These rocks are generally related to backarc volcanism, not linked to an arc-magmatic genesis, although they seem to be associated with contrasting processes. Most of the basalt plateaux in Patagonia (42°–48°S) seem to have been associated with the formation of asthenospheric windows beneath the retroarc zone linked to successive collisions of seismic oceanic ridges against the Chilean trench (Ramos and Kay, 1992; Gorring et al., 1997; Ramos, 2002, 2005), while the volcanic successions hosted in the Southern Central Andes (35°–39°S) have been ascribed as related to regional extension (Ramos, 1977; Muñoz and Stern, 1988; Bermúdez and Delpino, 1989; Stern, 1989; Bermúdez et al., 1993; Ramos and Folguera, 2005; Zapata and Folguera, 2005; Kay et al., 2006; Kay, unpublished data). Moreover, onset of this extension in this area has been proposed to be related to the steepening of the subducted Nazca plate after a period of shallow subduction in the Late Miocene, based on the arc-related rocks exposed further east of the fold and thrust belt at 36°30′S (Kay, 2002, unpublished data).

Even though extensional processes have been proposed on the basis of geochemical signatures of post-Miocene intra-plate products, few and poorly constrained structural field evidence has been found in relation to them. Polanski (1954, 1963), González Díaz (1964, 1972a,b), Ramos (1977), Kozlowski et al. (1993), Giampaoli and Dajczgewand (2005) and Backé et al. (2006) are some of the few studies that have

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documented post-Miocene extension in the retroarc between 35° and 39°S, although they have generally failed in explaining its relation to retroarc mafic eruptions.

One of the broadest concentrations of retroarc basaltic–andesitic products in the Southern Central Andes is associated with profuse extensional faulting as we will discuss in the Tromen volcanic area (Fig. 1). This accumulation of retroarc products (Fig. 1) was unconformably emplaced over the Chos Malal fold and thrust belt, which is defined as the contractional belt resulting from the inversion of Late Triassic to Early Jurassic normal faults since the Late Cretaceous to the Late Miocene. These post compressional volcanic sequences have initially led Zapata et al. (1999) to interpret them as related to an extensional regime during post-Miocene times. Then these authors defined the Chos Malal trough as a graben-like structure superimposed to the Chos Malal fold and thrust belt, although they did not show evidence of extensional structures associated with the volcanic eruptions. Previously, the origin of Tromen accumulations, such as other similar volcanic edifices scattered all over the region, had been related to arc processes (Muñoz and Stern, 1988; Muñoz Bravo et al., 1989; Bermúdez, 1991; Bermúdez et al., 1993). Recently, geochemical studies have shown that most of the sequence that forms the Tromen volcanic plateau comes from typical intra-plate melts, with no slab connection, where only the basal-less voluminous products around 4 Ma would have an arc affinity (Kay, 2002; Kay et al., 2006). Contrastingly, the Tromen volcanic plateau has been

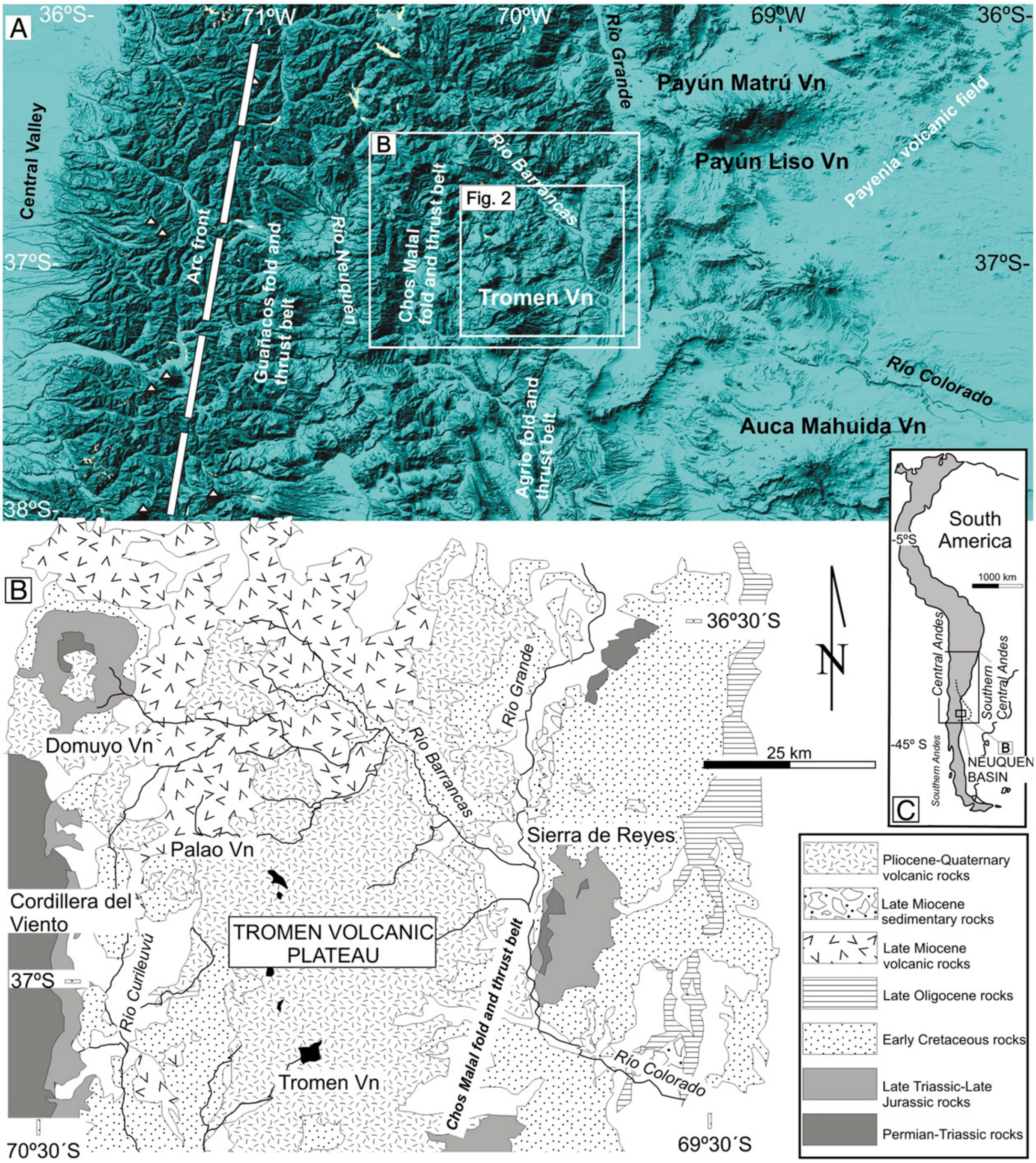



**Fig. 1.** Main geological units of the area of study corresponding to the Andean retroarc between 36°30′–37°30′S. Note the important development of Plio-Quaternary volcanic rocks superimposed to Mesozoic to Middle–Late Miocene sequences denuded in the Chos Malal fold and thrust belt. A) Digital elevation model corresponding to the regional location of the study area and main tectonic features. B) Simplified geological map of the area under study and immediate surroundings (modified from Narciso, 2001). C) Location of B in the western border of South America and extent of the Neuquén basin.

recently considered to have been emplaced in a compressive tectonic setting, mainly because of its location into the Chos Malal fold and thrust belt and due to the finding of folding affecting Quaternary lavas (Galland et al., 2005). We will discuss those points through the manuscript, proposing additional interpretations for those features in a broader context of additional field, seismic and gravimetric data, which agree with previous geochemical inferences.

## 2. Geological setting

The Southern Central Andes (33°–39°S) are formed over a normal segment of subduction (30°E) of the Nazca plate beneath the South American plate, although their structure is related to variable geometries of the subduction system through time. During the last 25 Ma, the existence of arc and retroarc associations indicates the persistence of the subduction process (Kay et al., 2006). Although subduction and arc production have been steady processes, the Benioff zone geometry has changed during this lapse, as the arc front has moved several hundred kilometers to the east, first during the Late Cretaceous and second in the Late Miocene (Kay, 2002; Ramos and Folguera, 2005; Kay et al., 2006). After those shallowings of the subducted plate, the current position of the arc front at the inner parts of the fold and thrust belt has been re-established.

The Andean retroarc between 36°30′ and 37°30′S is characterized by the presence of a Late Triassic to Early Cretaceous extensional basin, named the Neuquén basin (Fig. 1). Different mechanisms have acted synchronously to form the Chos Malal fold and thrust belt, which is the result of the inversion of Late Permian, Late Triassic and Early Jurassic extensional detachments and thrusting of Late Jurassic to Early Cretaceous ductile horizons forming stacked sedimentary sheets in the Neuquén basin at these latitudes (Fig. 1) (Zollner and Amos, 1973; Ramos, 1977; Kozlowski et al., 1993; Manceda and Figueroa, 1995; Cobbold et al., 1999; Zapata et al., 1999; Cobbold and Rossello, 2003; Zapata and Folguera, 2005). A regional unconformity separates Mesozoic sequences from Cenozoic piles (Groeber, 1946), where the lower section was deformed mainly during the late Early to Late Cretaceous as constrained by fission track ages (Burns, 2002) and associated syn-orogenic deposits (Ramos, 1977; Cobbold and Rossello, 2003; Ramos and Folguera, 2005), and then during the Eocene (Cobbold et al., 1999). The oldest products emplaced over the unconformity were formed in a Late Oligocene arc and in an intraplate retroarc basin of the same age (Ramos and Barbieri, 1989; Suárez and Emparán, 1995; Kay and Copeland, 2006; Kay et al., 2006). Younger volcanic sequences also unconformably cover Cretaceous deformation, and represent Middle to Late Miocene volcanic piles with arc affinities (Llambías et al., 1979, 1982; Kay et al., 2006). Late Oligocene to Late Miocene volcanic successions are in turn folded and thrusted by a Late Miocene phase of deformation that affected mainly the retroarc zone of the Southern Central Andes (Fig. 1) (Llambías et al., 1979; Ramos and Barbieri, 1989). Early Pliocene to Quaternary volcanic associations in the retroarc zone, which were formed and accumulated after the steepening of the subducted Nazca plate at these latitudes, lie almost horizontally, and are not incorporated into the fold and thrust belt. Part of these rocks co-existed with extensional

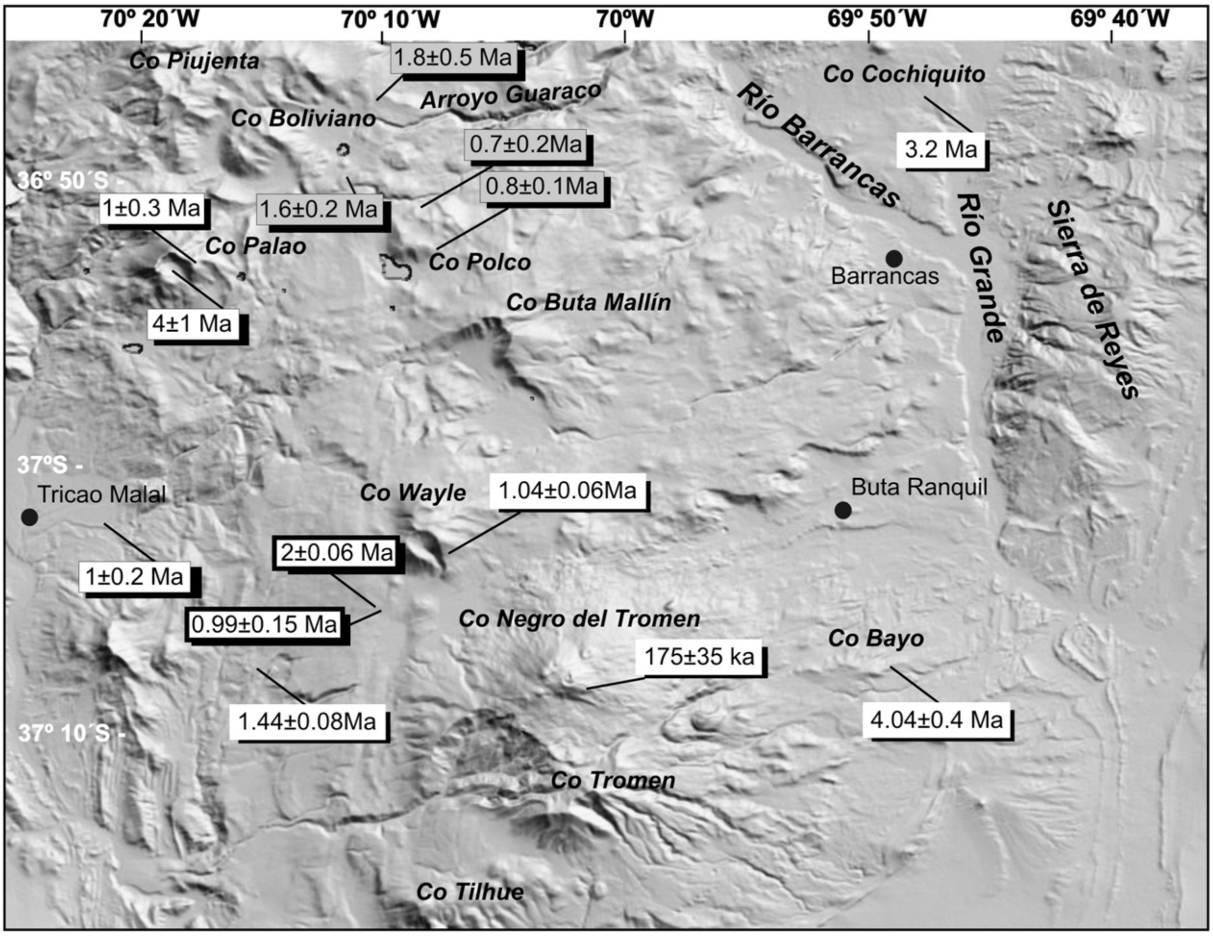



**Fig. 2.** Published and new radiometric ages plotted on digital elevation model of the Tromen volcanic plateau (GTOPO30) (gray squares, in the northern part of the study area, Table 1) in the Tromen volcanic plateau area (Fig. 1) (Valencio et al., 1979; Linares and González, 1990 (white squares); Galland et al., 2005 (bold squares); Kay et al., 2006 (white frameless squares).

events that controlled their distribution and related basin geometry (Ramos and Folguera, 2005; Zapata and Folguera, 2005).

North of 37°30′S, the Pliocene to Quaternary Tromen volcanic plateau is superimposed to the Chos Malal fold and thrust belt (Fig. 1). It constitutes one of the broadest volcanic accumulations in the entire Southern Central Andes with a relatively important amount of radiometric ages (Fig. 2) (Valencio et al., 1979; Linares and González, 1990; Galland et al., 2005; Kay et al., 2006). To the east in the foothills, even broader–extensive volcanic accumulations were emplaced at the same time (foreland plateau sequences), such as the Payenia volcanic field, whose southern extreme is constituted by the Auca Mahuida shield volcano (Fig. 1) (Holmberg, 1964; Hildreth et al., 1999), although they are covering only smoothly folded Late Cretaceous sequences located to the east of the emergent orogenic front. Radiometric ages of the three more important volcanic centers (Auca Mahuida, Payun Matru and Nevado volcanic centers) reveal that this foreland volcanic

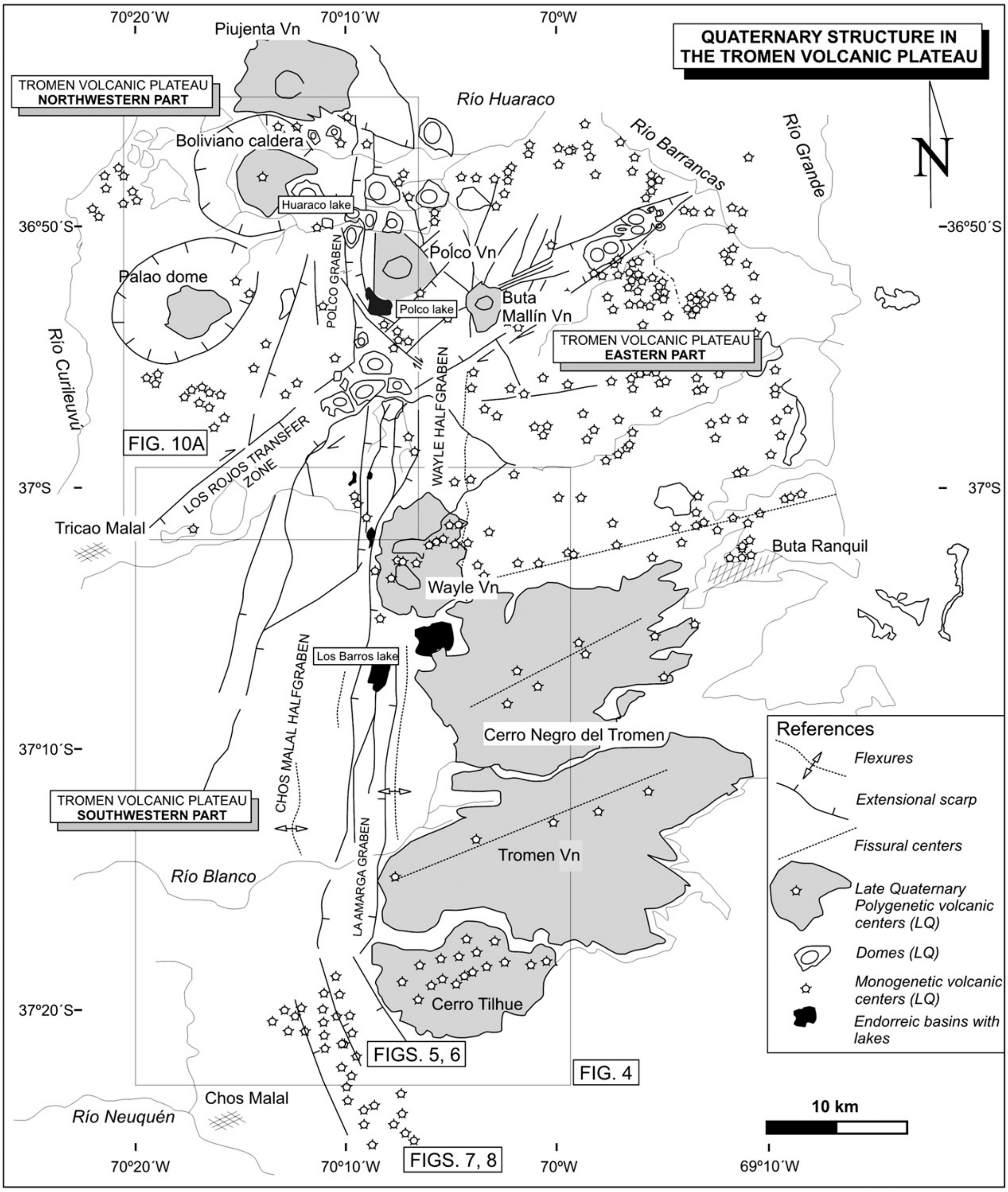



**Fig. 3.** Quaternary structure of the Tromen volcanic plateau and volcanic features. The southern area corresponds to La Amarga graben, and the northern part constitutes its continuation north of the transfer system corresponding to Los Rojos fault system. Note two main domains, one on the west, where extensional structures develop along a N to NNE strike, and one to the east where NE structures are controlling the emplacement of a monogenetic volcanic field.

**Table 1**
New radiometric ages performed in the Tromen volcanic plateau

| Volcanic centre/sample | % Ar atm | Ar rad. Nl/g | % K | Material | Integrated age (Ma) | Weighted mean age (Ma) |
|---|---|---|---|---|---|---|
| Early Quaternary sequences west of Polco lake | 92 | 0.08 | 1.158 | Whole rock | 1.8±0.5 | – |
| Early Quaternary sequences east of Huaraco lake | 85–92 | 0.097–0.104 | 1.525 | Whole rock | 1.8±0.5<br>1.6±0.2 | 1.6±0.2 |
| Polco volcano | 86–91 | 0.073–0.084 | 2.565 | Whole rock | 0.7±0.2<br>0.8±0.1 | 0.8±0.1 |

plateau is Quaternary in age (Muñoz Bravo et al., 1989; Bermúdez, 1991; Rossello et al., 2002).

## 3. Stratigraphy of the Tromen volcanic plateau

The Tromen volcanic plateau counts with a relatively important number of radiometric ages, although poorly integrated geological maps are available (Groeber, 1946; Zollner and Amos, 1973; Llambías et al., 1982). A new tectonic evolution scheme based on geochemical data and radiometric ages has been proposed recently to account for the emplacement of the retroarc andesitic–basaltic sequences over the fold and thrust belt (Figs. 1 and 2) (Kay et al., 2006). The basal part of this Plio-Quaternary sequence corresponds to the Cerro Bayo with 4.04±0.4 Ma, which is a silicic dome complex formed by differentiation of arc derived melts (Fig. 2; Kay et al., 2006). The following units are mainly represented by Early Quaternary andesitic–basaltic lava flows, which have experienced an arc decrease affinity with a tendency to derive from intra-plate melts. The youngest volcanic vents are related to the Wayle volcano (1.04±0.06 Ma), which is a stratovolcano with no arc affinities (Kay et al., 2006), as well as the last

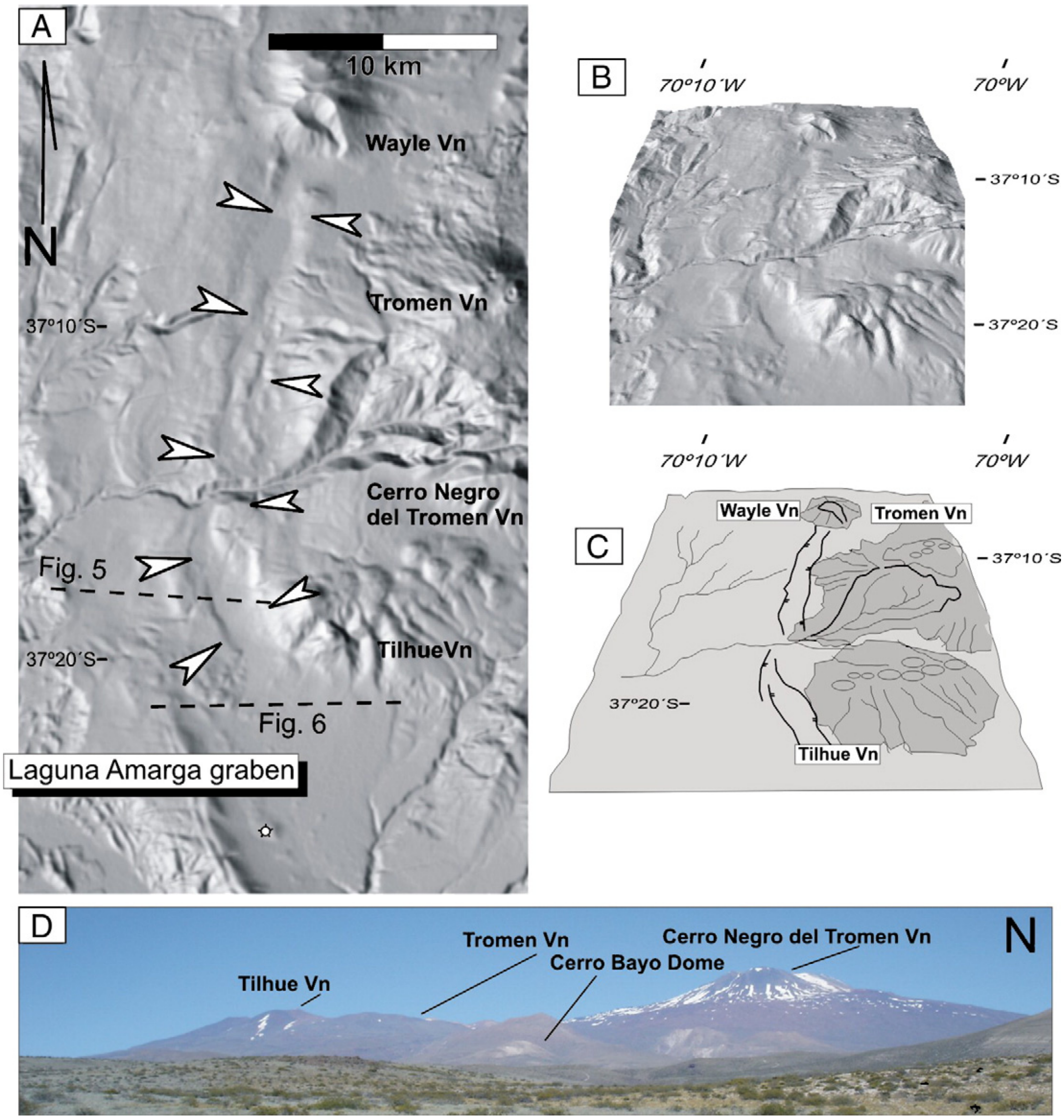



**Fig. 4.** Southern sector of the study area, corresponding to La Amarga graben (white arrows indicate the trough edges), located to the east of the Tromen volcano. The Wayle volcano is a 1 Ma center located in the N-striking axis of this extensional structure that affects 2–1.7 Ma volcanic sequences. Most of the extension was accommodated in the 2–1 Ma interval. See Fig. 2 for radiometric age sources. A) Shaded digital elevation model of the La Amarga graben. B) 3D perspectives of A. C) Interpretation of B. D) Main polygenetic centers that are part of the Tromen volcanic plateau.

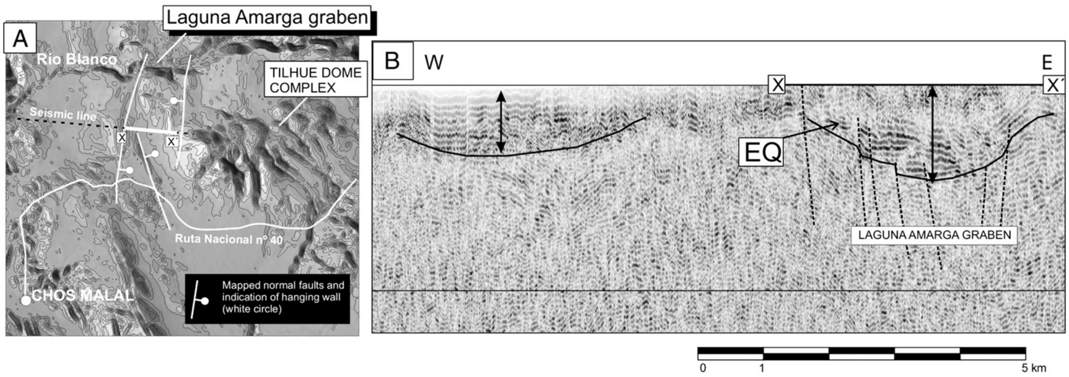



**Fig. 5.** A) West–east seismic line across the Chos Malal fold and thrust belt in the southern part of the study area (see Fig. 4 for location) and indication of the mapped Quaternary extensional depocenters (white segments) (Early Quaternary units, EQ). B) Detail of the depocenters across the seismic line. See text for discussion. Compare with the seismic line in Fig. 6 across the southern end of La Amarga graben, on the western slope of Tilhue volcanic center and note the changes in the style of deformation across this extensional structure, from a graben-like depocenters to halfgraben systems (see text for further details).

melts of the Tromen volcano dated at 175 ka. This scheme shows that even though the origin of those volcanic piles is more complex and heterogeneous than previously though (Zollner and Amos, 1973; Bermúdez and Delpino, 1989), less than 1 million year terms are not connected with the asthenospheric wedge, and therefore these volcanoes do not belong to the Quaternary volcanic arc as initially proposed.

Plio-Quaternary successions in the Tromen volcanic plateau can be divided in three main groups: i) a poorly constrained Early Pliocene sequence with arc affinities (Kay et al., 2006), ii) a Late Pliocene to Early Quaternary volcanic plateau (EQ) of mainly andesitic composition outcropping in the western side of the study area, east of the Middle Miocene folded sequences, and iii) a series of Late Quaternary polygenetic and monogenetic volcanoes and domes (LQ) scattered

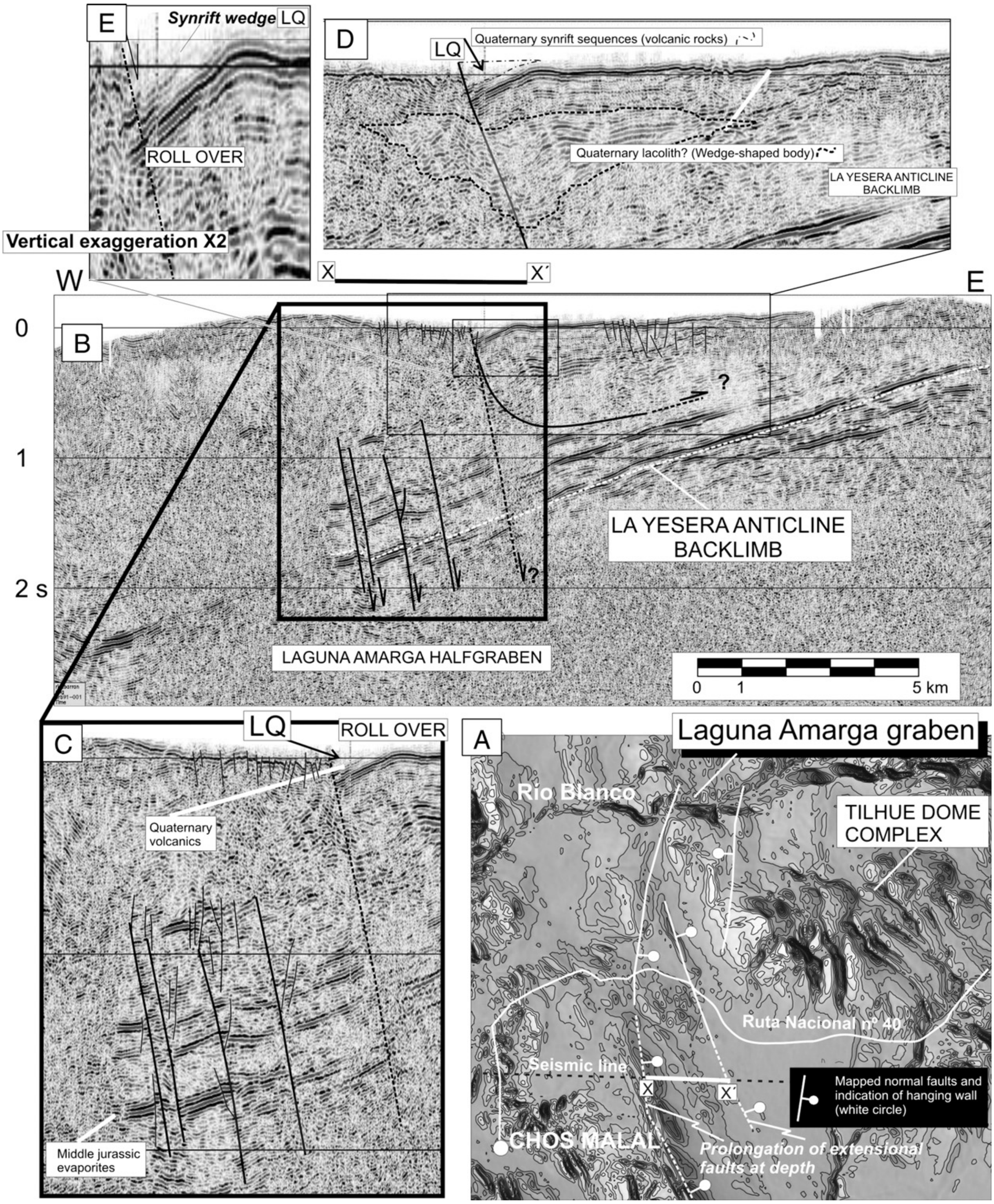



**Fig. 6.** A) Location of a west–east seismic line across western age of the La Amarga trough in the southern part of the study area and its location related to mapped extensional structures (see Fig. 4 for location in a regional perspective). B, C) Interpretation of seismic line represented in A. Note that an anticline is associated with the hanging wall of an extensional fault. D) Determined anomalous body in the seismic information, formed by a series of strong reflectors tentatively interpreted as wedge-shaped stacked sills in the extensional structure associated at surface with voluminous volcanism displayed in Fig. 3. E) Detail of extensional roll-over and Quaternary synrift sequences related to the extensional faults.

through the area following N, NE and ENE trending fissures (Fig. 3). Among this last group Cerro Tromen, Wayle, Polco, Boliviano, Piujenta and Buta Mallín stratovolcanoes are the main erupting centers, as well as the Palao dome and Tilhue dome complex (Figs. 2 and 3). Other hundreds of small volcanic centers are also grouped in this last category (Fig. 3) having as a common characteristic to be emplaced over Early Quaternary units. Early Quaternary basaltic andesites and andesitic piles have been dated at 1.8±0.5 and 1.6±0.2 (whole rock K/Ar, Table 1) in the northern part of the study area (Fig. 2). The other ages are available in the literature and represent a similar temporal range in the southern part of the study area (Fig. 2) (Valencio et al., 1979; Galland et al., 2005; Kay et al., 2006). They show that the basement of the main polygenetic volcanoes, such as Wayle and Cerro Negro del Tromen volcanoes, has a Late Pliocene to Early Quaternary age as to the north (Fig. 2). These sequences ranging from 2±0.06 to 1±0.2 Ma form a N-trending elongated stripe in the retroarc zone (Figs. 2 and 3) east of the Cordillera del Viento basement uplift and west of the Tromen basement high (Fig. 1). As previously stated, the distribution of those sequences, as well as their emplacement east of the Present day arc front (Fig. 1) had led Zapata et al. (1999) to propose that they could have been related to backarc spreading. Then the term "Chos Malal trough" was then used to define the basin where retroarc products were emplaced over the Chos Malal fold and thrust belt (Fig. 2). Two unconformities bound this Latest Pliocene to Early Quaternary succession: A smooth upper unconformity established with less than 1.3 to 1.4 Ma volcanic piles, and a lower one with tightly folded Miocene and Mesozoic sequences.

Less than 1.3 Ma volcanic piles related to monogenetic basaltic–andesitic sequences, dome complexes and stratovolcanoes are located over Pliocene to Quaternary lava flows and more locally over Miocene and Mesozoic folded strata following mainly NE and ENE lineaments (Fig. 3). While monogenetic andesitic to basaltic fields form a continuous blanket becoming thicker to the east and covering most of the study area, polygenetic volcanoes and dome complexes are located through a N-trending 30 km wide band at around 70°–70°20′W, immediately to the east of the proposed Early Quaternary depocenter (Figs. 2 and 3). Those polygenetic centers and dome complexes share common characteristics such as conical shapes and heights between 2500 and 2900 m, and a basement with an average elevation of 1800–2000 m. Few radiometric ages show that those centers (LQ) with similar morphology were implanted over the Late Pliocene–Early Quaternary plateau (EQ) immediately after the second half of the Quaternary (1.04±0.6 Ma—40Ar/39Ar—Cerro Wayle, Kay et al., 2006; 0.7±0.1 Ma and 0.8±0.2 Ma—K/Ar—Cerro Polco, Table 1). Most of these centers are in a moderately high erosion degree, not being reconstituted by younger eruptions. Only the Cerro Negro del Tromen has been active at least up to the Late Quaternary at 175±35 ka (40Ar/39Ar) (Fig. 2; Kay et al., 2006) and constitutes the last stage of the Tromen volcano (Groeber 1946; Llambías et al., 1982). Even though the Tromen volcano has not been dated, its morphology suggests an equivalent age to the Polco and Wayle volcanoes located immediately to the north (Figs. 2 and 3). Last eruptions of the Cerro Negro del Tromen would have occurred when the area was already occupied by ancient Mapuche communities (Groeber, 1928), and moreover, the central crater is still associated with geothermal fields.

## 4. Structural analysis

The Tromen volcanic plateau was affected by different sets of extensional and transtensional faults, with NNE and N dominant

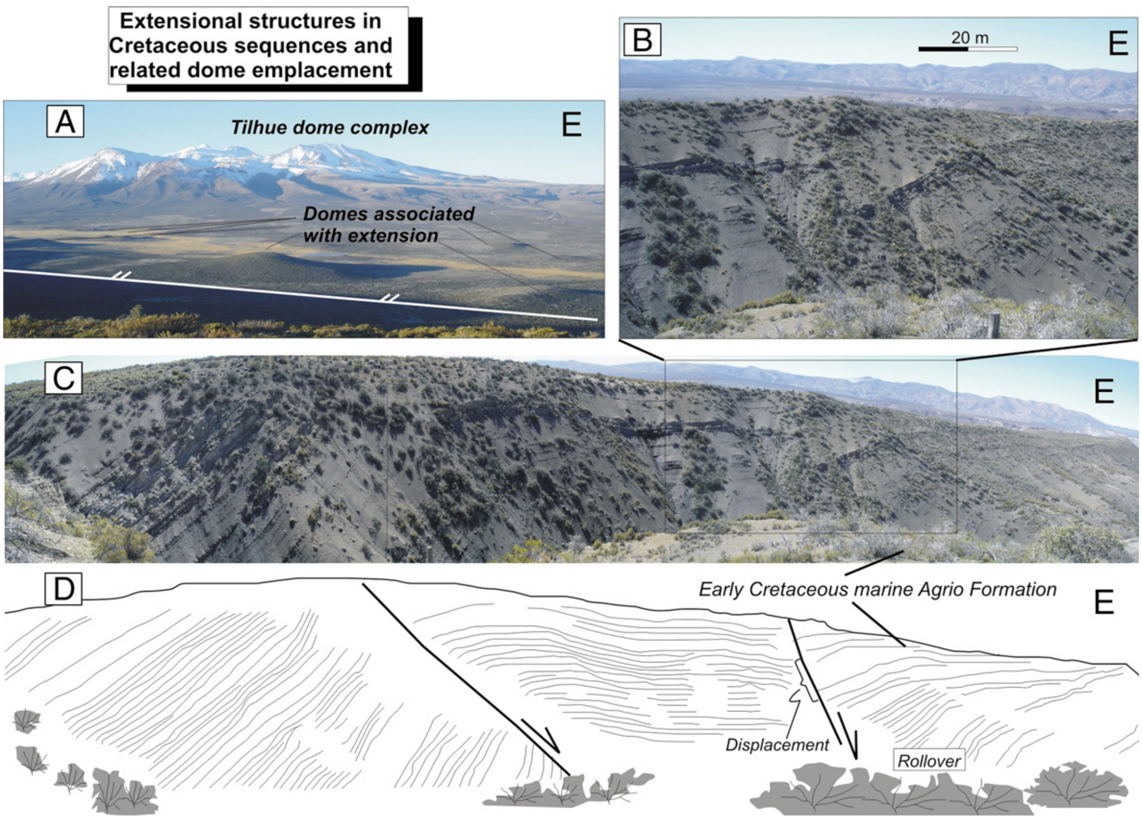



**Fig. 7.** Evidence of extensional faulting affecting the basement of the Quaternary effusions south of the seismic line displayed in Fig. 6, following regionally the same trend of structures (see Figs. 3 and 8). A) Field view of monogenetic domic field south of La Amarga graben. B) Detail of a normal fault located at the foot wall of the main extensional structure displayed in Fig. 6. C) Location of normal fault displayed in B, and its relation to a small roll-over at its hanging wall and another extensional fault located immediately to the west. Note the geometric similarity between major structure interpreted in Fig. 6 (anticline at the hanging wall of a major extensional fault) and the small structure displayed here. D) Interpretation of C.

trends (Fig. 3). The Late Pliocene to Early Quaternary volcanic rocks (EQ) are affected by fault scarps, while younger volcanoes and domes (LQ) are rarely cut (Fig. 3).

Three areas can be distinguished in relation to fault distribution and geometry (Fig. 3): i) an eastern part where mainly monogenetic basalts and andesites are controlled by ENE-striking structural lineaments, locally forming graben structures but usually buried by volcanic accumulations; ii) a northwestern area where N to NNW and NNE fault scarps are related to halfgraben systems, often segmented by WNW and NE-striking faults, and where relatively important, in terms of volume, volcanic edifices were formed; iii) and a southwestern area where the basement of the biggest stratovolcanoes through the entire retroarc zone is affected by N-trending normal faults (Figs. 3 and 4). We will only describe the two last areas in detail: the best expositions of the basement beneath the Late Quaternary volcanoes are exposed in the northern zone; and the southern area counts with a relatively good seismic reflection coverage, which allows examining deeper structure of fault sets, mapped and tracked to the north and further south.

*4.1. Southwestern area*

The southwestern part of the Tromen volcanic plateau is characterized by a high relief to the east that represents the western flank of the Tromen volcano and Tilhue dome complex and a west-dipping low plain to the west that has a basin and range topography (Fig. 4). A 7 km wide trough flanks the western slope of the biggest volcanic edifices in the area changing its strike from NNE to the north to NNW in the south. This trough, called La Amarga graben, is formed over Early Quaternary volcanic sequences and is filled at its northernmost part by the 1.04 Ma Wayle lavas (Fig. 4). Morphologically it is a symmetrical-linear depression (Figs. 3 and 4) although seismic information reveals important structural changes along strike (Fig. 5).

Two west–east 2D seismic lines (Figs. 4 and 5) were registered there as part of two different surveys, both performed before the early 90's. The quality of the data is relatively poor, mainly due to the structural complexity of the Chos Malal fold and thrust belt, although the shallower part of the seismic information, linked to outcrop data, gives a sight of the structure associated with the Quaternary structure.

Fig. 5 shows the analysis performed on a stacked 2D seismic line, across the Laguna Amarga graben at the western flank of Tilhue dome complex (see location in Fig. 4). There, below 0.5 s of two-way time, the data quality is extremely poor, showing no reflection events in most of the interval. That fact is a direct response of the structural complexity of the area, related to the Cretaceous to Miocene deformation. However, beneath the Laguna Amarga graben that was defined by outcrop data, the seismic line shows a group of strong reflectors next to the surface. Those reflectors lie in a conspicuous depression limited and affected by extensional faults (Fig. 5). The high amplitude reflectors are interpreted as volcanic sequences filling a

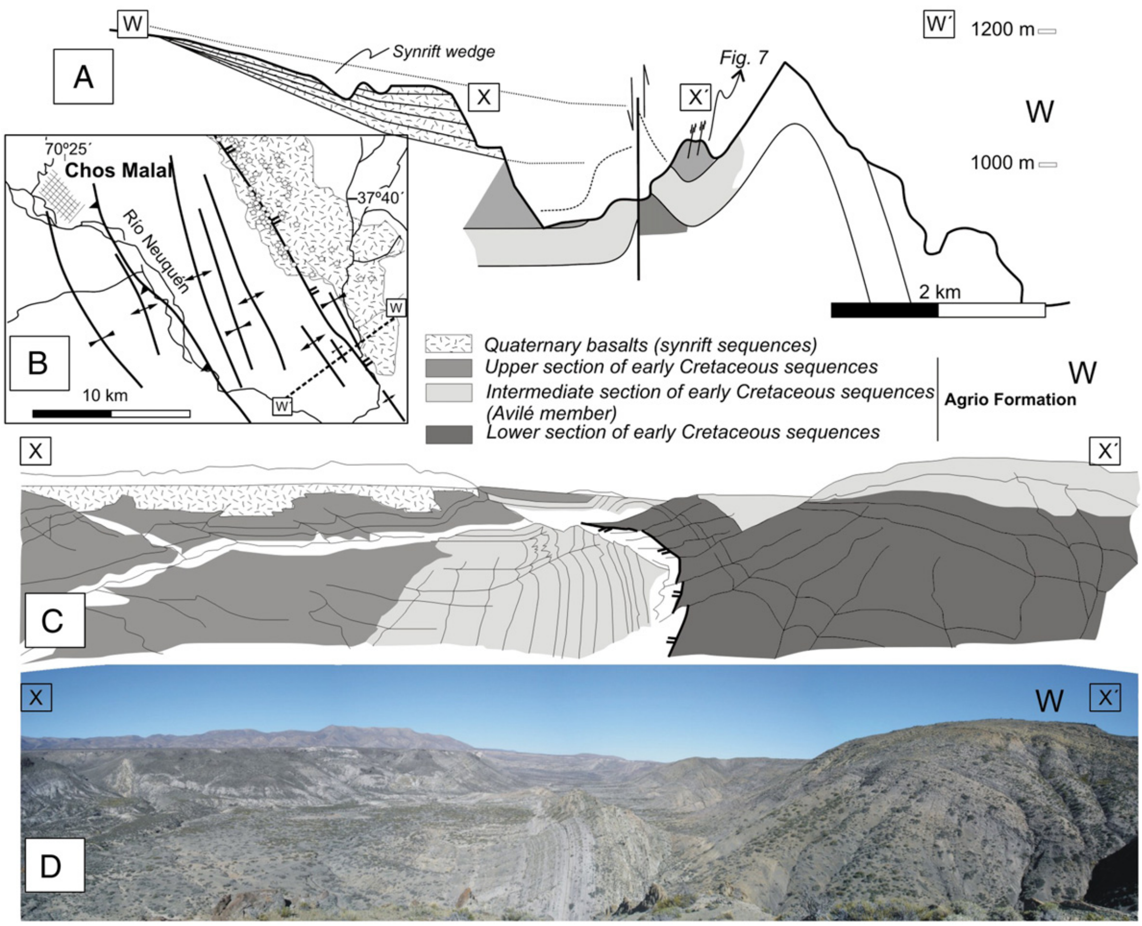



**Fig. 8.** Southernmost evidence of extension documented in the present work. Southern continuation of the major normal fault associated with synrift volcanic sequences displayed in Fig. 6 penetrates into the Chos Malal fold and thrust structure, affecting previous contractional structure. A) Structural profile where the relation between synrift deposits and the extensional structure affecting previous folding is shown. B) Regional location of profile displayed in A. C) Stratigraphic evidence of continuation of faulting along the southern projection of structure displayed in Fig. 6. Note that the lower terms of the Agrio Formation are tectonically in contact with the upper terms of the same unit, in accordance with displacements represented in Fig. 6. D) Cartoon corresponding to C interpretation.

graben structure, in contrast with a low amplitude background corresponding to the deformed Cretaceous sedimentary rocks. To the west, there is also another group of high amplitude reflectors contained in a shallower depression (Fig. 3).

Fig. 6 shows the analysis on a time migrated 2D seismic line, located in a southern position with respect to the previous one (Figs. 4 and 5). In that geographic setting, the irregular surface of the Chos Malal fold and thrust belt is replaced by the flat backlimb of the La Yesera anticline, an east-verging basement block whose axial surface is located to the east outside the 2D line. The seismic information shows that the backlimb of the La Yesera anticline is affected by a series of east-dipping extensional faults forming a halfgraben system that defines a tectonic depression (wedge geometry) filled by Quaternary volcanic rocks, represented by high amplitude reflectors located near the surface. The geographic position of this extensional system is coincident with the southern prolongation of the Laguna Amarga graben, beyond the area of the mapped fault scarps (Figs. 4 and 6). There, onlap relations between the upper volcanic reflectors and their basement show that the tilting of deeper sequences was older than, or at least coetaneous to, the accumulation of the Quaternary sequences (Fig. 6).

Fieldwork performed immediately to the south of the seismic lines displayed in Figs. 5 and 6, shows that extensional faults are affecting Early Cretaceous marine sequences of the Agrio Formation at surface (Fig. 7), over which a series of andesitic to dacitic domes was emplaced. These faults are formed at the footwall of the main normal fault determined from seismic interpretation and mapping (Figs. 3, 4 and 6), dipping in the same direction and defining similar geometries at different scale. Particularly, one of the normal faults displayed in Fig. 7 is associated with a roll-over with similar geometry to the one described from seismic data in Fig. 6. Main normal fault displayed in Fig. 6 is located around 1 km to the east controlling a depocenter of Quaternary lavas (Fig. 8). These extensional structures, with displacements no higher than 20 m (Fig. 7), can be considered minor in relation to the main structures that depressed the previous compressive structures and provoked the partial collapse of the fold and thrust belt. However, they closely reflect at surface the major extensional geometry at depth. In Fig. 6 (B and C) minor extensional faults like the ones depicted in Fig. 7 are interpreted from seismic data as affecting the footwall of the main extensional depocenter, showing that this scale of deformation is shallow. One kilometer to the east the southern continuation of the major normal fault, interpreted in Fig. 6, runs through folded and thrusted marine Cretaceous sequences (Fig. 8). Contrastingly to the structure displayed in Fig. 7, this fault is expected to involve substantial amounts of displacement, judging its behavior analyzed in Fig. 6 capable of accommodating enough space for synrift deposits to the east. Fortunately, the high resolution of the stratigraphy in this part of the Neuquén basin allows visualizing important stratigraphic displacements along that fault, compatible with the ones expected from seismic interpretation (Fig. 6). Fig. 8 shows the southernmost recognized position of the extensional structure affecting the Chos Malal fold and thrust belt. There, the southern continuation of the major normal fault controlling the volcanic depocenter juxtaposes the lower terms of the Agrio Formation, located beneath regressive sandstones of the Avilé member, to the upper terms of the same unit, located on top of the same sandstones.

To the north no seismic lines exist, although the morphological expression of the extensional structure is increasingly more

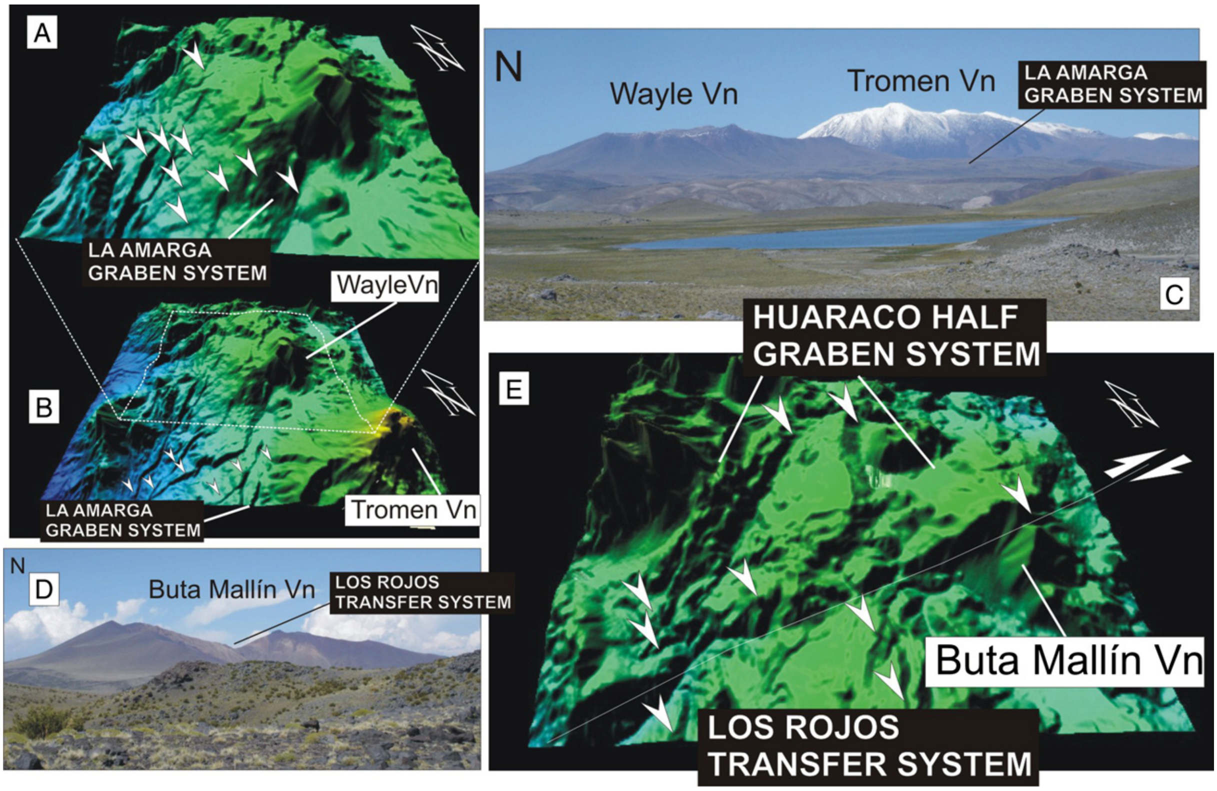



**Fig. 9.** A) 3D perspective view of a digital elevation model showing the southern part of the study area corresponding to the western flank of the Wayle and Tromen volcanoes. The Wayle is a 1 Ma volcano (Kay, 2002; Kay et al., 2006; Kay, unpublished data), while the Tromen is a composed volcanic structure with a young edifice at the summit less than 200 ka and active up to historical times (Groeber, 1928). B) and C) Extensional faults affect Late Pliocene to Early Quaternary volcanic sequences (EQ) on the western flanks of the two volcanoes, and previously folded Miocene and Mesozoic sequences, forming 2.0–1.4 Ma volcanic depocenters (see Figs. 2 and 3 for location). D) and E) The Buta Mallín volcano is located over a NE-trending main transfer zone (Los Rojos transfer fault; see Fig. 3 for location) affecting the 2–1.4 Ma volcanic plateau (EQ). Arrows indicate position of the extensional scarps on the digital elevation model.

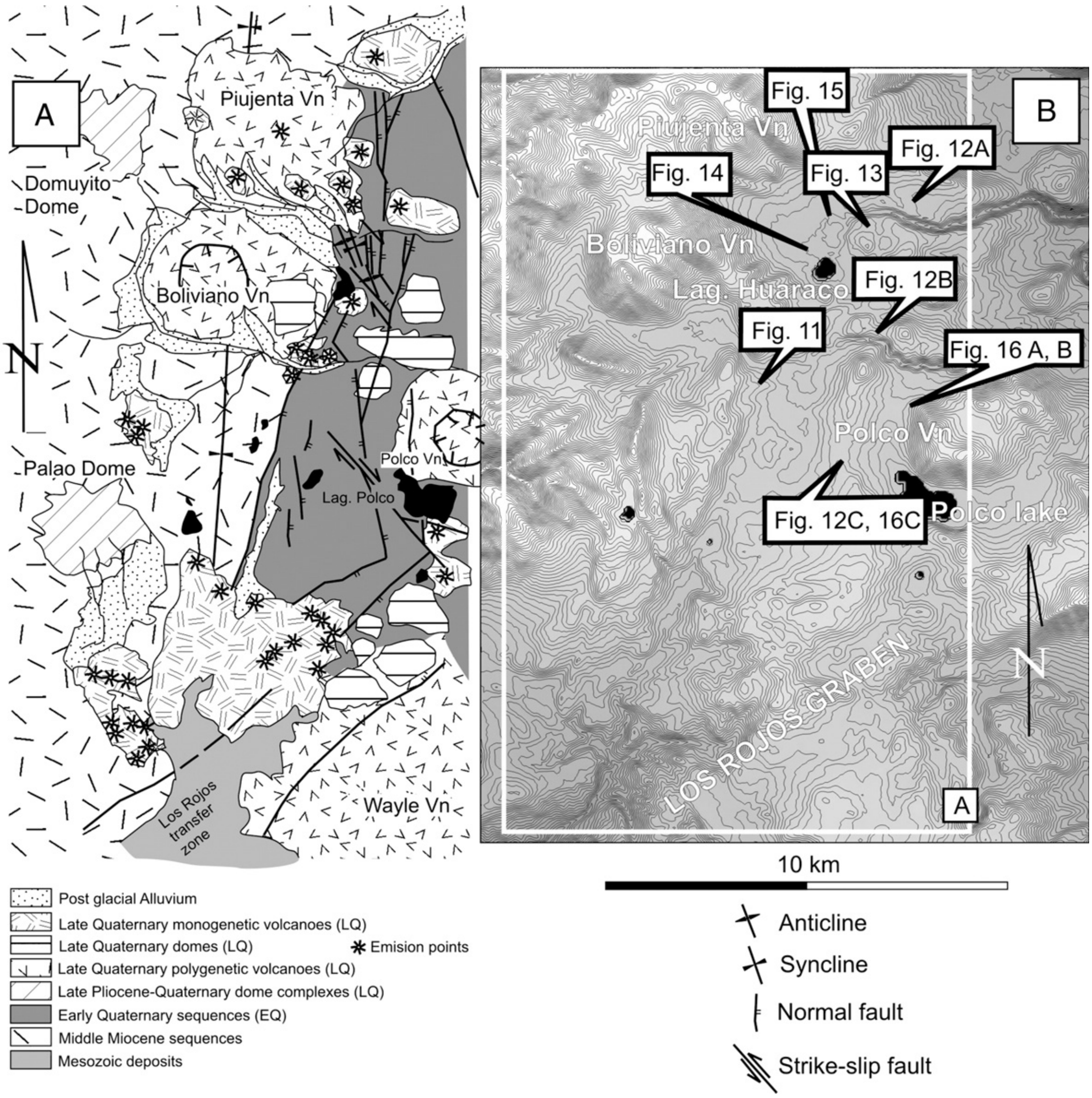



**Fig. 10.** Northern part of the study area located between the Palao and Polco volcanic centers (see location in Fig. 3). A set of NNE-striking extensional faults juxtapose Early quaternary basalts and folded Miocene sequences (see Fig. 11). These 2–1.5 Ma sequences are dismembered by N extensional faults with variable polarity along strike. Those changes are accommodated by different mechanisms from bands of transpressive folds (see Fig. 12 and 10) to discrete strike-slip faulting and to broad transtensional systems.

important because of widespread Quaternary nearly flat lava flows that constitute an excellent marker to track young structure (Fig. 9).

A series of east-facing scarps develops west of La Amarga graben forming N to NNE-trending narrow halfgrabens. These faults end against the ENE-striking Los Rojos transfer fault, located north of Wayle volcano

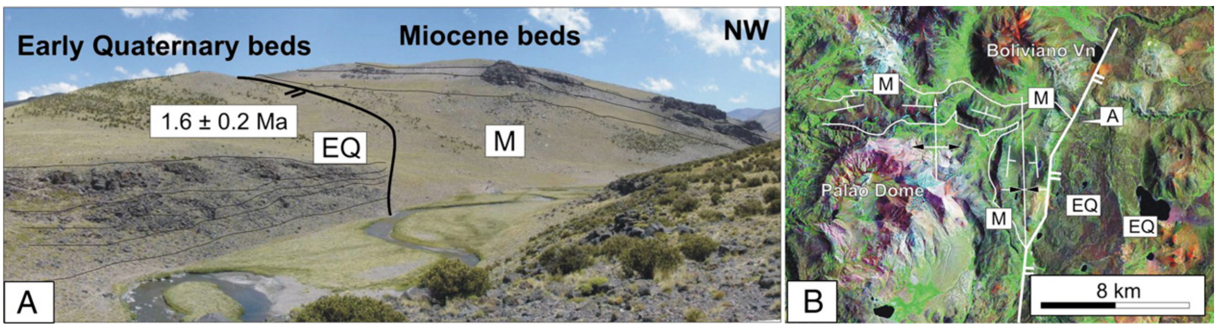



**Fig. 11.** Western border of the extensional basin located west of the Boliviano and Palao volcanic centers. Lower Quaternary lavas are filling extensional depocenters and are in turn affected by extensional structures, and are unconformably overlain by less than 1 Ma volcanic rocks, evidencing the occurrence of a main phase of extension in the region between 2 and 1 Ma. A) Vertical fault juxtaposing folding Late Miocene sequences against early flat Lower Quaternary volcanic sequences. B) TM image where contractional structure affecting Miocene beds is displayed, as well as its relation to Quaternary extensional depocenters.

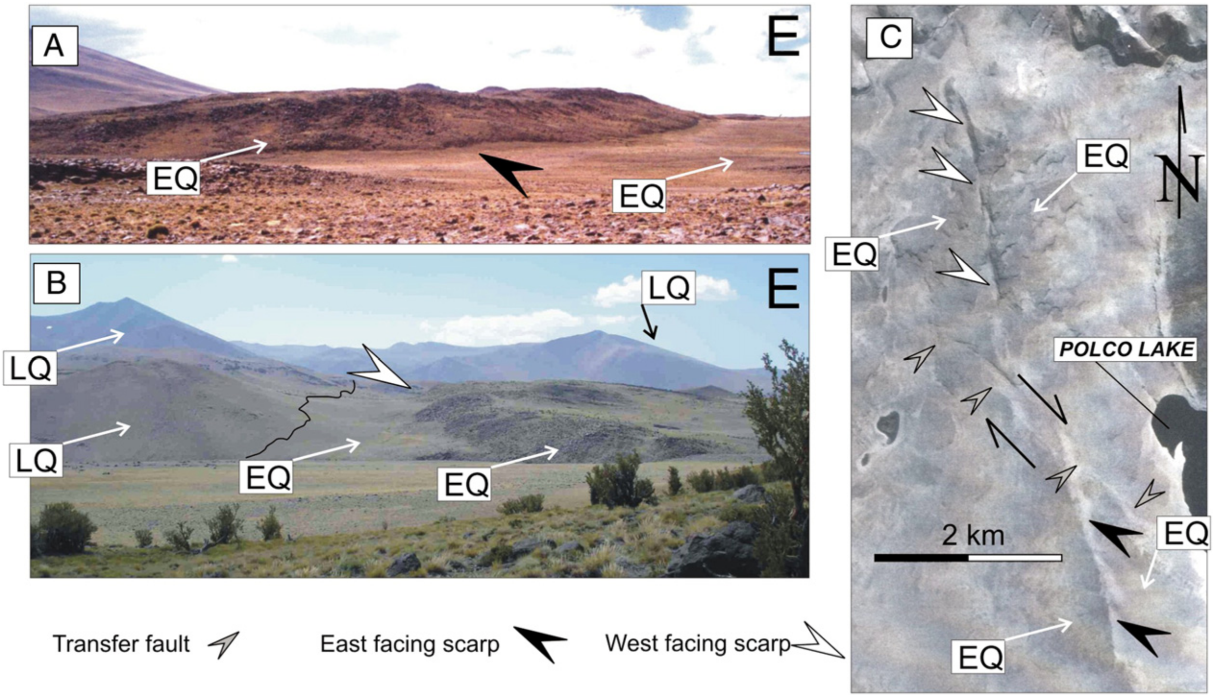



**Fig. 12.** Changes in polarity of the extensional structure along strike, in the northern part of the study area. A) East facing extensional scarp, trending in the NNW direction, in the northernmost part of the study area (north of Huaraco lake; Fig. 10). B) West facing normal scarp south of Huaraco lake (Fig. 10). C) Aerial picture of the NW-trending transfer fault east of the Polco lake (Fig. 10). Early Quaternary units = EQ; Late Quaternary units = LQ.

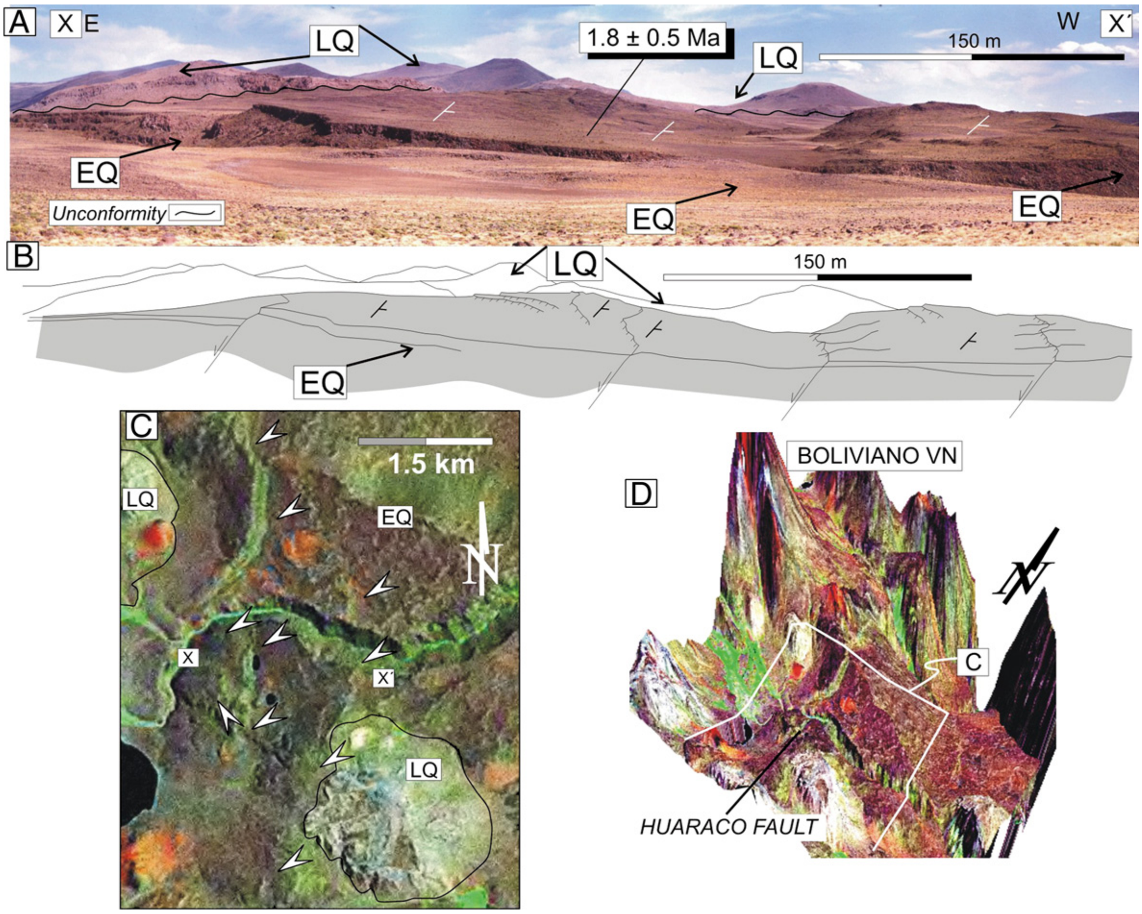



**Fig. 13.** A, B) Extensional faults in the northernmost part of the study area affecting a volcanic plateau dated at 1.8 ± 0.5 Ma. See domes and small polygenetic volcanic centers located in the background, unconformably covering the extensional faults and tilted halfgrabens. The Polco volcano belongs to this series of small centers and has yielded an age of 0.8 ± 0.1 Ma, evidencing that the main phase of extension has occurred between 1.8 ± 0.5 and 0.8 ± 0.1 Ma. C) Landsat TM image, where the morphological-field expression of the scarps shown in A is visible. See Fig. 10 for location in a regional map (arrows indicate fault traces). D) Oblique perspective view of the extensional faults (Landsat TM image over a digital elevation model exaggerated ×2) affecting the basement at the eastern slope of the Boliviano volcano. EQ = Early Quaternary units; LQ = Late Quaternary units. See Fig. 14 for regional location.

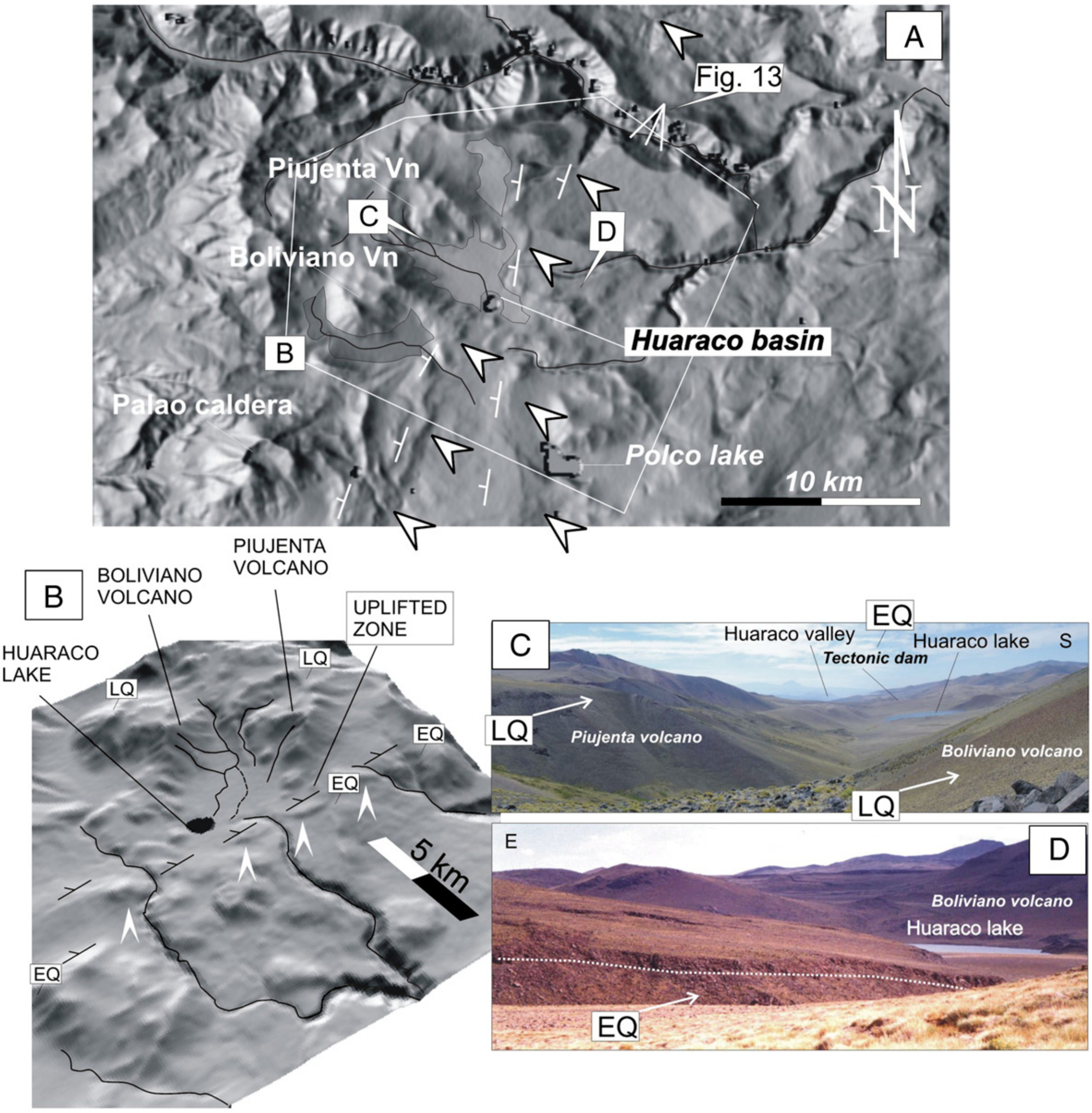



**Fig. 14.** Alterations to the fluvial network related to extensional tectonics in the northern part of the study area. A) Shaded DEM where main NE-trending extensional scarps are indicated (white arrows) in association with presently flooded fluvial basins and fossilized ones, upstream the tectonic dams. B) 3D DEM of the area indicated in A. See that tilted blocks (see also D) have obtruded previous fluvial channels forming closed basins all along the hanging wall of an extensional fault at the back of a tilted block. C) Field picture taken from the Boliviano volcano to the Huaraco tectonically closed basin (see A for location). D) Tilted block formed by Early Quaternary volcanics damming the Huaraco lake (see A for location).

(Figs. 3 and 9). The Los Rojos fault system defines a major topographic step between the higher northern area and the southern one. This structure accommodated fault displacements between the northern and southern areas and at the same time constituted an important channel for magmatism. At the eastern end of this fault, one of the major volcanoes in the Tromen volcanic plateau, the Buta Mallín volcano, raises

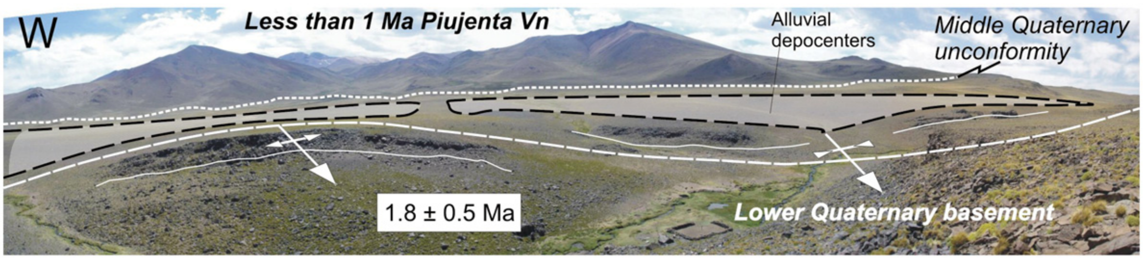



**Fig. 15.** Narrow transfer zone occupied by small folds in Early Quaternary volcanic sequences, accommodating jumps in trend of the extensional structure. Polygenetic volcanoes such as the Piujenta volcano in the background are unconformably overlying that structure, which is in turn drowned by thick postglacial alluvial and lacustrine sediments. See location in Fig. 10.

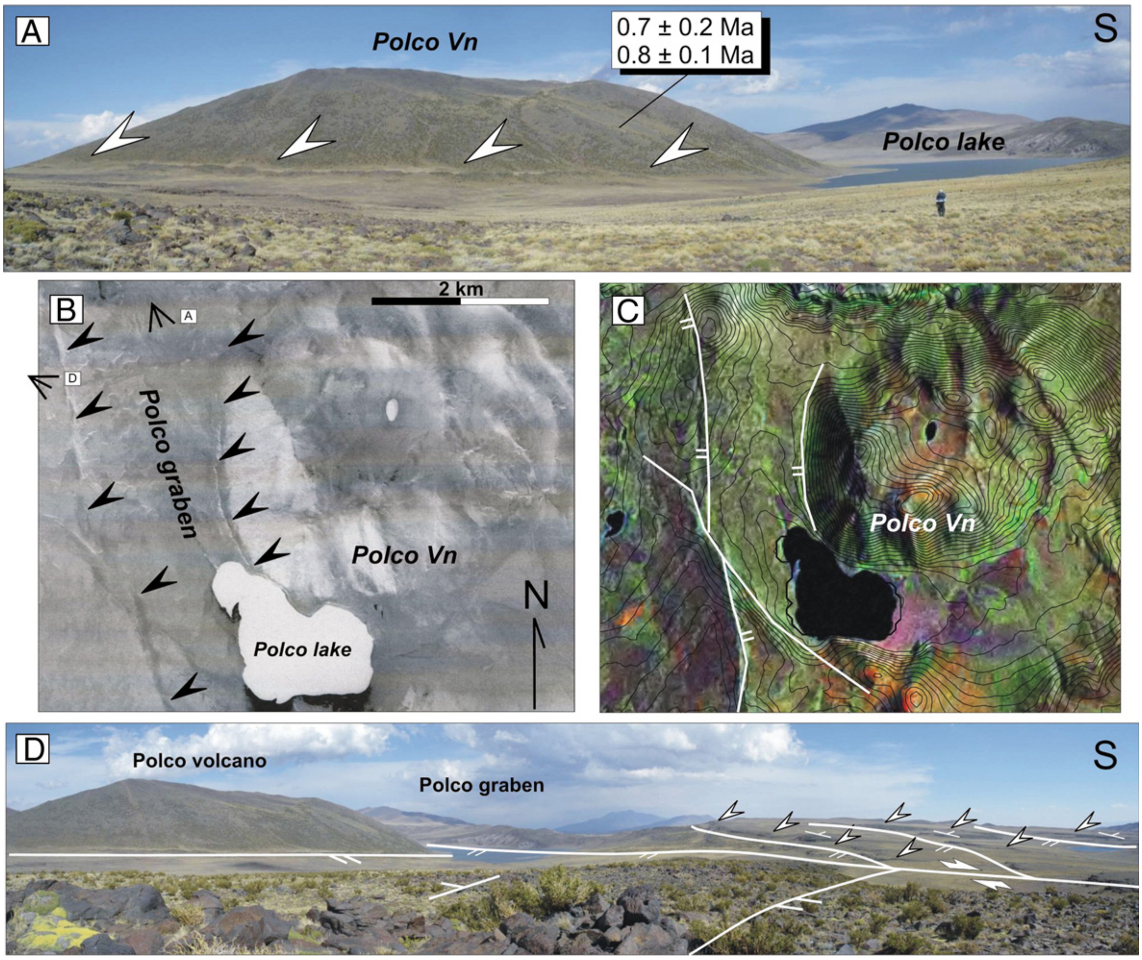



**Fig. 16.** A) Field picture of the Polco volcano and the extensional structure developed on it. B) Negative aerial picture of the Polco halfgraben. C) Landsat TM image with superimposed topographic contours of the Polco halfgraben. D) Field picture of the extensional structures forming the Polco halfgraben. The Polco halfgraben (B—negative aerial picture, C—Landsat TM image) hosting the Polco volcano is compartmentalized by a NE transfer zone. The Polco halfgraben is formed at its western side by a series of east-facing extensional scarps formed over Early Quaternary beds and an eastern west-looking scarp affecting this 0.8±0.1 Ma volcanic center (A, B, C, D). This indicates that part of the extensional structure was still active since 1 Ma.

(Figs. 3 and 9). On the other hand at the western end of the Los Rojos transfer zone a graben structure develops, where a series of domes is hosted in (Figs. 3 and 10). While big stratovolcanoes and dome complexes are mainly located immediately to the east of the N-trending extensional structure (Figs. 3 and 9), north of the Los Rojos transfer zone, the line of big volcanic edifices jumps to the west of the fault system (Figs. 3 and 10).

*4.2. Northwestern area*

This area has the best field evidence of extensional faults associated with two lacustrine basins corresponding to the Polco and Huaraco lakes (Fig. 10). Again fault sets are relatively continuous up to their intersection with the Los Rojos transfer fault where they vanish (Figs. 3, 9 and 10). Main vergence of the extensional structure is defined by NE-striking fault planes dipping to the east, although sudden changes in the opposite direction are common. In this area the western edge of the Early Quaternary extensional basin is visible, south of the Boliviano volcano (Fig. 10), where folded Middle to Late Miocene beds are in contact along a southeast-dipping normal fault with Early Quaternary flat lavas (1.6±0.2 Ma) (Fig. 11). Those Early Quaternary sequences lie almost horizontally to the east through the rest of the extensional basin, although they become locally interrupted and dismembered by extensional faults (Fig. 12).

Changes in fault-dips along the extensional system are solved by different mechanisms from discrete strike-slip faults to broad transtensional systems and narrow transpressional bands (Fig. 10), where small folds accommodate displacements (Fig. 12). The westernmost extensional faults (Huaraco halfgraben system; Fig. 11) form a series of halfgrabens with average lengths of 30 km and widths of 200 to 300 m (Figs. 10 and 13), which contrast to the 1 km wide halfgrabens and grabens developed in the southern study area along the La Amarga trough (Fig. 6). Narrow extensional troughs and high basement topography beneath the Late Quaternary volcanic centers characterize this northern part (Figs. 9E and 10). Moreover, in this area, exposures of Early Quaternary basement are much more widespread and Late Quaternary effusions are less common. Those Early Quaternary sequences affected by extensional faults have been dated at 1.8±0.5 Ma (Fig. 13; Table 1).

A series of halfgrabens associated with east-dipping fault planes located east of the Huaraco lake (Fig. 13) buries the Early Quaternary basement to the west beneath the western polygenetic volcanoes and domes (Figs. 10 and 14). Those were emplaced in a NE halfgraben, which has been completely filled by young volcanic effusions, Pleistocene gravels and lacustrine clays (Fig. 14). That structure, and consequent topographic low formed after the 2–1.4 Ma time interval, is still altering the pre-existing fluvial network producing closed volcanic and lacustrine–fluvial basins. Exhumation of the Early Quaternary basement by tilting associated

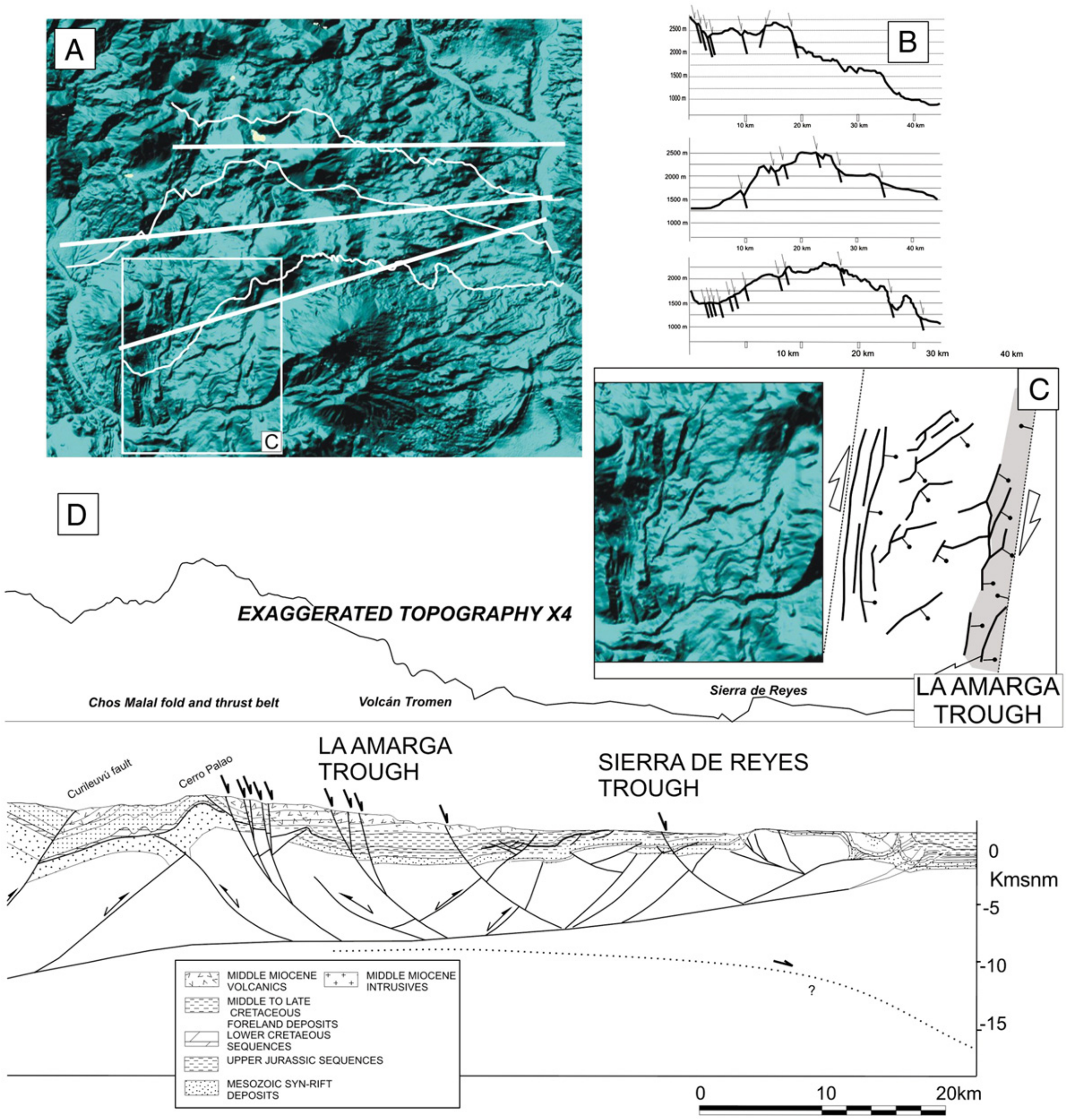



**Fig. 17.** Structural profile across the Chos Malal fold and thrust belt depicting the several phases of deformation that affected the area (the eastern part has been taken from Zapata et al. (1999), while the western part has been modified from Folguera et al. (2007a). A) Topographic shaded image and the three transects displayed in B. B) Topographic profiles with indication of fault scarps. Profile locations are indicated in A. C) Plan view of the main scarps developed west of the Tromen volcano. See that their geometric arrangement is compatible with some degree of right-lateral displacements along NNE-trending faults. D) Extensional faults displace compressive structure of the Chos Malal fold and thrust belt. Note the main topographical break at the western side of the Quaternary extensional basin, coincidentally with La Amarga trough.

with the activity of extensional faults was faster than fluvial incision, producing tectonic dams that flooded previous fluvial basins (Fig. 14). Those postglacial deposits onlap the eastern slopes of the Late Quaternary volcanic centers, such as the Boliviano and Piujenta volcanoes (Fig. 14).

These tilted halfgraben blocks continue to the north until the axis of the extensional system jumps 4 km to the east (Fig. 10). This discontinuity in the position of the extensional system is solved by a NW transpressive band, where shift transfer is accommodated by a series of *en-echelon* NNW low-amplitude folds in Early Quaternary sequences (Fig. 15). The folded structure is unconformably overlain by the La Piujenta volcano (Fig. 15). Syncline axis have been drowned by lacustrine to fluvial sediments linked to damming processes associated with the tilting of the Huaraco halfgraben system. This implies that tilting related to extensional faults in the northernmost sector would have lasted longer into the Late Quaternary, therefore being younger, than transpressive transfer displacements (Fig. 15). That could also imply that extensional faults north of the Huaraco lake would be younger than to the south (Fig. 10). That would be in accordance with a higher topography in the northern part, probably related to the permanence of thermal effects associated with uplift, and fewer and smaller polygenetic centers in the area perhaps related to an incipient extensional process.

As in the previously described southern sector, younger generations of volcanoes and domes lie over an irregular topography formed immediately after the Early Quaternary extension (Figs. 13 and 15). Almost all the young volcanic centers have some kind of structural control, either along transfer faults, a typical situation in the adjacent area to the east (Fig. 3), or along graben and halfgraben systems. Even though fault scarps formed over Late Quaternary volcanic centers are very rare, the Polco volcano is one documented case (Figs. 12 and 16).

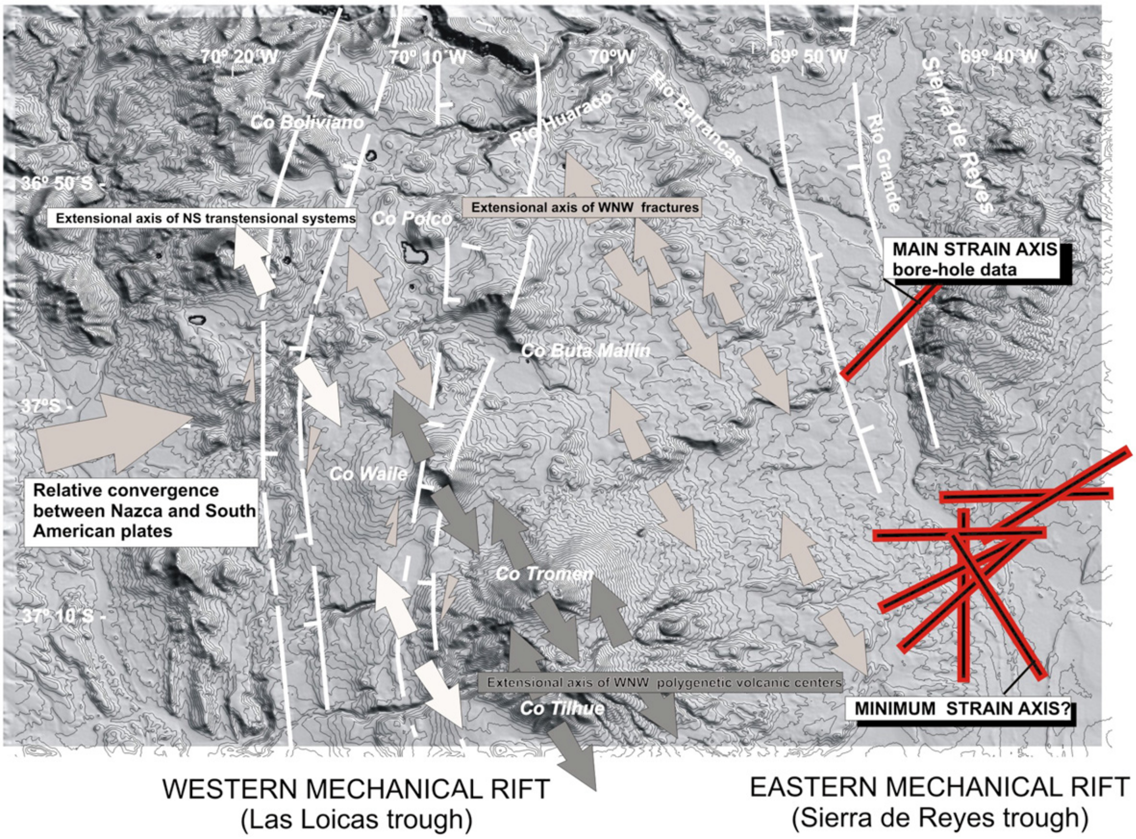



**Fig. 18.** Zones of documented extension in relation to breakout analysis in the Tromen plateau. Breakout analyses are from Guzmán et al. (2005). Note the predominance of NW extensional axis compatible with the development of NE grabens, transfer zones with that orientation, and NE fissural polygenetic volcanic centers such as Wayle and Tilhue volcanic centers (see Fig. 3).

As previously stated, the Polco volcano has two radiometric ages (1.8±0.1 Ma and 1.7±0.2 Ma—K/Ar—Table 1), which locate it in the Late Quaternary as a contemporaneous to the Wayle volcano to the south. The Polco volcano is located in a halfgraben structure crossed by a right-lateral strike-slip transfer fault that produces alternating polarities in the extensional structure along strike (Fig. 12). Extensional structures that outline this tectonic low are formed over Early Quaternary successions (Figs. 12 and 16), although a west facing scarp affects basal (dated) lavas of the Polco volcano in the axial part of the halfgraben. This observation implies that even though extensional structures and related topography formed during the Early Quaternary, tectonic activity still persists or at least has persisted until recently. That is somehow logical if we take into account the morphological alteration of the fluvial network documented in the area, which imply fast exhumation rates due to the activity of local structures (Fig. 14).

## 5. Discussion

Based on our previous observations, extensional structure seems to have been mostly formed along the 2–1.4 Ma interval, after the eruption of Early Quaternary volcanic successions and previously to the emplacement of polygenetic, monogenetic volcanoes and dome complexes during the last 1 Ma. Strike-slip and minor transpressional structure formed during this period are only a local response to spatial problems related to extension, defining transfer zones. Extension initiated during the Early Quaternary and controlled the emplacement of young volcanic effusions, as well as fluvial and lacustrine deposits linked to the alteration of the fluvial network by rapid relief creation. Those young deposits, mainly generated during postglacial times (at ca. 30 ka based on Dixon et al., 1999, who determined glacial times at the arc front at these latitudes) indicate that extensional faulting is recent, which is in accordance with rare faulting in the basal products of the Late Quaternary volcanic successions that irregularly resurfaced the Tromen volcanic plateau.

Both in the northern and southern study area, extensional systems have modified the landscape during the Quaternary defining the main Andean topographic break (Fig. 17). This is not coincident with the Late Miocene emergent fault systems (the thrust front zone) in the fold and thrust belt at 37°S. Those thrusts are located along this transect further to the east, on the eastern slope of Sierra de Reyes (Figs. 1 and 15D). The La Amarga graben (Figs. 3, 4, 5 and 6) defines the sharpest topographic step between the remnants of the Chos Malal fold and thrust belt to the west and the western edge of the Tromen volcanic plateau (Fig. 17). That transition along the northern area is smoother, suggesting that along that transect extensional collapse of the Cretaceous to Miocene compressive structure would not have finished, which is in accordance with younger indicators of fault activity in that area (Fig. 17).

On the other hand, this orogenic collapse would have not been purely related to gravitational extension, since structural analysis reveals that circumscribed to main N-trending faults, a second set of minor NE-trending extensional faults is disposed following *en-echelon* arrangements (Fig. 17A and D), and suggesting a horizontal main strain axis in the NE direction. That would imply that even though extensional slip is the main mechanism that characterizes Quaternary tectonics at these latitudes at the outer part of the fold and thrust belt, horizontal displacements would still persist in the eastern retroarc (Fig. 18; Guzmán et al., 2005).

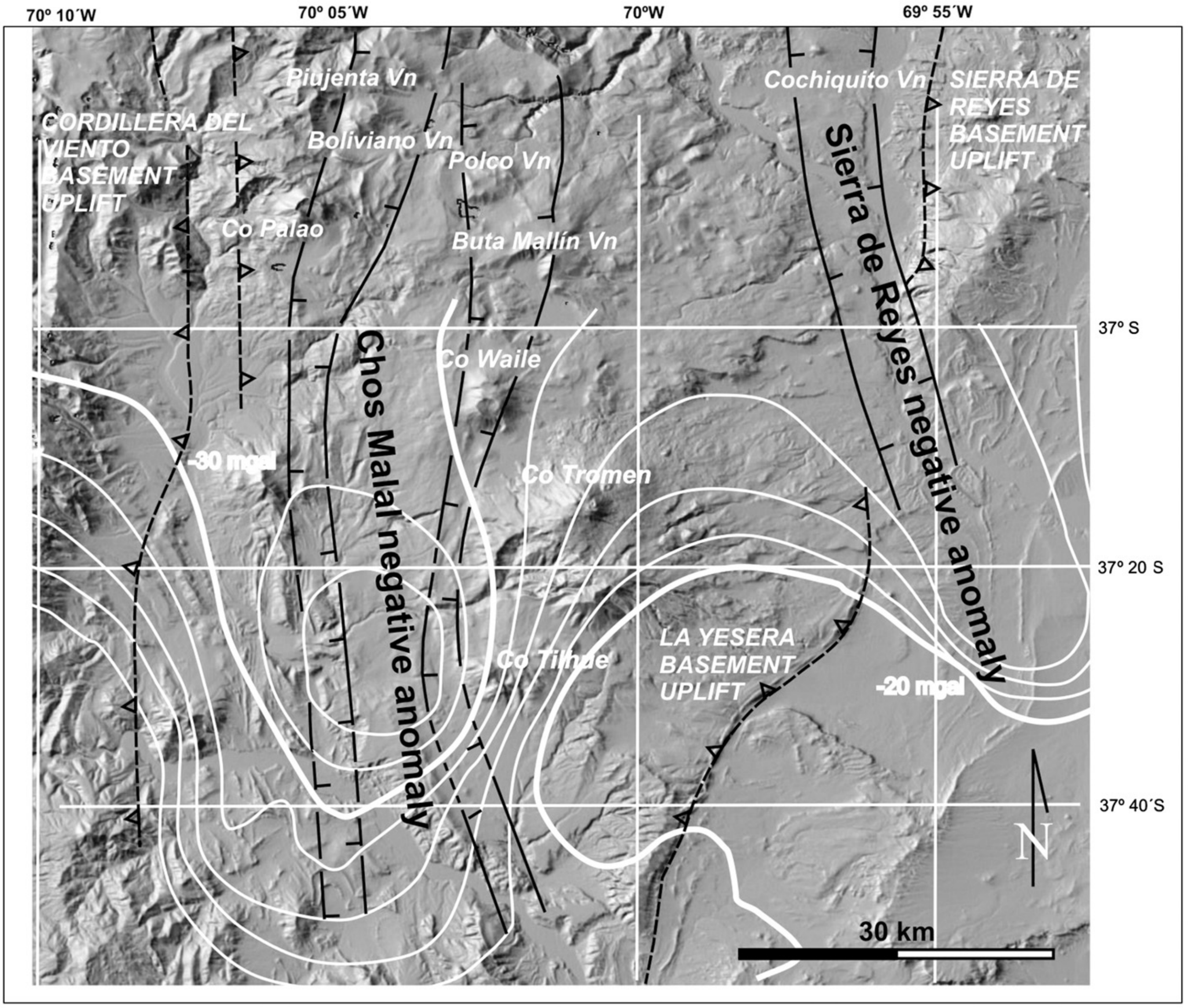
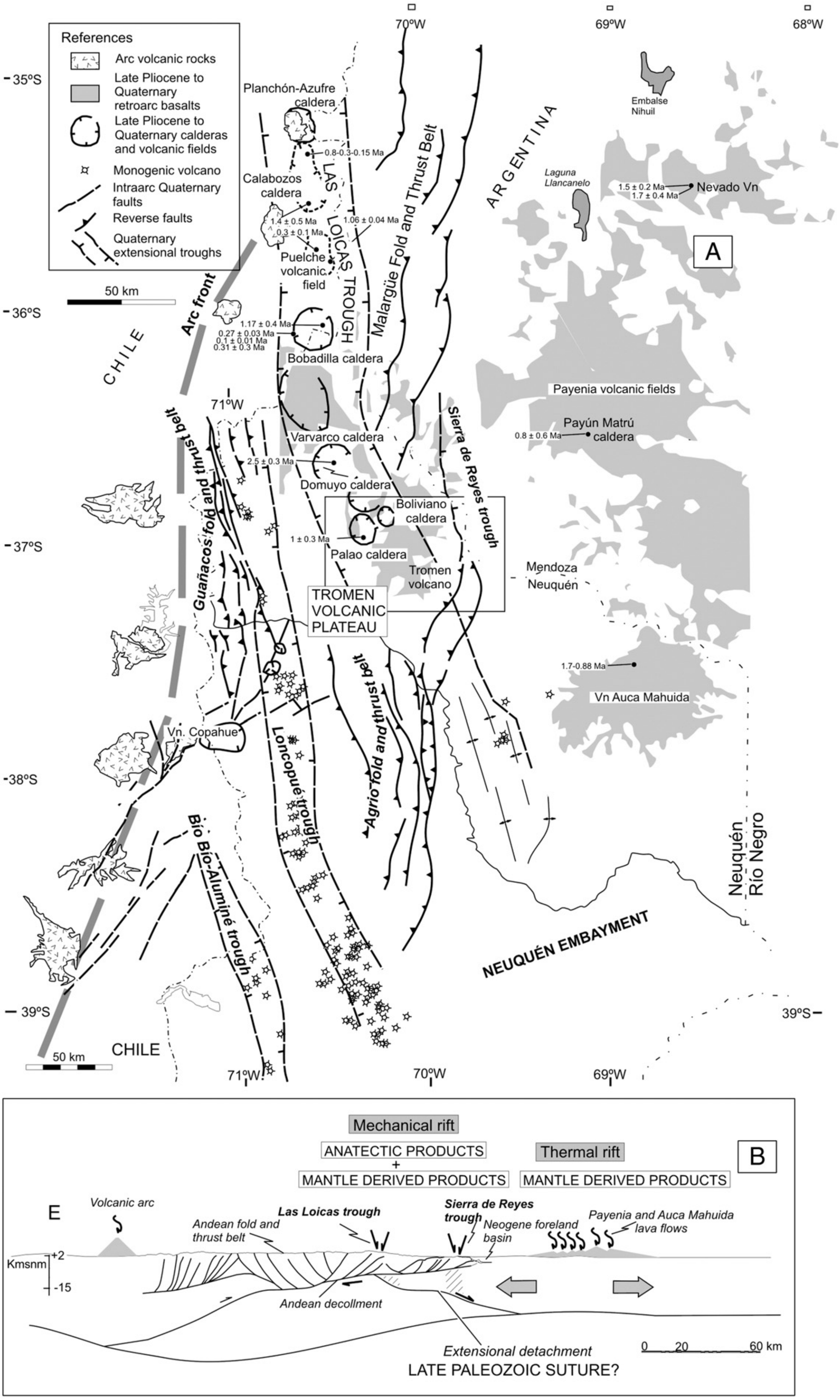



**Fig. 19.** Gravimetric residual calculated from the Bouguer anomaly after upward continuation analysis (Repsol-YPF gravity dataset; Folguera et al., 2007b). Deep crustal effects have been filtered to relate variations in gravity to the variable basement depth beneath the Late Pliocene to Quaternary sequences. Note the two gravimetric lows, one aligned with the area of extensional faults west of the Tromen and Wayle volcanoes, and the other with the western flank of the Sierra de Reyes, whereas a high is bordering the Tromen and Tilhue volcanic centers through their western slopes between the two lows (see Fig. 18).

The Sierra de Reyes trough is another extensional area, located immediately to the east, along the western slope of a basement block uplifted in the Late Miocene (Figs. 17 and 18) (Folguera et al., 2006a). There, a more reduced volcanic plateau over which the Rio Grande flows, when reaching the Rio Barrancas (Figs. 1, 2 and 18), is linked to extensional faults documented by seismic lines and borehole data (Folguera et al., 2006a). Similarly, this tectonic basin coincides with the second more important topographic break to the east in the fold and thrust belt (Fig. 17). Both troughs, La Amarga and Sierras de Reyes, are characterized by N-trending, with minor inflections, graben-like structures, and are separated by an extensive east-dipping plain covered by NE-trending lineaments of young monogenetic eruptions (Figs. 3 and 18). Recently, published breakout data collected in the southern part of the Sierra de Reyes (Fig. 18) (Guzmán et al., 2005) show that two to three main stress axis are superimposed in the area: a NW to NNW axis and a NE axis. The former is coincident with the extensional direction inferred from fissures associated with main polygenetic volcanoes through the area and alignments of monogenetic basaltic cones, as well as with the minimum strain axis of N-trending graben structures determined from minor sets of faults in the topography (Figs. 17 and 18). On the other hand ENE axis determined from breakout analysis could reflect the main strain axis imposed by relative

**Fig. 20.** A) Regional map of the Andean fold and thrust belt between 35° and 39°S and superimposed extensional troughs and mantle-derived products in the foreland zone. Radiometric ages are from Hildreth et al. (1984, 1991, 1999), Muñoz Bravo et al. (1989), González Ferrán (1995), Linares and González (1990), Rossello et al. (2002). Structural data comes from Ramos (1977), Folguera et al. (2004, 2006a,b, 2007a). B) Regional schematic cross section along the Southern Central Andes (36°30′S) where the fold and thrust belt constructed in the Cretaceous to the Late Miocene is represented. The areas that concentrate extension are located at the eastern part of the fold and thrust belt. The probable situation of the associated thermal anomaly would be immediately to the east, beneath the Auca Mahuida volcanic shield.


References
Arc volcanic rocks
Late Pliocene to Quaternary retroarc basalts
Late Pliocene to Quaternary calderas and volcanic fields
Monogenic volcano
Intraarc Quaternary faults
Reverse faults
Quaternary extensional troughs
50 km
70ºW
69ºW
68ºW
71ºW
35ºS
36ºS
37ºS
38ºS
39ºS
Planchón-Azufre caldera
0.8-0.3-0.15 Ma
Calabozos caldera
1.4 ± 0.5 Ma
0.3 ± 0.1 Ma
1.06 ± 0.04 Ma
Puelche volcanic field
LAS LOICAS TROUGH
Malargüe Fold and Thrust Belt
ARGENTINA
Embalse Nihuil
Laguna Llancanelo
1.5 ± 0.2 Ma
1.7 ± 0.4 Ma
Nevado Vn
A
Arc front
CHILE
1.17 ± 0.4 Ma
0.27 ± 0.03 Ma
0.1 ± 0.01 Ma
0.31 ± 0.3 Ma
Bobadilla caldera
Payenia volcanic fields
Payún Matrú caldera
0.8 ± 0.6 Ma
Sierra de Reyes trough
Guañacos fold and thrust belt
Varvarco caldera
2.5 ± 0.3 Ma
Domuyo caldera
Boliviano caldera
1 ± 0.3 Ma
Palao caldera
Tromen volcano
Mendoza
Neuquén
TROMEN VOLCANIC PLATEAU
1.7-0.88 Ma
Vn Auca Mahuida
Agrio fold and thrust belt
Loncopué trough
Vn. Copahue
Bio Bio-Aluminé trough
Neuquén
Río Negro
NEUQUÉN EMBAYMENT
CHILE
Mechanical rift
ANATECTIC PRODUCTS
+
MANTLE DERIVED PRODUCTS
Thermal rift
MANTLE DERIVED PRODUCTS
B
E
Volcanic arc
Andean fold and thrust belt
Las Loicas trough
Sierra de Reyes trough
Neogene foreland basin
Payenia and Auca Mahuida lava flows
Kmsnm
+2
-15
Andean decollment
Extensional detachment
LATE PALEOZOIC SUTURE?
0 20 60 km

convergence between Nazca and South American plates slightly refracted (Fig. 18).

Based on the previous discussion, the Tromen volcanic plateau is a post-shortening accumulation at the outer part of the Chos Malal fold and thrust belt, where compressive structure has been downwardly displaced and consequently drowned by thick volcanic piles (Figs. 10, 11 and 17). This collapse has been documented in the present work at the western part of the plateau, while in Folguera et al. (2006a) a similar situation is described respect to its eastern edge against the Sierra de Reyes uplift. Between the two troughs (Figs. 17 and 18), relicts of the compressive structure are present at the summit of the Tromen volcano. The structural cross-sections indicate to the east a basement uplift during the Late Miocene as in the Sierra de Reyes (Figs. 17 and 18) (Zapata et al., 1999). The La Yesera basement block constitutes the southern continuation of the Tromen basement uplift, whose backlimb lies beneath thick piles of Tromen and Tilhue volcanic eruptions (Fig. 6). Fig. 6 illustrates how the La Amarga extensional faults displaced the western limb of that basement structure beneath thick piles of fault-controlled Quaternary depocenters, and how the Late Miocene structure rises to the east beyond the area of collapse. At the higher structural relief, no extensional faults seem to have affected the Late Miocene structure from seismic analysis, although a series of NE fractures are visible in map view (Figs. 3 and 18). That basement differential depth beneath the Plio-Quaternary sequences is reflected by gravimetric data (Fig. 19). Bouguer anomaly reflects superimposed effects related to density contrasts at different depths. However, upward continuation analysis permits to filter those superficial density contrasts related to the 20 to 15 shallower kilometers, isolating gravity anomalies associated with Moho differential depths and density contrasts at the lower crust. Then subtracting those isolated deep contributions to the Bouguer anomaly, the residual Bouguer anomaly is obtained. In the Tromen volcanic plateau, the gravimetric residual highlights the two main extensional depocenters, namely the La Amarga and Sierra de Reyes lows, where the corresponding basements have differentially subsided (Fig. 19). The geometry and southern extent of both negative anomalies closely describe the structure determined from field and seismic analysis (Fig. 19). Moreover, a gravimetric high located between them is coincident with the area of shallow basement interpreted as a topographic relict of the Quaternary extension. The western anomaly (Chos Malal negative anomaly in Fig. 19) becomes higher from north to south immediately west of the Tilhue and Tromen volcanic centers (Fig. 19). That is in accordance with assumptions of a more advanced extensional collapse at the southern part of the study area, while to the north high topography and indicators of Present basement exhumation could indicate an ongoing extensional process.

The areas that suffered Quaternary collapse at both the eastern and western edges of the Tromen volcanic plateau constitute in a regional view the southernmost extreme of the 300 km long Las Loicas trough, which affected the western part of the Chos Malal and Malargüe fold and thrusts belts (Fig. 20) (Folguera et al., 2005, 2006a). The Las Loicas trough (35°–38°S) contains a bimodal association of Late Pliocene to Quaternary volcanic products (Fig. 20A), represented by crustal melts and mantle-derived products with poor arc affinity (Hildreth et al., 1984, 1991, 1999). These volcanic centers represent calderas, huge dome complexes and monogenetic basaltic–andesitic fields located in a retroarc position east of the Present arc front, and west of the large volcanic plateau that occupies the foreland area between 35° and 38°S (Fig. 20). This latitudinal band (35°–38°S) not only describes the north to south extent of both the foreland plateau sequences and the Las Loicas trough but also the potential amplitude of the proposed shallow subduction zone that affected the area (Folguera et al., 2006a), implying a genetic connection among them.

Additionally, as early stated by Hildreth et al. (1999), and strengthened by radiometric determinations (Hildreth et al., 1984; Muñoz Bravo et al., 1989; Hildreth et al., 1991, 1999; Rossello et al., 2002; Kay et al., 2006), the foreland plateau sequences, represented at the Tromen plateau latitudes by the Auca Mahuida shield volcano, have been synchronously emplaced to effusions and intrusions of crustal melts and mantle-derived products in the Las Loicas trough over the then fossilized fold and thrust belt. Particularly the Auca Mahuida shield volcano has been entirely formed in the 1.7–0.88 Ma time interval (Fig. 20) (Rossello et al., 2002), which is strikingly coincident with the Tromen volcanic plateau temporal range associated with the main phase of extension. Basal sequences of the Tromen volcanic plateau (with a mean age of 1.6±0.2 Ma; Fig. 2, Table 1) have been contained in extensional depocenters when emitted (Figs. 5 and 11), and fault-controlled volcanoes and domes were only locally affected by extension (with a mean age of 0.8±0.1 Ma for the Polco volcano; Fig. 16, Table 1), and both correlate with Auca Mahuida's older and younger products respectively, determining that the entire evolution of this center occurred during the main extensional stage that affected the retroarc.

Even though there is consensus about an intra-plate origin for those sequences emplaced entirely in the foreland area such as Auca Mahuida shield volcano (Fig. 20) (Hildreth et al., 1999; Kay et al., 2006) and that the more plausible related mechanism would be retroarc extension (González Díaz, 1964, 1972a,b; Bermúdez et al., 1993) little field evidence has been reported about the existence of normal faults cutting those lava flows as previously stated. On the contrary, the Las Loicas trough and particularly its southern extreme, described in the present work, is a direct consequence of the development of normal faults affecting the fold and thrust belt. Extension seems to have differentially affected the upper crust at 37°S as in most rift systems occur (Fig. 20), with a higher number of normal faults to the east. Therefore, the Las Loicas trough, and its sub-basins namely the La Amarga and Sierra de Reyes lows, could be interpreted as the zone of mechanical rifting, where crustal melts and underplating mafic rocks were emplaced (Fig. 20B), while foreland mantle-derived volcanic associations (foreland plateau sequences) would be preferentially located over the main thermal anomaly resulting from the process of crustal attenuation. This model implies an asymmetric rift developed during the Late Pliocene–Quaternary superimposed to the Cretaceous to Miocene fold and thrust belt (Fig. 20). Distribution of normal faulting and volcanic associations is compatible with the activity of an east-dipping detachment (Fig. 20). Good candidate for such a lithospheric discontinuity could be the postulated suture between two Late Paleozoic amalgamated terrains, denominated Chilenia and Cuyania (Ramos et al., 1984; Ramos, 1988) that have constituted the western edge of Gondwana immediately to the north. The southward continuation of the suture between the two micro-continents in the segment under study has been recently tracked by aero-magnetic studies, between the eastern-frontal part of the fold and thrust belt and the foreland plateau sequences located to the east (Fig. 20B) (Chernicoff and Zapettini, 2004). This lithospheric discontinuity may have controlled the development of rift basins, first in the Late Triassic, when thick piles of volcaniclastic associations were accumulated (Manceda and Figueroa, 1995), and then in the Late Pliocene to Quaternary.

## 6. Conclusions

The Tromen volcanic plateau constitutes one of the few examples of active retroarc spreading in the Southern Central Andes. Development of Quaternary extensional basins are not a frequent process along Andean strike, being related to particular phenomena such as steepening of Nazca plate beneath South American plate after a stage of shallow subduction. Young and probably active volcanism in that area is a direct consequence of the persistence of the extensional process that has produced the partial collapse of the fold and thrust belt.

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