Geological Society, London, Special Publications Online First

Tectono-stratigraphic evolution of the Andean Orogen between 31 and 37°S (Chile and Western Argentina)

Reynaldo Charrier, Victor A. Ramos, Felipe Tapia and Lucía Sagripanti

Geological Society, London, Special Publications, first published August 27, 2014; doi 10.1144/SP399.20

Notes

Tectono-stratigraphic evolution of the Andean Orogen between 31 and 37°S (Chile and Western Argentina)

REYNALDO CHARRIER[1,2]*, VICTOR A. RAMOS[3], FELIPE TAPIA[1] & LUCÍA SAGRIPANTI[3]

[1]*Departamento de Geología, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile*

[2]*Escuela de Ciencias de la Tierra, Universidad Andres Bello, Campus República, Salvador Sanfuentes 2357, Santiago, Chile*

[3]*Laboratorio de Tectónica Andina, Instituto de Estudios Andinos Don Pablo Groeber, Universidad de Buenos Aires-CONICET, Intendente Güirales 2160, Ciudad Universitaria, C1428EGA, Capital Federal, Buenos Aires, Argentina*

**Corresponding author (e-mail: rcharrie@ing.uchile.cl)*

Abstract: In this classic segment, many tectonic processes, like flat-subduction, terrane accretion and steepening of the subduction, among others, provide a robust framework for their understanding. Five orogenic cycles, with variations in location and type of magmatism, tectonic regimes and development of different accretionary prisms, show a complex evolution. Accretion of a continental terrane in the Pampean cycle exhumed lower to middle crust in Early Cambrian. The Ordovician magmatic arc, associated metamorphism and foreland basin formation characterized the Famatinian cycle. In Late Devonian, the collision of Chilenia and associated high-pressure/low-temperature metamorphism contrasts with the late Palaeozoic accretionary prisms. Contractional deformation in Early to Middle Permian was followed by extension and rhyolitic (Choiyoi) magmatism. Triassic to earliest Jurassic rifting was followed by subduction and extension, dominated by Pacific marine ingressions, during Jurassic and Early Cretaceous. The Late Cretaceous was characterized by uplift and exhumation of the Andean Cordillera. An Atlantic ingression occurred in latest Cretaceous. Cenozoic contraction and uplift pulses alternate with Oligocene extension. Late Cenozoic subduction was characterized by the Pampean flat-subduction, the clockwise block tectonic rotations in the normal subduction segments and the magmatism in Payenia. These processes provide evidence that the Andean tectonic model is far from a straightforward geological evolution.

This chapter will focus on the general framework of the Andes along this segment of the orogen, as an introduction to the different specific contributions of the following chapters. This part of the southern Central Andes of Argentina and Chile has received the attention of numerous overviews and syntheses in recent years, such as the publications of Mpodozis & Ramos (1989), Ramos *et al.* (1996*b*), Ramos (1988*b*, 1999) and Charrier *et al.* (2007, 2009). However, several articles have been published in recent years that complement and modify the tectonic and palaeogeographic reconstructions and interpretations presented in previous syntheses. Therefore, the objective of this introductory chapter will be to present a brief updated summary, taking into consideration the most recent advances in the geological knowledge of the region.

Tectonic cycles

The continental margin of southern South America was an active plate margin during most of its history. The Neoproterozoic to late Palaeozoic evolution is punctuated by a succession of tectonic regimes in which extension and compression alternate through time. As a result, terrane accretion and westward arc migration alternate with periods of rifting and extensional basin formation. Although accretion of some terranes has been documented until Jurassic time, as in Patagonia (Madre de Dios terrane; Thompson & Hervé 2002), the post-Triassic history is characterized by the eastward retreat of the continental margin and eastward arc migration, attributed to a combination of shallowing of the subducting plate and subduction erosion. The period between the latest Permian and earliest Jurassic

From: Sepúlveda, S. A., Giambiagi, L. B., Moreiras, S. M., Pinto, L., Tunik, M., Hoke, G. D. & Farías, M. (eds) *Geodynamic Processes in the Andes of Central Chile and Argentina*. Geological Society, London, Special Publications, **399**, http://dx.doi.org/10.1144/SP399.20

corresponds to an episode of arrested continental drift, which, however, does not mean that subduction along the continental margin ceased. Different palaeogeographic organizations were developed at that time, and a widely distributed magmatism with essentially different affinities occurred. It is therefore possible to differentiate major stages in the tectonostratigraphic evolution of the Chilean–Argentine Andes, which can be related to the following episodes of supercontinent evolution: (a) breakup of Rodinia; (b) Gondwanaland assembly; and (c) post-Pangaea breakup (Fig. 1).

These stages can in turn be subdivided into shorter tectonic cycles separated from each other

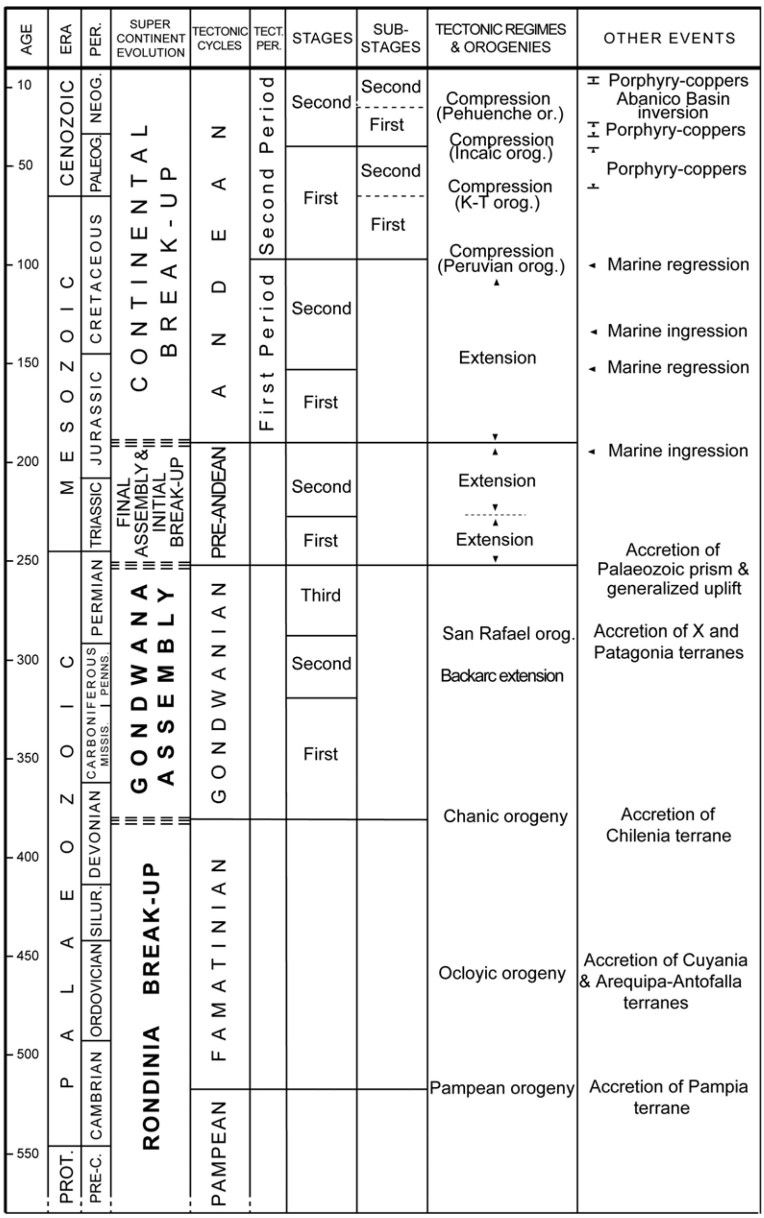

Fig. 1. Tectonic cycles, orogenies and events in the evolution of the continental margin of southern South America compared with the supercontinent evolution.

by regional unconformities or by significant palaeogeographic changes that indicate the occurrence of drastic tectonic events in the continental margin. These tectonic events have been related to modifications in the dynamics of the lithospheric plates (see James 1971; Rutland 1971; Charrier 1973; Aguirre *et al.* 1974; Frutos 1981; Jordan *et al.* 1983*a*, 1997; Malumián & Ramos 1984; Ramos *et al.* 1986; Isacks 1988; Ramos 1988*a*; Mpodozis & Ramos 1989). As a result of that, tectonic cycles have been identified along the western southern South America, which according to Mpodozis & Ramos (1989) and Charrier *et al.* (2007) are (Fig. 1): *Pampean* (Neoproterozoic–Early Cambrian), *Famatinian* (latest Cambrian–Early Devonian), *Gondwanian* (Late Devonian–early Late Permian), *pre-Andean* (latest Permian–earliest Jurassic) and *Andean* (Early Jurassic–Present).

Morphostructural units

The northern part of the analysed segment (31–33°S) is located in the flat-slab subduction segment developed between *c.* 27 and *c.* 33°S. There the passive Juan Fernández Ridge has been subducting the continental margin since *c.* 12 Ma with an eastward dip of *c.* 20° to the east beneath the forearc to almost horizontal beneath the retroarc (Jordan *et al.* 1983*a*; Yáñez *et al.* 2001; Pardo *et al.* 2002). This Andean segment, known as the Pampean flat-slab segment, is characterized by the absence of recent volcanic activity and of a Central Depression, existing further south in the normal subduction segment (south of 33°S). Therefore, in this segment no differentiation can be made easily between a Coastal and a Principal Cordillera, and the Coastal Cordillera has been extended further east (Rodríguez 2013; Rodríguez *et al.* 2013, 2014). East of this extended Coastal Cordillera, other morphostructural units are developed, which gradually disappear southwards or are not developed further south in the normal subduction segment. These are, from west to east: the Frontal Cordillera, the Precordillera and the Sierras Pampeanas (Fig. 2). The alignment of the crustal earthquake epicentres parallel to the projection of the subducted Juan Fernández Ridge shows the strong control that this subduction exerted in the more recent morphologic, magmatic and tectonic features of the Andean cordillera in the flat-slab segment (Alvarado *et al.* 2009).

South of the flat-slab subduction segment (south of *c.* 33°S), the Wadati–Benioff zone dips *c.* 30°E (Cahill & Isacks 1992). As indicated, in this segment, a Central Depression is well developed separating the Coastal Cordillera, to the west, from the Principal Cordillera, to the east, with the edifices of the volcanic arc (Fig. 2). The western flank of the Principal Cordillera is located in Chile, while the eastern flank is located in Argentina.

Pampean tectonic cycle (Neoproterozoic–Early Cambrian)

The Pampean tectonic cycle as proposed by Aceñolaza & Tosselli (1976) includes sedimentation, magmatism and important deformation that took place in Early to Middle Cambrian in northwestern Argentina (Coira *et al.* 1982). The orogenic deformation at that time, in the central segment analysed here (31–37°S), was located along the Eastern Pampean Ranges, and its extension to the south (Fig. 2) (Ramos 1988*a*; Rapela *et al.* 1998; Chernicoff *et al.* 2012).

The Eastern Sierras Pampeanas comprises an orogenic belt characterized by metamorphic rocks of middle-to-high amphibolite facies, low-grade metapelites and granulite facies meta-basic rocks (Gordillo 1984; Kraemer *et al.* 1995; Rapela *et al.* 1998). Medium-grade para- and ortho-gneisses and schists constitute the dominant lithology; large massifs composed of garnet-cordierite pelitic migmatites are also characteristic (Rapela *et al.* 1998). Geochemical and isotopic studies show a typical calc-alkaline magmatic arc related to subduction (Lira *et al.* 1996; Rapela *et al.* 1998). Ultrabasic rocks dominated by harzburgites, chromitites and serpentinites have been interpreted as a disrupted ophiolitic sequence (Escayola *et al.* 1996; Ramos *et al.* 2000).

This orogenic belt has been interpreted as (a) the result of a collision between a Pampean block against the Río de La Plata Craton (Ramos 1988*a*; Ramos & Vujovich 1993; Rapela *et al.* 1998); (b) in the context of a subduction of a mid-ocean ridge beneath the palaeo-Pacific Gondwana margin (e.g. Gromet & Simpson 2000; Simpson *et al.* 2003; Piñán-Llamas & Simpson 2006; Schwartz *et al.* 2008); or (c) the result of complex strike-slip tectonics between Kalahari and Río de la Plata craton (Rapela *et al.* 2007; Casquet *et al.* 2012; Spagnuolo *et al.* 2012*a*).

In recent years more precise studies of the pre- and post-collisional suites seem to indicate that the main episode of deformation is bracketed between 537 and 530 Ma (Iannizzotto *et al.* 2013), and the tectonic evolution comprises a complex geological history to fit all of the observations (Escayola *et al.* 2007; Ramos *et al.* 2010). This model implies a primitive island arc that under western subduction collided against the Río de la Plata Craton by the end of the Ediacarian (Escayola *et al.* 2007). This oceanic terrane of the Eastern Sierras Pampeanas known as the Córdoba terrane

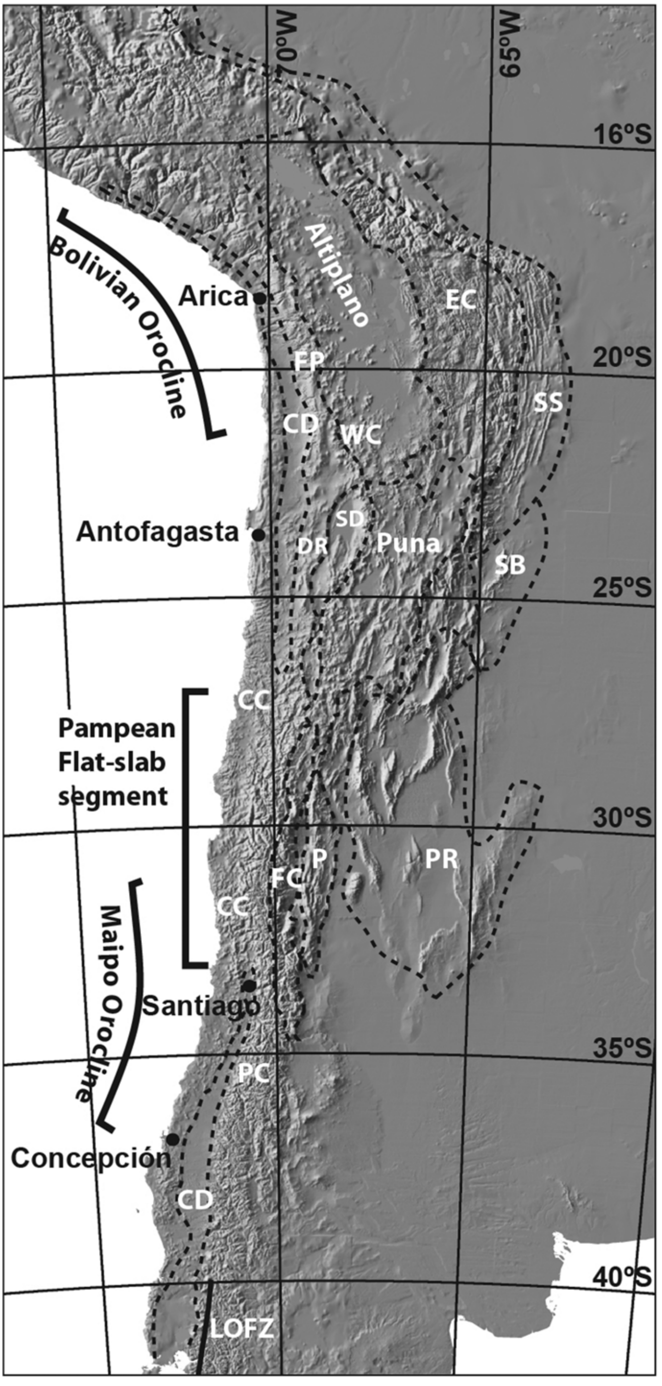

Fig. 2. Digital elevation model of the Andes between 16 and 40°S with indication of the main geographical, tectonic and morphostructural features. Abbreviations: CC, Coastal Cordillera; CD, Central Depression; DR, Domeyko Range; EC, Eastern Cordillera; FC, Frontal Cordillera; FP, Forearc Precordillera (western flank of the Altiplano); LOFZ, Liquiñe–Ofqui Fault Zone; P, Precordillera in Argentina; PC, Principal Cordillera; PR, Pampean Ranges; SB, Santa Barbara System; SD, Salar Depressions; SS, Subandean System; WC, Western Cordillera. Rectangle: Andean region considered in this chapter.

is composed of several belts of ophiolites (Mutti 1997; Ramos *et al.* 2000, 2010). This collision was followed by the final collision of Pampia through an east-dipping subduction against the Río de la Plata craton as proposed by Kraemer *et al.* (1995), Escayola *et al.* (2007) and Ramos *et al.* (2010). Among the post-collisional effects, the emplacement of mafic bodies of Ocean-Island Basalts (OIB) signature emplaced at about 520 Ma could be interpreted as evidence of slab breakoff (Tibaldi *et al.* 2008), associated with general anatexis and crustal delamination as indicated by extensive rhyolitic plateaux preserved in the northern sector of Eastern Sierras Pampeanas, such as the Oncán Rhyolites and Los Burros Rhyodacites of 532–512 Ma (Leal *et al.* 2004). These regions have been affected by ductile shear deformation along some weakness zones during the early Palaeozoic (Martino 2003).

Famatinian tectonic cycle (Cambrian to Late Devonian)

The Famatinian orogenic cycle as proposed by Aceñolaza & Tosselli (1976) comprises the evolution of two important sedimentary sequences, separated by an important angular unconformity. The basal sequence comprises Early Cambrian to Middle Ordovician carbonatic and clastic platform deposits of the Cuyo Precordillera deformed during the Ocloyic diastrophism at about 460 Ma (Astini *et al.* 1996; Ramos 2004, and references therein). Both sequences were deformed during the Middle to Late Devonian, developing the Chanic unconformity that separates these deposits from the late Palaeozoic sequences. The different sedimentary, magmatic and metamorphic rocks of these two sequences will be described from west to east.

Frontal Cordillera

In Cordón del Carrizalito region, in the southern Frontal Cordillera, north of the Río Diamante valley, is exposed a sequence of turbidites of the Las Lagunitas Formation (Fig. 3) (Volkheimer 1978). Graptolites of Ordovician age have been found in these turbidites, previously interpreted as Carboniferous deposits (Tickyj *et al.* 2009*a*). These rocks are characterized by low-grade metamorphism, and are intruded by pre-tectonic to syntectonic granitoids such as the Carrizalito Tonalite and Pampa de Los Avestruces Granite deformed during the Chanic orogeny (Tickyj *et al.* 2009*b*; Tickyj 2011). The studies of García-Sansegundo *et al.* (2014*a*) described the Chanic structures as west-vergent, in contrast with the east-vergent late Palaeozoic structures.

North of 34°S at Cordón del Plata region, in northern Frontal Cordillera (Fig. 3), Heredia *et al.* (2002, 2012) described the Vallecitos beds, low-grade metamorphic rocks correlated with Devonian turbidites of western Precordillera. These rocks as well as the Las Lagunitas Formation were deformed during the Middle to Late Devonian Chanic deformation.

Exposures of metamorphic basement rocks that include ultrabasic rocks occur within the Frontal Cordillera as a medium-grade unit further south (Polanski 1964, 1972; Bjerg *et al.* 1990; López & Gregori 2004), known as the Guarguaraz Complex (Willner *et al.* 2011). This complex consists of garnet–micaschist and quartzitic schist, metasediments with intercalated lenses of garnet bearing amphibolite with a N- or E-MORB (normal or enriched mid-ocean ridge basalt) geochemical signature, serpentinite with tremolite-/talc-bearing wall rocks and marbles and calc-silicates. Willner *et al.* (2011) interpreted this sequence as related to a high-pressure–low-temperature metamorphism, with a metamorphic peak dated in 385 Ma, followed by decompression and retrograde metamorphism between 348 and 337 Ma, associated with the new stage of subduction along the Pacific margin. These high pressure–low temperature conditions (12–14 kbar–550 °C) are interpreted as a collisional metamorphism, distinctive from the subduction complexes of the western series (basal accretion) younger than 307 Ma and the eastern series (frontal accretion) younger than 330–345 Ma (Hervé *et al.* 2013).

Cuyo Precordillera

This region comprises a series of platform sedimentary rocks, which are unconformably deposited on scarce syn-rift deposits, mainly preserved in the northern Precordillera. The Cerro de la Totora Formation includes some evaporites and red-beds of Early Cambrian age (515 Ma), which fill the half-graben system developed on the Grenvillian age basement (Rapalini & Astini 1998; Rapalini 2012).

The platform deposits comprise mainly an Early Cambrian to Early Ordovician carbonate sequence bearing typical *Olenellus* trilobites of Laurentia derivation (Bordonaro 1980, 1992). Various studies have characterized the complex third-order sequences of these carbonates (Cañas 1999; Keller 1999), the palaeogeographic connections of their fauna (Benedetto *et al.* 1999) and their tectonosequences (Astini *et al.* 1995; Thomas & Astini 1996).

These platform deposits are bounded to the west by slope deposits (Alonso *et al.* 2008; Voldman *et al.* 2010) and the Famatinian ophiolites (Haller & Ramos 1984, 1993). This sequence of mafic, ultramafic and granulitic rocks of Middle to Late

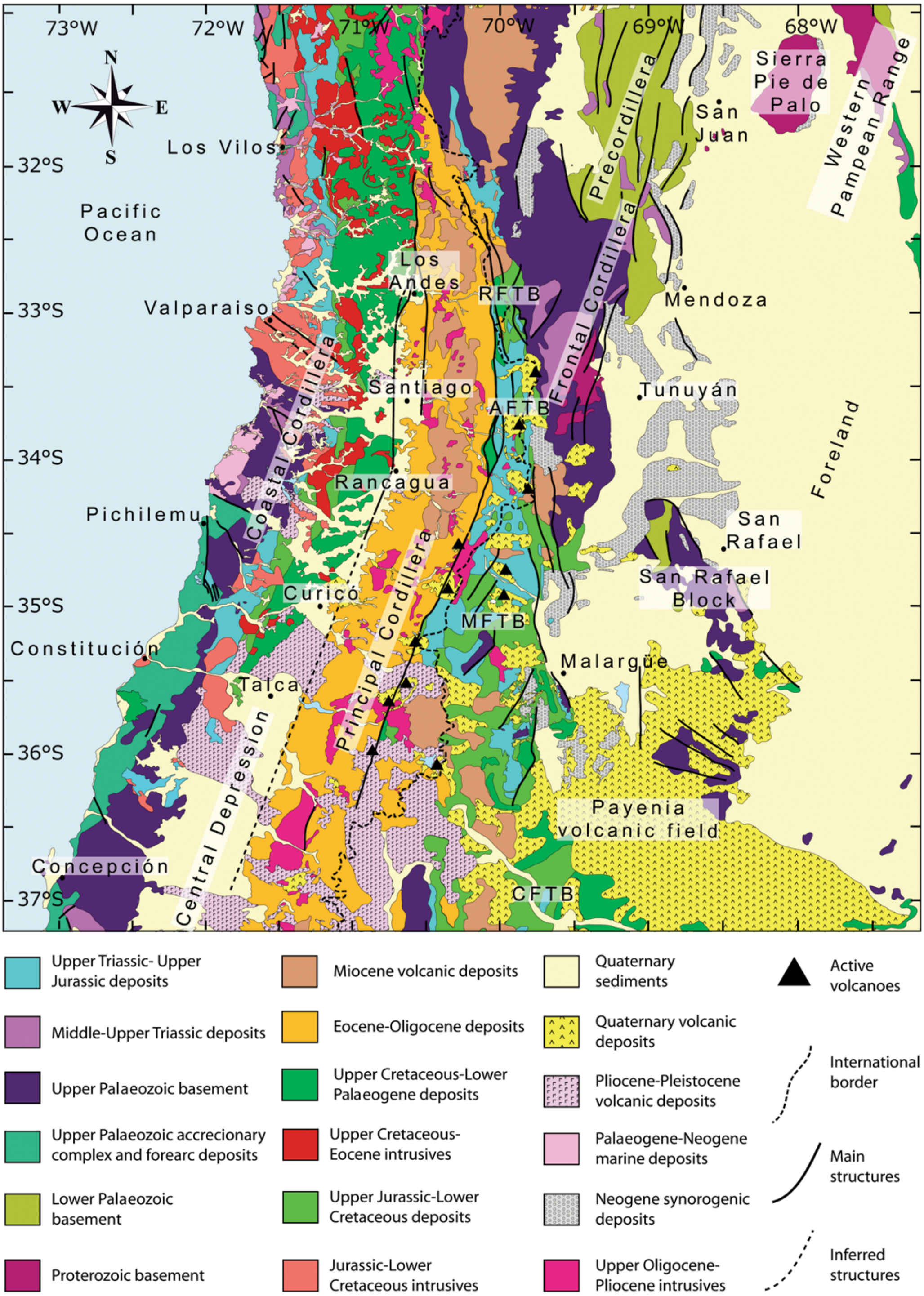

Fig. 3. Geological map of the Andean region between 31 and 37°S. *Abbreviations*: RFTB, Ramada fold-and-thrust belt; AFTB, Aconcagua fold-and-thust belt; MFTB, Malargüe fold-and-thust belt; CFTB, Chos-Malal fold-and-thrust belt.

Ordovician age extends for more than 1000 km along the eastern slope of the Andes near the boundary between the Precordillera and the Frontal Cordillera (Fig. 3) (Ramos *et al.* 2000). These rocks show a dominant E-MORB composition, as well as the Silurian and Devonian mafic rocks and pillow lavas further to the west (Cortés & Kay 1994). The time of emplacement of these ophiolites is constrained by the Middle to Late Devonian age of the low-grade metamorphism of these rocks (Buggish *et al.* 1994; Davis *et al.* 1999; Robinson *et al.* 2005).

The subsequent clastic deposits above the platform successions were characterized by two syn-orogenic sequences; the older comprises the sandstones, conglomerates, glacial deposits and turbidites with olistostromes and olistoliths of Late Ordovician to Silurian age, represented by numerous formations (Astini *et al.* 1996). A second syn-orogenic sequence is represented by the turbidites and clastic deposits of Early to Middle Devonian age. Both sequences are separated by an angular unconformity seen in the Cuesta del Tambolar region between the eroded tilted carbonates and the Silurian deposits, interpreted there as the expression of a peripheral bulge associated with the deformation of the Sierra de Pie de Palo (Fig. 3) (Astini *et al.* 1995). Both sequences are affected by the Chanic unconformity, associated with an important period of uplift, stacking and deformation of the Frontal Cordillera and western Precordillera with a characteristic west-vergence (Von Gosen 1992; García-Sansegundo *et al.* 2014*a*).

Western Sierras Pampeanas

The western Sierras Pampeanas as defined by Caminos (1979) encompasses the Sierra de Pie de Palo and the belt of westernmost Sierras Pampeanas, such as the Valle Fértil, La Huerta and other basement uplifts further to the east. This region is the locus of the Famatinian orogeny, which has been preserved in metamorphic facies that, based on their characteristics, can be divided into several belts.

The western slope of Sierra de Pie de Palo preserved a belt of limestones and quartzites, known as the Caucete Group (Vujovich & Ramos 1994), heavily deformed and overridden by the Pie de Palo Complex, an ophiolite sequence of Grenville age (Vujovich & Kay 1998). Based on detrital zircons and geochemistry, the Caucete Group has been correlated with the sedimentary Cambrian and Ordovician sequences of Precordillera (Naipauer *et al.* 2010*a*, *b*). The metamorphic conditions of the Caucete Group indicate high pressures and modest temperatures in amphibolite facies. These conditions occurred during subduction of a cold sedimentary slab in an A-subduction zone setting (Van Staal *et al.* 2011) around 460 Ma (Ramos 2004). The data indicate a clockwise pressure–temperature (P–T) trajectory reaching a peak pressure of roughly 13 kbar at 450 °C, and then heating as pressure declined, reaching a maximum temperature of roughly 500–560 °C at pressures of 8–10 kbar. This fact has been explained by these authors as continuous subduction of a cold sedimentary slab (Caucete Group) after amalgamation with the Pie de Palo Complex in the subduction channel, followed by underthrusting of progressively more buoyant Precordillera crust.

Further to the east the remaining western Sierras Pampeanas have been extensively studied. Two dominant rock types characterized this region, a western magmatic belt that consists of latest Cambrian, Early to Middle Ordovician calc-alkaline granitoids and metamorphic rocks produced in the same interval (Ramos 1988*a*, 2004). After the pioneering work of Pankhurst & Rapela (1998) and Quenardelle & Ramos (1999), several new studies have characterized the geological evolution of the Ordovician magmatic arc. The petrological conditions of these granitoids have been studied by Otamendi *et al.* (2008, 2009*a*, *b*, 2010*a*, *b*, and references therein) complemented by the analyses of Verdecchia *et al.* (2007) and Casquet *et al.* (2012, and references therein). The wall rocks of these granitoids were characterized by Verdecchia *et al.* (2007), who found fossil shelly faunas preserved in the metamorphic rocks of Ordovician age. Further north, the Ordovician rocks are preserved in sedimentary facies and sedimentological studies show that sedimentation took place in an extensional environment (Mángano & Buatois 1996). Similar conclusions were obtained for the Ordovician age of the metamorphism (Collo *et al.* 2008), and the extensional regime of the magmatic rocks (Collo *et al.* 2009).

Tectonic evolution of the Famatinian cycle

Although several tectonic models have been proposed to explain the early Palaeozoic history of central Chile and western Argentina, sometimes with contrasting interpretations, such as accretions of allochthonous terranes (Ramos 1988*a*; Astini *et al.* 1995) or by continent–continent collisions involving Laurentia and Gondwana (Dalla Salda *et al.* 1992*a*, *b*), in recent years some consensus has been obtained for the evolution of that region (see Ramos & Dalla Salda 2011).

Most of the authors agree that the main deformation that affected the early Palaeozoic the Precordillera platform and slope deposits occurred at about 460 Ma almost in the upper part of the Darriwillian (Thomas & Astini 2003; Ramos 2004). This deformation explains the stacking of different thrust sheets of the eastern Precordillera and the development of olistoliths in the foreland basin during Late Ordovician as part of the Ocloyic deformation (Thomas & Astini 2007). These authors explain the deformation by a collision of the Cuyania (or a larger Precordillera) terrane, an allochthonous terrane derived from the Ouachita embayment of Laurentia that collided against the proto-margin of Gondwana (Astini *et al.* 1995; Thomas & Astini 1996). The first palaeomagnetic data obtained from Cerro Totora syn-rift deposits confirmed this origin for Cuyania (Rapalini & Astini 1998), and, although the new data from the polar apparent curve of Gondwana poses some uncertainties in the location of Cuyania in the Early Cambrian, the recent palaeomagnetic analysis of Rapalini (2012) shows that the origin in the Ouachita embayment is still the best alternative to explain most of the existing data.

The western margin of Sierras Pampeanas shows that the Cambrian–Ordovician calc-alkaline magmatic arc lasted between the Furongian (497–485 Ma) and the Darriwilian (457–458 Ma), reaching the maximum activity in the Early Ordovician (Pankhurst & Rapela 1998; Quenardelle & Ramos 1999; Rapela *et al.* 2010; Dahlquist *et al.* 2013, and references therein). The metamorphic peak was around 460 Ma (Ramos 2004; Van Staal *et al.* 2011; and references therein). This peak was associated with the collision of the Cuyania terrane (Von Gosen *et al.* 2002; Chernicoff & Ramos 2003) by the end of Middle Ordovician.

The consensus that has been obtained for the Ocloyic deformation is greater than that for the various alternatives still discussed for the Silurian and Devonian evolution, which ends with the Chanic deformation at Middle to Late Devonian times. There is agreement to relate that deformation with the collision of the Chilenia terrane, but is not clear where the magmatic arc was located. Most authors have agreed with the proposal of Cucchi (1972), who dated by K–Ar the deformation and low-grade metamorphism of western Precordillera as Late Devonian. New Ar–Ar ages and metamorphic studies confirm the age and the low-grade metamorphism related to the collision (Buggish *et al.* 1994; Robinson *et al.* 2005; Voldman *et al.* 2009).

The main problem that has persisted since the early proposal of Ramos *et al.* (1984, 1986) is the polarity of subduction. These authors proposed an eastern subduction, a criterion that was followed by subsequent studies (see Willner *et al.* 2011, and references therein). On the other hand, the hypothesis of a western subduction beneath the Chilenia terrane proposed by Astini *et al.* (1995) was followed by Davis *et al.* (1999), Gerbi *et al.* (2002), Heredia *et al.* (2012) and González-Menéndez *et al.* (2013), among others. The uncertainty about the location and age of the magmatic arc make these two alternatives difficult to reconcile. Heredia *et al.* (2012) interpreted a Devonian arc developed in the Frontal Cordillera based on the clasts found in the Devonian (?) Vallecitos beds, but the ages of this arc and these beds are not well constrained. Since the peak of high-pressure metamorphism occurred at 385–390 Ma (Willner *et al.* 2011) in Middle Devonian times, and is related to the collision of Chilenia and Cuyania, the arc inferred from the Vallecitos clasts could be Late Devonian and associated with east-dipping subduction from the Pacific side. The other criterion to establish the polarity of subduction is the dominant Chanic vergence of deformation. García-Sansegundo *et al.* (2014*a*) describe a dominant west-vergence for the early Palaeozoic rocks of the Frontal Cordillera in the Cordón del Carrizalito region. Until the age and location of the magmatic arc are established, it will not be possible to address the polarity of the subduction. Moreover, the propagation of the uplift and deformation of the Frontal Cordillera produced the syn-orogenic deposits of the Angualasto Group in the Precordillera at the Early Carboniferous (Limarino *et al.* 2006).

Gondwanian tectonic cycle (Mississippian–Lopingian)

The Gondwanan units north of *c.* 33°S differ considerably from those exposed south of this latitude and will be described in two different segments.

Northern segment

North of *c.* 33°S the following Gondwanan units were recognized from west to east on both sides of the Andean Cordillera.

Accretionary prism rocks. Polyphase deformed metamorphic rocks of the Choapa Metamorphic Complex are exposed along or next to the coast line, northwards of Los Vilos (Fig. 3). This complex consists mostly of grey-coloured phyllites, schists, fine-grained gneisses and metabasites (Muñoz-Cristi 1942; Thiele & Hervé 1984; Hervé 1988; Hervé *et al.* 1988; Irwin *et al.* 1988; Godoy & Charrier 1991; Rivano & Sepúlveda 1991; Rebolledo & Charrier 1994; Charrier *et al.* 2007; Hervé *et al.* 2007; Richter *et al.* 2007; Willner *et al.* 2008, 2012; García-Sansegundo *et al.* 2014*b*), with protoliths of fine- to coarse-grained sedimentary deposits for the phyllites, quartz-mica schists and gneisses, and basic to ultrabasic volcanic rocks, with occasional pillow structures, for the green-coloured, amphibole schists. The Choapa Metamorphic Complex resulted from basal and frontal accretion in a subduction complex and has been subjected to different $P-T$ metamorphic conditions. The presence of phengite-rich muscovite and garnet relics indicates the first stage of very high pressures, probably in the subduction channel, followed by retrogression to greenschist facies conditions. This occurred between 308 and 274 Ma (from Late Pennsylvanian to the end of Cisuralian, in the Early Permian) with a high-pressure–low-temperature peak at *c.* 279 Ma (Willner *et al.* 2008, 2012). Exhumation and deformation, like broken formation-type breccias (mélange-type 1 of Cowan 1985), of the metamorphic complex continued during Mesozoic times and resetting events on minerals have ages that correspond to known extensional or compressional Mesozoic events in this region of the Andes (Willner *et al.* 2012). Recent U–Pb Sensitive High Resolution Ion Micro Probe (SHRIMP) age determinations on detritic zircons from the Choapa Complex immediately north of the region considered here indicate that sedimentation occurred until at least Early Triassic and, thus, that metamorphic processes affected the accretionary prism until at least early Mesozoic times (Emparan & Calderón 2014).

Forearc basin deposits. Two sedimentary stages have been recognized in the forearc region. In the first one, the meta-sedimentary unit Agua Dulce Metaturbidites, and the not metamorphic, strongly folded turbiditic Arrayán Formation, were deposited in a forearc basin (Rivano & Sepúlveda 1991; Rebolledo & Charrier 1994). These units have maximum depositional ages of 337 and 343 Ma, respectively (Willner *et al.* 2008). Supply of the Arrayán Formation is from the NW and the deposits accumulated on the western side of the basin in Carboniferous time (Rebolledo & Charrier 1994; Willner *et al.* 2008, 2012). Platformal deposits of the forearc Arrayán basin are exposed on the eastern side of the basin in the present day western Frontal Cordillera, intruded by granitoids of Cisuralian age (Elqui plutonic complex). These slightly contact-metamorphosed deposits consist of a rhythmic alternation of slates and sandstones of at least 1500 m thick, which have been included in the Hurtado Formation (Mpodozis & Cornejo 1988). These deposits are considered to be the prolongation of a series of similar outcrops representing a transgressive–regressive event, some of which further north contain fossil remains indicating a Middle Devonian to Mississippian age, and a provenance of sediments from a volcanic source located to the east and SE (Charrier *et al.* 2007 and references therein). The continuous Devonian to Mississippian sedimentation in the retrowedge Arrayán basin (Charrier *et al.* 2007; García-Sansegundo *et al.* 2014*b*) demonstrates that the Late Devonian Chanic deformation did not affect the western margin of the Chilenia terrane.

The second sedimentary stage occurred in third stage of the Gondwanian cycle (Charrier *et al.* 2007) and is characterized by coarse- to fine-grained, fossiliferous marine deposits with turbiditic and calcareous intercalations exposed close to the coast, north of Los Vilos. The Quebrada Mal Paso Beds and Huentelauquén Formation (Muñoz-Cristi 1973; Charrier 1977; Mundaca *et al.* 1979; Rivano & Sepúlveda 1983, 1985, 1991; Irwin *et al.* 1988; Méndez-Bedia *et al.* 2009) unconformably overlie the Arrayán Formation, and mark a major palaeogeographic change at the moment of deposition. A maximum depositional age of 303 Ma was obtained by Willner *et al.* (2008). Although Rivano & Sepúlveda (1983, 1985, 1991) favour a Late Pennsylvanian to Cisuralian (Early Permian) age, other authors consider that its fossil content indicates a Permian (Fuenzalida 1940; Muñoz-Cristi 1942, 1968; Minato & Tazawa 1977; Thiele & Hervé 1984; Mundaca *et al.* 1979) or a mid-Permian age (Díaz-Martínez *et al.* 2000). A Guadalupian age would be consistent with its maximum depositional age of 303 Ma (Willner *et al.* 2008) and its unconformable superposition on the Arrayán Formation.

Main magmatic arc rocks. The magmatic arc is not exposed in the study region, although it is well represented further north in the Frontal Cordillera, between 29 and 31°S, where it forms the Elqui–Limarí and Chollay batholiths, and still further north the Montosa–El Potro batholith (Nasi *et al.* 1985; Mpodozis & Kay 1990, 1992). The Elqui plutonic complex includes series of plutons that range in age from the Mississipian to the Late Triassic (Hervé *et al.* 2014), indicating a protracted magmatic history in this region of the Frontal Cordillera. New U–Pb ages obtained by Hervé *et al.* (2014) plus those obtained by previous authors (Pankhurst *et al.* 1996; Pineda & Calderón 2008; Coloma *et al.* 2012) form four groups, falling into the Late Mississipian, Late Pennsylvanian to Cisuralian, Late Lopingian to Middle Triassic, and Late Triassic, respectively. The second group with ages between 301 and 284 Ma predates the San Rafael orogeny, coincides in time with the evolution of the Choapa metamorphic complex and corresponds to the next Gondwanan unit to the east. Geochemical features indicate development in a magmatic arc associated with a subduction zone on a gradually thickening crust.

The rhyolitic welded ash-tuffs and flows of the Guanaco Sonso Formation (lower portion of the Pastos Blancos Group) exposed in the Elqui drainage basin (*c.* 30°S) are related to this plutonic activity. They yielded K–Ar biotite ages of 281 ± 6, 262 ± 6 and 260 ± 6 Ma, and a U–Pb zircon age of 265.8 ± 5.6 Ma, which except for the first one correspond to the Guadalupian (Martin *et al.* 1999). Based on these ages, the Guanaco Sonso Formation should instead be included in the post-tectonic Guadalupian to early Lopingian third stage of Gondwanian evolution of Charrier *et al.* (2007) and thus be related to the Colangüil plutonic activity, which yielded ages between *c.* 279 and *c.* 252 Ma (Sato *et al.* 1990; Sato & Llambías 1993, 2014), rather than to the pre-tectonic second group of Hervé *et al.* (2014).

In the Elqui valley, immediately north of the region considered here, K–Ar hornblende and biotite age determinations in this batholith yielded Permian ages of 297 ± 9 and 258 ± 4 Ma, respectively (Nasi *et al.* 1985, 1990), which coincide within errors with the age of the second group of Hervé *et al.* (2014). These ages also coincide fairly well with a recent U–Pb age determination of 282.7 ± 5.8 Ma for a rhyolitic volcanic sequence that still further north overlies the western El Tránsito Metamorphic Complex (Salazar *et al.* 2009). The felsic character of these units makes it difficult to differentiate them from each other and the wide age range covered by them suggests that there existed a long lasting felsic volcanic activity from at least Pennsylvanian to Triassic times. Late Pennsylvanian to Cisuralian activity corresponds to the second group of Hervé *et al.* (2014) and is pre-tectonic relative to the San Rafael orogeny, whereas the Guadalupian to early Lopingian activity is post-tectonic. The latter, according to its age, would correspond to a volcanic activity coeval with intrusion of the Colangüil plutonic activity, deposition of the Huentelauquén Formation and the subduction-related lower portion of the Choiyoi Group (Kay *et al.* 1989; Kleiman & Japas 2009). A third stage of activity would include the felsic upper portion of the Choiyoi Group in Argentina and the Matahuaico Formation, exposed further west in Chile in the Elqui river drainage, which has been assigned to the early stage of the next tectonic Pre-Andean cycle (Charrier *et al.* 2007).

Retroarc magmatic rocks. The Colangüil batholith and associated volcanic rocks are exposed north of 31°S to east of the previous arc rocks in the Cordillera Frontal along the Argentine slope in the province of San Juan. The batholith is composed of several granitoids varying from granodiorites to granites as the Los Puentes, Los Lavaderos, Las Opeñas, Agua Blanca and Chita plutons (Sato *et al.* 1990), with K–Ar ages varying between 272 and 247 Ma (Sato & Llambías 1993). The coarse-grained granodiorites have an Early to Middle Permian age, and they are typically calc-alkaline with magmatic arc affinities, associated with the final stage of subduction in a retroarc setting, and as early post-orogenic products respect to the orogenic San Rafael deformation (Sato & Llambías 1993). The granites are commonly fine grained and characterized by granophyric textures consistent with intrusions at shallow levels, and have a transitional signature from calc-alkaline to alkaline (A-type). They were interpreted as reflecting an evolution to an extensional post-orogenic setting during Late Permian times. These granitoids are associated with lava flows, ignimbrites and tuffs of andesitic and rhyolitic composition, which follow the same trend as the plutonic rocks. Based on the geochemical characteristics, the calc-alkaline series was assigned to a pre-Choiyoi field, typical of an arc setting, while the younger transitional series was assigned to a Choiyoi field of within-plate affinities in an extensional regime (Kay *et al.* 1989).

Retroarc basin deposits. Several authors have described the sedimentation in the retroarc region of this segment of the Andes as part of the Calingasta and Uspallata basins developed in the Frontal Cordillera and the Precordillera, as well as an intraplate basin known as the Paganzo basin developed between the Precordillera and the Sierras Pampeanas (Fig. 3) (Ramos *et al.* 1986; López Gamundi *et al.* 1994, among others). These authors recognized two different stages separated by the San Rafael orogenic deformation in the Middle Permian. The first stage is unconformably overlying the Devonian deposits and comprises mainly Late Carboniferous to Early Permian sequences, where a complete record of different glacial stages has been recognized. The Early Carboniferous is only preserved in the eastern Precordillera (Fig. 3) where the Angualasto Group of mainly Visean age recorded the first infills of the retroarc marine basin with an early glacial stage (Fernández-Seveso & Tankard 1995; Limarino *et al.* 2013). The upper part of the first stage comprises widely developed marine deposits in the Precordillera, and recorded the glacial diamictites, overlain by transgressive postglacial shales (Pazos 2002; Limarino & Spalletti 2006). These transgressive facies were succeeded by deltaic and fluvial sequences bearing coal beds where recent U–Pb ages indicate a late Bashkirian age (Gulbranson *et al.* 2010; Spalletti *et al.* 2012; Limarino *et al.* 2013).

The sequences above the San Rafael unconformity of Early–Middle Permian age are mainly volcaniclastic, pyroclastic and volcanic rocks associated with the lower and upper parts of the Choiyoi Group (Kay *et al.* 1989; Kleiman & Japas 2009). The lower part of the Choiyoi volcanic rocks is subduction related, while the upper part corresponds to an extensional regime that controlled the extensive rhyolitic plateaux in the foreland area (Mpodozis & Ramos 1989; Mpodozis & Kay 1992; Llambías 1999).

There is no agreement on the dominant tectonic regime after the Late Devonian Chanic compressive deformation. Fernández-Seveso & Tankard (1995) interpreted that the described sequences reflect changes from transtensional to extensional regimes. A similar extensional regime was proposed by Astini (1996), Astini *et al*. (2011), and Martina *et al*. (2011) for the Mississippian (348–342 Ma) based on the occurrence of rhyolites at about 28°S in the southern Puna, coeval with the well-known occurrence of A-type granites in the Sierras Pampeanas (Grosse *et al.* 2009). On the other hand, after the Chanic deformation during Middle to Late Devonian times (Ramos *et al.* 1986) compressional deformation and flexural loading produced the foreland basin where the Mississippian deposits of the Angualasto Group and El Ratón Formation have accumulated (Heredia *et al.* 2012). As a result of this deformation, the Protoprecordillera was uplifted and remained as a positive area until the end of the Carboniferous, when it collapsed by extensional faulting (Limarino *et al.* 2013).

Southern segment

South of 33°S and further south of the considered region, four Gondwanan units are exposed continuously paralleling the coast from west to east (see Fig. 3): a metamorphic complex; a north–south elongated Coastal Batholith that intrudes the former; an extensive batholith emplaced in the Frontal Cordillera; and an extensive volcanic episode in the Frontal Cordillera and further east in the San Rafael Block (Fig. 3) represented by the Choiyoi Group.

Metamorphic complex. In this segment the metamorphic complex includes the eastern and a western series that form a paired metamorphic belt (González-Bonorino 1970, 1971; González-Bonorino & Aguirre 1970; Aguirre *et al.* 1972; Hervé *et al.* 1974, 1984, 2003, 2013; Hervé 1977; Kato & Godoy 1995; Willner 2005; Willner *et al.* 2004, 2005, 2008; Glodny *et al.* 2005, 2006, 2008), interpreted recently as the result of frontal and basal accretion in a subduction system, respectively (Richter *et al.* 2007; Willner *et al.* 2008).

The western series, which was deposited shortly after the eastern series (Hervé *et al.* 2013), consists of polyphase deformed and metamorphosed sandstones and pelites, metacherts, metabasites, occasionally with pillow structures and scarce serpentine bodies, formed by basal accretion under a higher P–T metamorphic gradient, while the eastern series consists mainly of polyphase deformed metaturbidites, with recognizable primary structures and lenses of calc-silicate rocks, deposited in a retrowedge or forearc basin, metamorphosed by a low P–T gradient (Glodny *et al.* 2006; Richter *et al.* 2007; Hervé *et al.* 2013). All SHRIMP U–Pb age determinations on igneous detrital zircons from the accretionary complex yielded peaks older than Mesozoic. The youngest peak obtained from the eastern series was dated at 330–345 Ma, while the youngest peak in the western series was dated at 307 Ma (Hervé *et al.* 2013). All these ages are older or coeval with the Coastal Batholith, and coincide with ages determined for the Agua Dulce metaturbidites and the non-metamorphic Arrayán Formation north of *c.* 33°S, respectively. Moreover, ages of detrital zircons in both series indicate a major input from the Famatinian orogenic belt and subordinately from Pampean and Grenvillian sources (Hervé *et al.* 2013).

Ar–Ar dating of white mica in the metamorphic series indicates for the western series a peak of high-P–T metamorphism between 320 and 288 Ma and for the eastern series a peak of high-temperature metamorphism between 302 and 294 Ma (Willner *et al.* 2005). According to the age and the contact metamorphism affecting the eastern series, the sedimentation, at least in the western series, began before emplacement of the Coastal Batholith (see below).

South of the Lanalhue lineament (*c.* 38°S) conditions seem to have been different from those to north of this latitude. Here the metamorphic complex bends to the east and consists mainly of the western series, which is here much younger than further north (Hervé *et al.* 2013).

Deposits in the Coastal Cordillera close to Concepción, in the southern part of the considered region, form the newly proposed Patagual–El Venado unit (Mardonez *et al.* 2012). These deposits overlie unconformably the eastern series and are unconformably covered in the Bio Bío valley by the marine, Carnian Santa Juana Formation (Nielsen 2005). This unit consists of a tightly folded and slightly metamorphosed (epizone close to the anchizone) alternation of pelitic and thick psamitic layers, which differentiates them from the eastern series and the overlying early Late Triassic deposits. Its loosely constrained age, between the Early Permian (age of the thermal metamorphism in the eastern series of the metamorphic complex, south of 33°S) and the early Late Triassic Santa Juana Formation makes its age assignment difficult. Considering that this unit overlies the eastern series, which was affected by thermal metamorphism between 302 and 294 Ma (Willner *et al.* 2005), its maximum age is early Sakmarian, in the Early Permian. According to the lithologic description, strong deformation and low-grade metamorphism, which are reminiscent of the Agua Dulce metaturbidites and the Arrayán Formation, we suggest that the tectonic setting for this unit is the late Palaeozoic forearc or retrowedge basin. Another possibility is that these deposits accumulated in a rift basin during the first stage of the Pre-Andean cycle.

Its strong deformation and low metamorphic grade suggest that the Lopingian to Early Triassic deposits close to the continental margin would at that time still have been affected by processes related to subduction activity, as has been shown by the presence of Triassic detritic zircons in rocks of the Choapa Metamorphic Complex (Emparan & Calderón 2014).

Coastal batholith. This batholith consists of a series of plutons of calc-alkaline character, meta- to peraluminous composition, and granitic to quartz-dioritic lithologies exposed along the Coastal Cordillera, between 33 and 38°20′S, intruding to the east the metamorphic complex (Fig. 3). Further south (38°S), the batholith curves to the east and can be followed southwards along the Principal Cordillera. This shift is probably controlled by the NW-orientated Lanalhue lineament (Glodny *et al.* 2008; Hervé *et al.* 2013). According to the recent SHRIMP U–Pb age determinations, the Coastal Batholith was emplaced in a *c.* 19 Ma period, between 319.6 $\pm$ 3.3 and 300.8 $\pm$ 2.4 Ma, in Pennsylvanian time, according to Deckart *et al.* (2014). This age differs considerably from the ages recently obtained by Hervé *et al.* (2014) for the Elqui plutonic complex, which fall into the Early Permian (Cisuralian; 301–284 Ma). Ages for the metamorphic peaks on the western series indicate that metamorphism overlapped with emplacement of plutons of the Coastal Batholith (Hervé *et al.* 2013).

Frontal Cordillera batholith

Further east, along the Frontal Cordillera, there are several granitoid stocks and batholiths, exposed south of 33°S latitude (Fig. 3). These granitoids outcrop from the Cordón del Plata to the Cordón del Portillo region, and continuous further south until the Río Diamante valley. They have been described by Polanski (1964, 1972) and Caminos (1965) as typical calc-alkaline metaluminous granitoids emplaced in the Carboniferous deposits. Petford & Gregori (1994) and Gregori *et al.* (1996) compared this belt of Frontal Cordillera granitoids with the Coastal Batholith of Peru and concluded that they share similar La/Yb ratios, Al_2O_3 contents and several petrographic characteristics that show a typical subduction setting. These authors interpreted these granitoids as emplaced in a several thousand metres-thick sedimentary sequence formed in an extensional regime. The first U–Pb ages of the Frontal Cordillera of this segment were presented by Orme & Atherton (1999), ranging in age between 276 and 262 Ma and with εNd between −2.5 and −3.5. These postectonic granitoids were also recognized in the Frontal Cordillera by Gregori & Benedini (2013), who interpreted these Cisuralian and Guadalupian granodiorites, tonalites and monzogranites of I-type as emplaced subsequent to the San Rafael orogeny that closed the Carboniferous basin between 284 and 276 Ma. The new ages seem to discard the presence of Carboniferous granitoids in this sector of Frontal Cordillera assumed by Caminos (1979).

Choiyoi volcanic rocks. These volcanic rocks, recognized in this segment of the Andes by Groeber (1953), are widely represented in the Frontal Cordillera and further east in the San Rafael Block as well as in the foothills of western Sierras Pampeanas. The volcanic rocks of the Choiyoi Group formed after the San Rafael tectonic phase. This group is subdivided into two essentially different units. A lower unit consisting of volcanic rocks of basic to intermediate composition and calc-alkaline signature (Poma & Ramos 1994) developed in late Cisuralian and Guadalupian times in an arc setting in association with subduction of oceanic lithosphere, an upper volcanic unit consisting of silicic volcanic and volcaniclastic deposits and sub-volcanic intrusives derived from crustal melting under extensional tectonic conditions deposited in Lopingian to Anisian times (Kay *et al.* 1989; Mpodozis & Kay 1990, Llambías *et al.* 1993, 2003; Llambías & Sato 1995; Spalletti 1999; Martínez 2005; Martínez *et al.* 2006; Giambiagi & Martínez 2008). New U–Pb ages have been presented by Rocha Campos *et al.* (2011), which confirm a Guadalupian age for this section of the older Choiyoi volcanic rocks. The partly coeval age of this older Choiyoi unit with deposition of the Huentelauquén deposits, its location further east of the retrowedge or foreland basin, and its calc-alkaline signature indicate that it corresponds to a subduction related magmatic arc developed during closure of the retrowedge basin and uplift of the continental margin at the final stage of Gondwanan evolution (third stage of Charrier *et al.* 2007). The younger Choiyoi unit has, in turn, been assigned to the next pre-Andean tectonic cycle.

Gondwanan tectonic evolution

Based on the marked difference between the regions north and south of 33°S, it is difficult to reconcile the late Palaeozoic tectonic evolution of the two regions in one single coherent model, which is evidence that more information is necessary to solve this problem. However, some general conclusions can be drawn on the basis of the available information. The post-Devonian age of the units described from the western slope of the Andes suggests that these developed on the rear side of Chilenia. The recent chronologic data for the metamorphic complexes and plutonic belts north and south of 33°S indicate that:

(1) Maximum depositional ages for the deposits accreted by basal and frontal accretion in both regions are approximately the same; however, the peaks of high P–T metamorphism in the paired belt, south of 33°S, are older than in the Choapa Metamorphic Complex, to the north of this latitude.
(2) Emplacement of the Coastal Batholith, south of 33°S, is older (Pennsylvanian) than the Elqui plutonic complex (Cisuralian), in the Frontal Cordillera, north of 33°S. This evidence indicates that the Choapa Complex and the paired metamorphic complex south of 33°S probably belong to two different accretionary complexes, and that the plutonic belts correspond to two different subduction-related magmatic arcs.
(3) The late stage of emplacement of the Elqui plutonic complex in late Cisuralian and Guadalupian times is coeval with sedimentation of the Huentelauqén Formation, in the retrowedge basin, and the lower Choiyoi Group would thus correspond to the extrusive products of the magmatic arc.

Additionally, two features – the narrow width of the outcrops of the western series north of the NW-orientated Lanalhue lineament (*c.* 38°S) and the considerably wider outcrops of this series to the south of the lineament that interrupts the southward prolongation of the Coastal Batholith and apparently caused its bend towards the Principal Cordillera (Hervé *et al.* 2013), and the much younger depositional age of the western series to the south of the lineament containing abundant Permian detrital zircons (Hervé *et al.* 2013) – suggest that: (a) the accretionary complex was considerably wider than the present day outcrops; (b) its age is younger towards the SW; and (c) the probable orientation of the accretionary complex and the Gondwana coast was NNW–SSE.

Although there is no consensus on the tectonic regime during the Carboniferous, there is agreement that the San Rafael orogeny caused in Early to Middle Permian (late Cisuralian to early Guadalupian) generalized uplift of the region (Ramos 1988*b*; Mpodozis & Kay 1992; López Gamundi *et al.* 1994; Limarino *et al.* 2006, 2013; Giambiagi *et al.* 2011; Willner *et al.* 2008, 2012; García-Sansegundo *et al.* 2014*a*, among others). This tectonic event was responsible for deformation of the Arrayán Formation in the forearc (Charrier *et al.* 2007) and the cataclastic fabric in the El Volcán plutonic unit of the Elqui plutonic complex (Mpodozis & Kay 1990).

It has been proposed that the late Palaeozoic evolution of this sector of the Andes can be explained by a period of subduction in the Carboniferous times associated with extension after the Chanic compressive orogenic episode in the Middle to Late Devonian, with an active subduction-related magmatic arc. This arc expanded and migrated towards the foreland, reaching the Central Precordillera and the western side of the Sierras Pampeanas during Early Permian times, associated with the San Rafael orogenic deformation. Subsequent extension and formation of extensive rhyolitic plateaux were associated with delamination of the lower crust owing to injection of hot anhydrous asthenosphere. These processes were previously interpreted as produced by orogenic collapse and slab break-off by Mpodozis & Ramos (1989), Kay *et al.* (1989) and Mpodozis & Kay (1992). However, this evidence together with the new available U–Pb ages favour the interpretation advanced by Ramos & Folguera (2009), where these episodes can easily be explained by a period of slab shallowing followed by steepening of the subduction zone, as proposed by Martínez *et al.* (2006).

Pre-Andean tectonic cycle (Lopingian–late Early Jurassic)

The term Pre-Andean is used for a period of arrested or very slow subduction during which extensional tectonic conditions prevailed following deformation of the Late Permian deposits, closure of the retrowedge or forearc basin, exhumation of the continental margin and intense erosion on the Palaeozoic units. Groeber (1922) presented the first description of these deposits along the continental margin. Extensional conditions on the thickened crust of the continental margin determined the reactivation of pre-existent weakness zones like the sutures of the Palaeozoic terranes accreted to western Gondwana (Ramos & Kay 1991; Ramos 1994). The weakness zone defined a different palaeogeographic organization compared with those that prevailed earlier and later, that is, in the Gondwanan and Andean tectonic cycles, consisting of NW-trending rift basins (Charrier 1979; Uliana & Biddle 1988; Suárez & Bell 1992) (Fig. 4). Additionally, extension favoured the development of a widely distributed felsic magmatism that resulted predominantly from intense crustal melting (upper Choiyoi magmatic province; Rapela & Kay 1988; Kay *et al.* 1989; Llambías 1999; Spalletti 1999). End of this cycle is marked by resumption or more intense subduction activity along the continental margin and development of the Early Jurassic magmatic arc. The pre-Andean cycle reflects the tectonic conditions determined by the assembly of Gondwana, but also the initial processes that later resulted in its breakup.

Generalized extension and the existence of weakness zones (sutures) on the continental margin resulted in the development of the following basins and successions of associated basins (Fig. 4): (a) El Quereo–Los Molles, next to the coast, at *c.* 32°S; (b) La Ramada, further east in the high Andes, (c) Cuyo, in the Precordillera and Andean foreland, in the San Juan–Mendoza region; (d) Bermejo, SW of La Rioja, in the northeastern San Juan province; and (e) Curepto–Bio Bío–Temuco, further south, which extends south-southeastwards from the coast up to the high Andes, at 40°S. Deposits in these basins are generally marine next

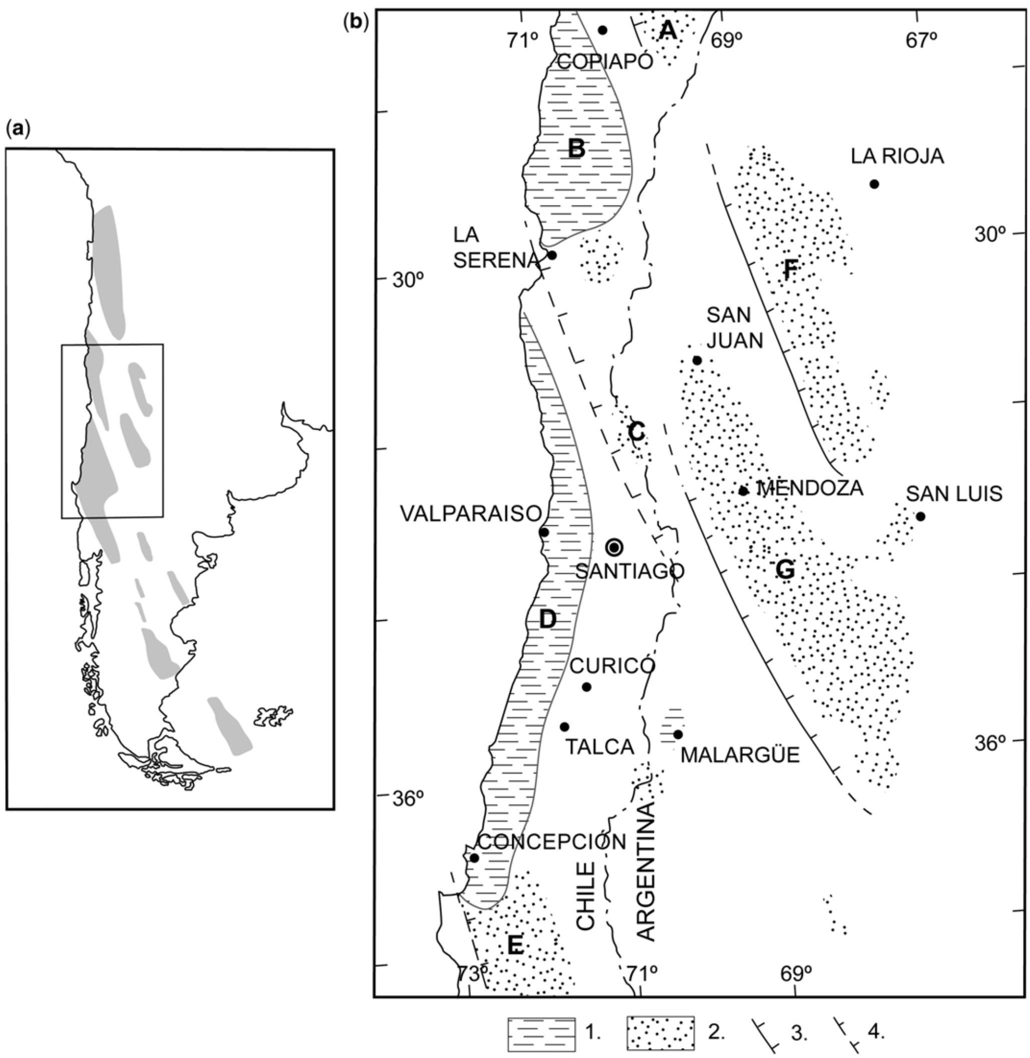

Fig. 4. Generalized palaeogeographic sketch for the Triassic in the Andean region of Argentina and Chile. (**a**) Southern part of South America showing in grey the approximate distribution of the basins, based on Uliana & Biddle (1988). Rectangle corresponds to the area represented in (b). (**b**). Distribution of the marine and continental deposits in the Triassic basins. 1, Marine deposits; 2, continental deposits; 3, observed basin bounding faults; 4, inferred faults. A, Profeta–La Ternera, basin; B, San Félix–Rivadavia basin; C, La Ramada basin; D, El Quereo–Los Molles basin; E, Curepto–Bio Bío–Temuco basin; F, Bermejo basin; and G, Cuyo basin; based on Charrier *et al.* (2007).

to the coast and continental towards their south-southeastern prolongation. The extensional faults that control the basins in Chile have not been clearly identified and the structural pattern is certainly more complicated than represented here. In Argentina, sedimentary polarity, seismic data and structural analyses indicate that some of the basins consist of hemigrabens (Milana & Alcober 1994; López Gamundi 1994).

Two rift stages have been detected in the evolution of the Pre-Andean cycle, each one consisting of a phase of tectonic subsidence followed by a phase of thermal subsidence (Charrier *et al.* 2007), a model that coincides with the one developed by Milana & Alcober (1994) and Milana (1998) for the Bermejo basin, in Argentina (Fig. 4). According to Charrier *et al.* (2007), in Chile, the first stage would have begun in Lopingian times (Late Permian) and ended by Ladinian to Carnian times (Middle Triassic to early Late Triassic), while the second one would have lasted from Late Triassic (post-Carnian) to Pliensbachian, in Early Jurassic times. Each phase of tectonic subsidence would have been accompanied by a pulse of felsic volcanism followed by marine or continental deposits, depending on the distance from the Triassic coast.

Sedimentary deposits of the first stage are known in the Coastal Cordillera north of 32°S in the El Quereo–Los Molles basin. These consist of a series of marine outcrops that can be grouped into the El Quereo Formation (Muñoz-Cristi 1942, 1973; Cecioni & Westermann 1968; Mundaca *et al.* 1979; Irwin *et al.* 1988; García 1991; Rivano & Sepúlveda 1991). These deposits reveal an Early? to Middle Triassic transgression–regression sedimentary cycle beginning with breccias and separated from the deposits of the second stage by the thick felsic volcanic and volcaniclastic Pichidangui Formation, associated with initiation of the second tectonic subsidence phase of the pre-Andean cycle.

Second-stage deposits have a latest Triassic to Early Jurassic age and therefore correspond to the late portion of the second stage, probably to the thermal subsidence phase occurring after the felsic volcanic event (Charrier *et al.* 2007). In the high Andes, at 31°S, Early Jurassic transgressive marine deposits of the Tres Cruces Formation are exposed overlying conformably the Late Triassic, continental, sedimentary and volcanic Las Breas Formation. This formation contains rests of *Dicroïdium* flora and was recently dated at 219.5 ± 1.7 Ma (Norian) (U–Pb SHRIMP zircon crystallization age) on a dacitic volcanic breccia from the base of the formation (Hervé *et al.* 2014). The Las Cruces Formation is in turn covered by backarc volcanic and volcaniclastic deposits of the Late Jurassic Algarrobal Formation (Dedios 1967; Letelier 1977; Mpodozis & Cornejo 1988; Pineda & Emparan 2006). At the coast, at 32°S, overlying the Pichidangui Formation, is the transgressive–regressive Los Molles Formation (Cecioni & Westermann 1968; Bell & Suárez 1995). The mostly marine deposits of the second stage, exposed along the Coastal Cordillera, south of 35°S, overlie, between 35 and 36°15′S, silicic volcanic deposits assigned to the bimodal volcanic Pichidangui Formation (Vicente 1974; Vergara *et al.* 1995) (La Totora–Pichidangui volcanic pulse) related to the upper Choiyoi magmatic province (Charrier *et al.* 2007). Further south of 36°15′S, they rest on Palaeozoic intrusive and metamorphic rocks (Fig. 3). The presence of a rather continuous series of marine deposits assigned to the second stage along the Coastal Cordillera, between 35 and 37°S (Curepto–Bio Bío–Temuco basin; see Charrier *et al.* 2007, Fig. 3.11, p. 39), suggests that the region covered by marine deposits during the thermal subsidence phase of the second stage was considerable and that the sea extended beyond the faults that controlled subsidence of the basin. We assign the marine Retian Malargüe rift deposits on the eastern versant of the Principal Cordillera, in Argentina, at *c.* 36°S (Riccardi & Iglesia Llanos 1999) (Fig. 4) to the earliest rift stages of the Jurassic backarc basin rather than to the second stage of the Pre-Andean cycle as previously proposed by Charrier *et al.* (2007). These deposits belong to one of the depocentres related to the Neuquén basin (Fig. 5).

Continental Triassic to Early Jurassic deposits were accumulated in the south-southeastward prolongation of the basins or in smaller isolated basins. These contain generally abundant volcanic and volcaniclastic deposits, like the Carnian–Norian Los Tilos sequence in the high Andes, at *c.* 30°S, somewhat north of the considered region (Martin *et al.* 1999), probably deposited in the prolongation of the San Félix basin (see Charrier *et al.* 2007, Fig. 3.11, p. 39). Other deposits apparently filled separated basins, like the La Ramada, in the high Andes, at 32°S (Álvarez 1996; Álvarez & Ramos 1999), the various depocentres of Cuyo basin located in the Frontal Cordillera, Precordillera and Andean foreland, between 31 and 36°S (Legarreta *et al.* 1992; Kokogián *et al.* 1993, 1999; Manceda & Figueroa 1995; Barredo *et al.* 2012), and the depocentres in the Sierras Pampeanas (Milana & Alcober 1994; Milana 1998), between 29 and 33°S (Fig. 4).

The best dated deposits are in the Cuyo basin in the Potrerillos depocentre, and were included in the Uspallata Group. These are separated from Devonian turbiditic deposits (Villavicencio Formation) and volcanic rocks of the Choiyoi Group by a normal fault and unconformably overlain by Miocene foreland deposits of the Mariño Formation.

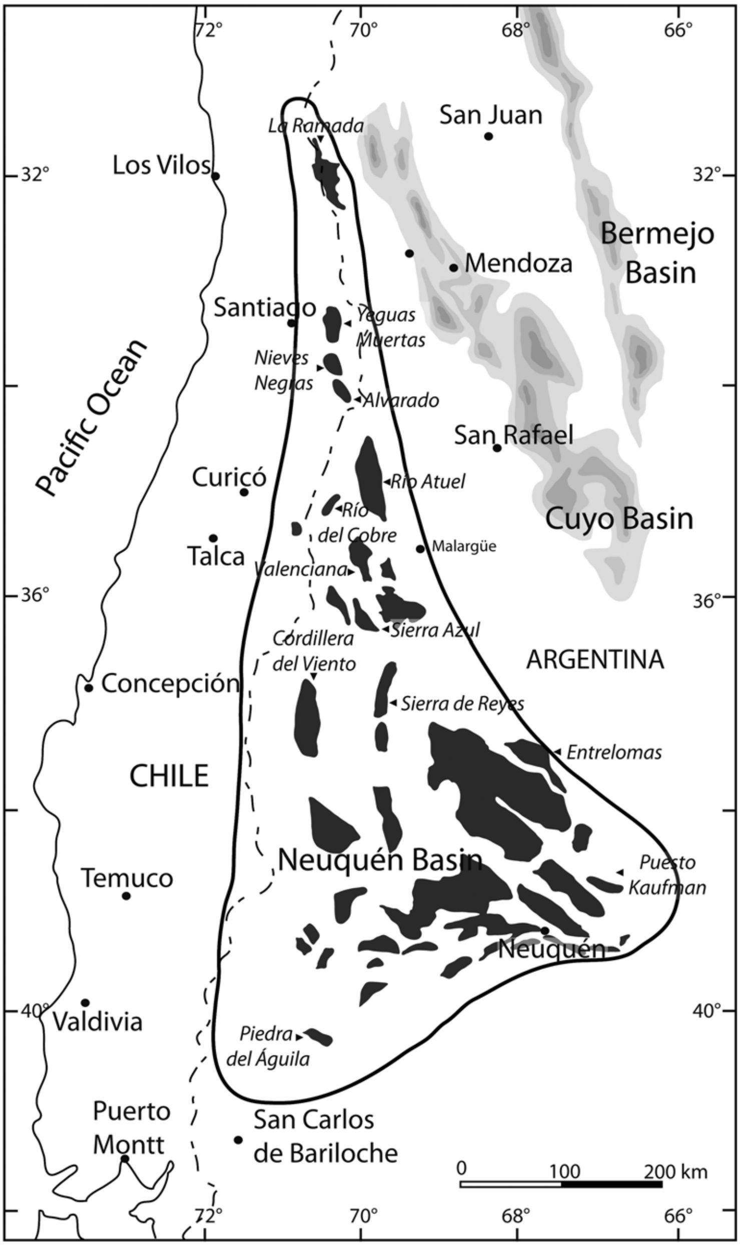

Fig. 5. Main depocentres of the Triassic–Early Jurassic rifts with the location of Alto del Tigre High (after Giambiagi *et al.* 2003*b*).

The Uspallata Group forms a 1385 m-thick continental sedimentary succession rich in fossil plants consisting of the following formations, from bottom to top (Spalletti *et al.* 1999, 2005, 2008): Río Mendoza (314 m; Anisian; 243 ± 4.7 Ma; Ávila *et al.* 2006), Cerro de las Cabras (190 m), Potrerillos (735 m; late Middle to early Late Triassic; 239.2 ± 4.5, 239.7 ± 2.2 and 230.3 ± 2.3 Ma), Cacheuta (44 m; early Late Triassic) and Río Blanco (102 m). The succession consists at the bottom and top of alluvial conglomerates and in the middle part of fluvial medium- to fine-grained deposits with tuff intercalations. The Río Mendoza, Cerro de las Cabras and Potrerillos formations correspond to the syn-rift phase of the basin, while the two upper units correspond to the sag phase. A rich fossil flora recovered in the Potrerillos and Cacheuta formations was used to propose a biozonation of the whole Triassic (Spalletti *et al.* 1999, 2005).

However, recent precise U–Pb dating in zircons from the Rincón Blanco, one of the northern depocentres of the Cuyo basin, has presented new ages from the base to the top of the sequence (Barredo *et al.* 2012). The SHRIMP age obtained for the base is 246.4 $\pm$ 1.1 Ma; the middle sequences yielded a SHRIMP age of 239.5 $\pm$ 1.9 Ma and Laser Ablation age of 238.0 $\pm$ 5.4 Ma; and the top, for both methods yielded 230.3 $\pm$ 1.5 and 230.3 $\pm$ 3.4 Ma (Barredo *et al.* 2012). These geochronological data, which are similar to those for the Potrerillos depocentre, indicate that almost the whole sedimentation is circumscribed to the Middle Triassic and the base of the Late Triassic, reaching neither the Norian nor the Rhaetian. The age differences observed between the Pre-Andean evolution in Chile and Argentina possibly indicate that extension began earlier in Chile than in Argentina. However, more precise chronological support is needed to make this decision.

Deposits in the Coastal Cordillera close to Concepción, in the southern part of the considered region, form the newly proposed Patagual–El Venado unit (Mardonez *et al.* 2012). These deposits overlay unconformably the eastern series and are unconformably covered in the Bio Bío valley by the marine, Carnian Santa Juana Formation (Nielsen 2005). This unit consists of a tightly folded and slightly metamorphosed (epizone close to the anchizone) alternation of pelitic and thick psamitic layers, which differentiates them from the eastern series and the overlying early Late Triassic deposits. Its loosely constrained age, which must be younger than the Early Permian, which is the age of the thermal metamorphism on the eastern series of the metamorphic complex, south of 33°S (between 302 and 294 Ma; Willner *et al.* 2005), and older than the early Late Triassic Santa Juana Formation, makes its age assignment difficult. According to these considerations, these deposits could correspond to (a) Permian forearc basin accumulations equivalent to the Huentelauquén Formation (third stage of the Gondwanan cycle) or (b) Latest Permian to Early Triassic deposits, which in this case would have accumulated during the first stage of the Pre-Andean cycle and, therefore, represent evidence for rifting in the first stage of the Pre-Andean cycle in this region.

In the Elqui plutonic complex, in the Frontal Cordillera north of 33°S, the plutonic and subvolcanic units included in the Late Lopingian to Middle Triassic age group (264–242 Ma) of Hervé *et al.* (2014) (Ingaguás superunit of Mpodozis & Kay 1990, 1992) represent the intrusive equivalents of the felsic upper Choiyoi Group (Nasi *et al.* 1985; Mpodozis & Kay 1990) and possibly of the Mathuaico Formation. These plutons, along with the Laguna gabbro, form an epizonal association of intrusive rocks derived from deep, garnet-bearing levels in a thickened crust, and hypersilicic, calc-alkaline to transitional A-type granites (Nasi *et al.* 1985, 1990; Mpodozis & Cornejo 1988; Mpodozis & Kay 1990, 1992). These units consist predominantly of biotite–hornblende granodiorites and monzogranites, and syenogranites; graphic granites are known from the youngest El Colorado units. The given age range comprises a 22 Ma time lapse that goes from the Capitanian (late Middle Permian) to the Anisian/Ladinian boundary (Middle Triassic), and therefore coincides with the first stage of the Pre-Andean cycle.

Norian and somewhat younger Triassic ages have been also obtained along the coast: (a) in the northern part of the considered region in the A-type to transitional Altos de Talinay Plutonic Complex (Gana 1991; Emparan & Pineda 2006; Emparan & Calderón 2014), and further south in the Tranquilla and Millahue units (Parada *et al.* 1988, 1991, 1999, 2007; Rivano & Sepúlveda 1991); (b) in the Norian 'Dioritas Gnéisicas de Cartagena' (Gana & Tosdal 1996), next to San Antonio, at 33°30′S, and (c) in the Norian fayalite, anorogenic A-type Cobquecura pluton (Vásquez & Franz 2008). All these widely distributed plutonic units demonstrate the great regional extension of the Choiyoi Magmatic Province.

Andean tectonic cycle (late Early Jurassic–present)

The beginning of this long-lasting cycle was determined in Chile by the initiation of subduction-related volcanism in the late Early Jurassic (Pliensbachian) (Charrier *et al.* 2007, and references therein). However, on the eastern versant of the Andes in central Argentina, a post-Choiyoi extensional event occurred in the Late Triassic that formed new depocentres in the region where later the backarc basin developed during Jurassic times. This extensional event and the initiation of sedimentation in the backarc region are considered in Argentina to mark the beginning of the Andean cycle. Thus, the age of the beginning of this cycle remains a question that needs further investigation: (a) do the Late Triassic deposits in Argentina belong to the second stage of the Pre-Andean cycle; or (b) did the new geodynamic conditions at this moment cause extension of the continental margin already in the Late Triassic, whereas subduction magmas reached the surface of the crust somewhat later in Pliensbachian time?

The Pre-Andean cycle, which began with renewal or intensification of subduction underneath the central Argentine–Chilean continental margin, reflects evolution of the continental margin during continental breakup and continental drift (Fig. 1). Subduction created conditions for arc magmatism, active almost uninterruptedly right through to the present day, and extensional tectonic conditions along the continental margin. During early evolution of this cycle (Pliensbachian to late Early or early Late Cretaceous), in northern and central Chile, the arc was located along the present day Coastal Cordillera, parallel to the western margin of Gondwana with a backarc basin on its eastern side. In contrast, the later evolution (Late Cretaceous and Cenozoic) is characterized by gradual eastward shift of the magmatic arc and by the development of retroarc foreland basins on the eastern side of the arc. These two major periods correspond to the Early and Late periods, respectively, described by Coira *et al.* (1982) for this tectonic cycle. However, each of these periods can be subdivided into shorter stages, which can be differentiated from each other by major palaeogeographic changes (Fig. 1). These changes are a consequence of major modifications of the convergence and subduction pattern in this region.

Early period (Pliensbachian–late Early Cretaceous)

The early period of the Andean tectonic cycle ended in late Early or early Late Cretaceous with the Peruvian tectonic phase (Fig. 1) that caused a considerable crustal thickening, major palaeogeographic reorganization and modification of the tectonic regime in this Andean region (Coira *et al.* 1982; Mpodozis & Ramos 1989). Evolution of this early period in central Chile and Argentina is characterized by a dominating extensional tectonic regime, a rather thin crust, the development of a magmatic arc slightly oblique to the present day Pacific coast and a backarc basin on its eastern side (Mpodozis & Ramos 1989, 2008; Ramos 2010). This orientation of the arc–backarc basin palaeogeographic pair suggests that the late Proterozoic and Palaeozoic sutures and other major structures along the western margin of Gondwana still exerted a control on the tectonic evolution of this region. The tectonic evolution was further controlled by a rather loose plate coupling (negative trench roll-back) caused by the subduction of a considerably old and dense oceanic plate that had remained practically quiet during the pre-Andean cycle.

The two stages in which this Early period has been subdivided are reflected in the late Early to Late Jurassic and latest Jurassic to late Early Cretaceous by two magmatic episodes along the arc and two transgression–regression cycles in the backarc. This separation is clear for the backarc basin deposits, although it is less evident for the arc deposits and plutonic units. However, the plutonic units of the second stage are slightly shifted to the east of the plutonic units of the first stage (Sernageomin 2002). In the arc region, the beginning of this cycle is defined by the first appearance of subduction related lavas covering and interrupting sedimentation of the westernmost marine deposits of the second stage of the pre-Andean cycle (i.e. Pan de Azúcar, Profeta and Los Molles formations; see Charrier *et al.* 2007), whereas in the eastern flank of the Andes it seems to have begun before. In fact, structuration of the backarc basins of the Early Period began there in the latest Triassic–earliest Jurassic (Pre-Cuyano sedimentary cycle), suggesting that the tectonic conditions (tectonic subsidence) had changed before the subduction-related magmas could reach the surface. The first stage (late Sinemurian–Pliensbachian to Kimmeridgian) is characterized by intense activity in the arc and development of a transgressive–regressive marine cycle in the backarc basin. At the end of this stage a second phase of tectonic subsidence followed by thermal subsidence began. This second stage (Kimmeridgian to Aptian–Albian) is characterized by apparently less activity in the arc, and by a second transgression–regression marine cycle in the backarc basin.

Palaeogeography during this Early Period was apparently controlled by NNW-orientated structures, somehow like in the Pre-Andean cycle. This is demonstrated by the reduction in the width of the presently remaining arc towards the north, and its almost complete absence in the Arica region, in northernmost Chile. This plus the eastward shift of the magmatic arc in the second stage, allows identification in the second stage and south of *c.* 30°S (latitude of La Serena) of another depocentre, the Lo Prado basin, located west of the arc (i.e. in the Coastal Cordillera) and therefore in a forearc position (Charrier 1984; Charrier *et al.* 2007). Additionally, in this region, the backarc basin, which is known as the Mendoza–Neuquén basin, gradually bends southeastwards, and becomes considerably wider than further north. This basin, which extends eastwards into Argentina, represents the southernmost part of the Jurassic–Early Cretaceous backarc basin, which is traceable without interruption along the eastern side of the magmatic arc from at least southern Ecuador to southern Argentina, at *c.* 40°S, and, possibly, still further south (Vicente 2005).

First stage (Pliensbachian–Kimmeridgian)

Magmatic arc. Along the coast a wide swath consisting mostly of Middle–Late Jurassic and Early Cretaceous plutons and associated volcanic units represents the arc activity (Fig. 3). In the northern part of the study region, Jurassic plutonic units can be continuously followed up to 34°S (Fig. 3). Further south, exposures are patchy, up to 38°S, where they begin to occur further east, in the high Andes, following the bend formed by the Palaeozoic units (south of the region included in Fig. 3; see Sernageomin 2002, for more detail). North of 33°S, they consist of monzodiorites and granodiorites of Late Jurassic age assigned to the Puerto Oscuro and Cavilolén units, with Sr initial ratios of 0.7034 and 0.7035 (Parada *et al.* 1988; Rivano & Sepúlveda 1991). These initial ratios, being lower than those obtained in the Late Triassic Tranquilla and Millahue units (0.7063 and 0.7050), indicate a different magma source directly derived from the upper mantle and associated with the recently renewed subduction activity. South of 33°S, they consist of several units (Laguna Verde, El Sauce, Peñuelas, Limache and Lliu-Lliu) comprising I-type, calc-alkaline diorites, tonalities, granodiorites and granites (Gana & Tosdal 1996). According to these authors, intrusion of these units occurred in only 6 myr, between 162 and 156 Ma (Oxfordian to Kimmeridgian times), implying a very rapid pulse of ascent of large amounts of magma. This magmatic pulse can be related to the event of rift-associated subsidence that facilitated extrusion of magmas in the backarc at this time (see Oliveros *et al.* 2012; Rossel *et al.* 2013) and permitted the marine ingression in the backarc basin.

Volcanic deposits associated with the Jurassic arc are well exposed in the Coastal Cordillera south of 31°S (Fig. 3). These are the Middle–Late Jurassic Ajial Formation (Thomas 1958; Piracés 1977; Vergara *et al.* 1995) and the Late Jurassic Horqueta Formation (Piracés 1977), separated from each other by the Middle Jurassic marine Cerro Calera Formation (Piracés 1976; Nasi & Thiele 1982) that represents a westward advance of the backarc deposits into the arc domain. Further south, at 35°S, the Jurassic arc volcanic activity is represented by the Middle Jurassic Altos de Hualmapu Formation (Morel 1981). The mentioned arc deposits conformably overlie Sinemurian marine deposits assigned to the late stage of the pre-Andean cycle in the Curepto region (Thiele 1965). The Horqueta volcanic activity coincides with the rapid plutonic pulse detected by Gana & Tosdal (1996) in the Coastal Cordillera west of Santiago (see above). The Jurassic arc formed a rather low relief, which probably indicates high rates of subsidence (Oliveros *et al.* 2007; Charrier *et al.* 2007).

Backarc deposits. The first transgression–regression cycle (*first stage*) in the backarc basin in this region is represented on the western side of the cordillera by the following marine deposits, from north to south: (a) lower member of the Lagunilla Formation (Aguirre 1960); (b) Río Colina Formation (Thiele 1980); (c) Nieves Negras Formation (Álvarez *et al.* 1997; Charrier *et al.* 2002) formerly Leñas–Espinoza Formation of Klohn (1960) and Charrier (1982); (d) Nacientes del Teno Formation, at 35°S (Klohn 1960) and 36°S (Muñoz & Niemeyer 1984); (e) Valle Grande Formation (González & Vergara 1962), at 35°30′S; and (f) Nacientes del Bio Bío Formation (De la Cruz & Suárez 1997; Suárez & Emparan 1997), at 38°30′S. The base of these formations is not exposed, except for the Nacientes del Teno, which unconformably overlies rhyolitic rocks of possible Triassic age at 35°S (Davidson 1971; Davidson & Vicente 1973), and of confirmed Triassic age (Cajón de Troncoso Beds), between 36 and 37°S (Muñoz & Niemeyer 1984). These formations consist of thick successions of sandstones (some of them turbiditic), marls and limestones, and represent a transgression–regression cycle that ends with thick Oxfordian evaporitic deposits, generally named '*Yeso Principal*' (Schiller 1912) or more formally Auquilco Formation (Groeber 1946), in Argentina, and the Santa Elena Member of the Nacientes del Teno Formation in Chile (Klohn 1960; Davidson 1971; Davidson & Vicente 1973). This gypsum unit, which is the middle member of the Lagunilla Formation, at 33°S (Aguirre 1960), is overlain by the upper member of the Lagunilla Formation (Aguirre 1960) and its southern equivalent, the Río Damas Formation (Klohn 1960), which consists of breccias and alluvial fan deposits that grade towards the east into the red, finer-grained and thinner fluvial sandstones of the Tordillo Formation (Klohn 1960; Arcos 1987). At its type locality (Río de las Damas, next to Termas del Flaco, at 35°S), the Río Damas Formation consists of a *c.* 3000 m-thick red continental, detrital succession, with coarse and fine intercalations, which includes at the top a member comprising >1000 m of andesitic lavas culminating in breccias containing enormous angular blocks, some over 4 m in diameter (Arcos 1987). Close to its contact with the Baños del Flaco Formation, dinosaur tracks are well exposed (Casamiquela & Fasola 1968; Moreno & Pino 2002; Moreno & Benton 2005). Thus, the Río Damas Formation and northern equivalents represent the final deposits of the first transgression–regression cycle in the backarc basin. Because of the thick backarc volcanic intercalation at the upper part of this formation (Rossel *et al*. 2014), which is overlain by coarse breccias, it has been considered to also represent the initial deposits of the Second stage of the Early Period, associated with the tectonic subsidence phase (Charrier *et al.* 2007). These deposits are conformably overlain by Late Jurassic to Early Cretaceous marine sediments that form the bulk of the second transgression–regression cycle of the second stage.

Along the eastern slope of the Principal Cordillera the depocentres of the first transgression are represented by a series of alternate sub-basins. The Ramada depocentre in the northern section (31°30′–32°30′S) has a complete section of continental and volcanic deposits of the Triassic Rancho de Lata Formation, unconformably overlain by the Los Patillos Formation of Early Jurasssic age. This last unit has a rich fauna of ammonites studied by Álvarez (1996) that includes from the Aalenian until the Callovian. The Alto del Tigre High is located in the central segment at the latitude of the Mount Aconcagua (32°30′–33°30′S) (Fig. 5). It is a positive area where there is no deposition of the Triassic–Early Jurassic deposits known since the early work of Groeber (1918).

Further south, the Yeguas Muertas, Nieves Negras, Alvarado, Río del Cobre, Río Atuel–La Valenciana, Palauco, Sierra Azul, Sierra de Reyes and Cordillera del Viento are some of the depocentres of the Nequén basin located south of 33°S (Fig. 5). In particular, the Rio Atuel–La Valenciana is an important subsidence zone west of Malargüe (34°–35°30′S) with a thick sequence of Triassic rift deposits that continue with the different units of the Cuyo Group represented by Arroyo Malo, El Freno, Puesto Araya and Tres Esquina Formations (Fig. 6) (Legarreta *et al.* 1993). The marine sequence dated by ammonites goes from Rhaetian to Toarcian in a complex fluvio-deltaic array (Lanés 2005).

It is interesting to remark that the Cuyo Group is overlain by the Callovian transgression of the La Manga Formation of the Lotena Group (Fig. 6). This unit includes a thin sequence of limestones between 50 and 100 m thick that covers all the depocentres from La Ramada towards the south, including the Alto del Tigre High (Giambiagi *et al.* 2003*a*, *b*). This carbonate platform is followed by a generalized regression that ended with the Auquilco Formation, a thick gypsum deposit up to 200 m thick widely distributed in the Principal Cordillera (Legarreta *et al.* 1993).

Second stage (Kimmeridgian–Albian)

From 30°S southwards the distribution of the marine deposits accumulated during the second stage forms two clearly separated depositional areas: one in the Coastal Cordillera, and the other in the Principal Cordillera, and mostly on its eastern side (Charrier 1984; Mpodozis & Ramos 1989; Charrier & Muñoz 1994; Charrier *et al.* 2007). The two basins are separated from each other by a volcanic domain that we propose to name the Lo Prado volcanic arc. Therefore, it is possible to identify three palaeogeographic domains at this moment, from west to east: (a) the Lo Prado forearc basin, bounded to the west by a relief formed on older units; (b) the Lo Prado volcanic arc; and (c) the Mendoza–Neuquén backarc basin, the latter including volcanic activity.

Forearc (Lo Prado forearc basin). Immediately north of the here considered region, in the Elqui river valley transect, at 30°S, on top of the Jurassic arc deposits, the forearc or rather the transitional deposits between the arc and a marine basin to the west are represented by the >4000 m-thick, volcanic, principally basaltic andesites and marine sedimentary Arqueros Formation (Berriasian–Albian) and the >2000 m-thick, continental, mostly red and volcanic Quebrada Marquesa Formation (Hauterivian–early Albian) (Aguirre & Egert 1965, 1970; Thomas 1967; Emparan & Pineda 2006; Rivano & Sepúlveda 1991). The Quebrada Marquesa Formation interfingers with and covers gradually the Arqueros Formation; in its lower portion it contains abundant marine intercalations, some of which are fossiliferous, and consists in its upper portion of a thick succession of pyroxene–olivine bearing basaltic andesites and pyroxene–amphibole bearing andesites (Aguirre & Egert 1965; Emparan & Pineda 1999, 2006; Emparan & Calderón 2014). In this region, the Early Cretaceous backarc deposits (Río Tascadero Formation) are exposed over 60 km to the east in the high cordillera (Mpodozis & Cornejo 1988), where, like the Arqueros Formation, they interfinger with and grade upwards to red continental, volcanic and volcaniclastic facies (Pucalume Formation). In our palaeogeographic reconstruction the Marquesa Formation represents the late Early Cretaceous western facies associated with the magmatic arc, and the Pucalume Formation represents either the easternmost deposits of the magmatic arc or volcanic deposits that resulted from volcanic activity in the backarc.

Southern deposits with similar facies and the same stratigraphic position that the Arqueros Formation are the Lo Prado (Berriasian to Valanginian) and the La Lajuela (Early Cretaceous) formations. Both formations are constrained to the Coastal Cordillera south of *c.* 34°S and correspond to the oldest forearc basin deposits, which contain abundant lavas derived from the volcanic arc flanking the basin to the east. These units overlie, from north to south, the Late Jurassic arc-related Agua Salada Volcanic Complex (Emparan & Pineda 2006; Emparan & Calderón 2014), the Horqueta (Thomas 1958; Piracés 1977; Nasi & Thiele 1982;

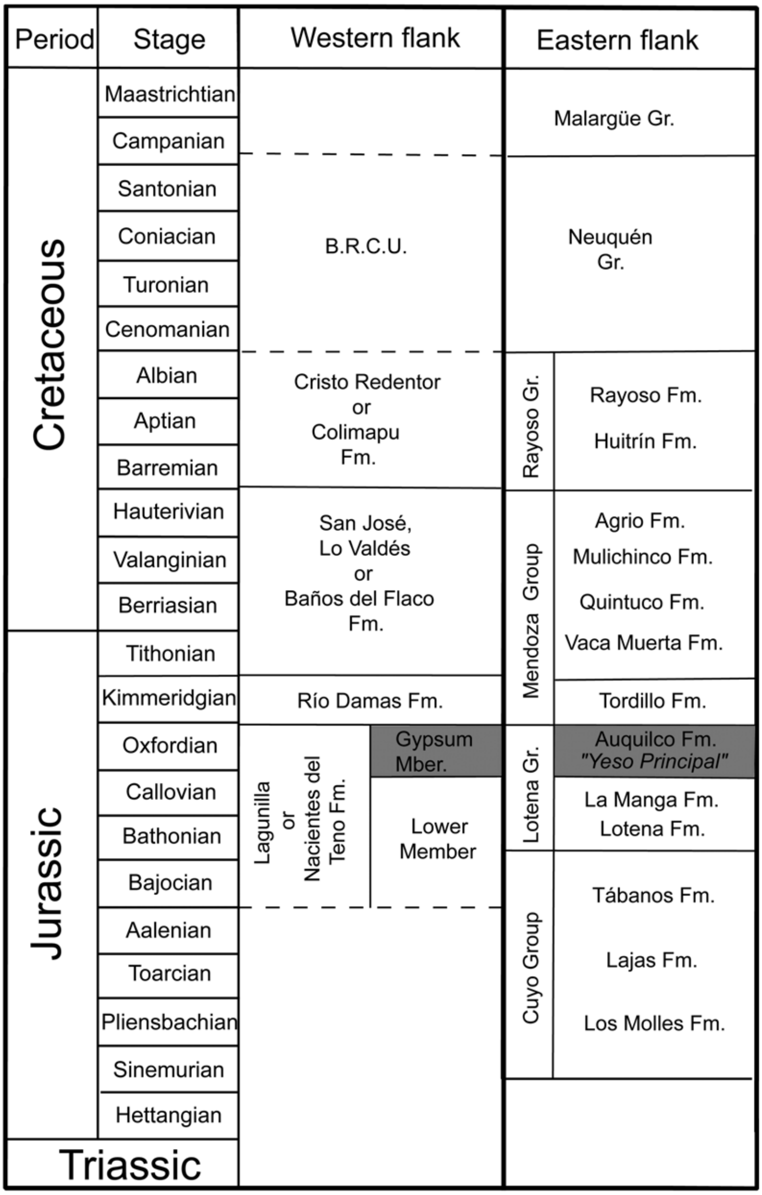

Fig. 6. Stratigraphic succession of the Jurassic to Cretaceous deposits in the Principal Cordillera in central Chile and Argentina, between 32 and 37°S. Based on Aguirre (1960), Klohn (1960), González & Vergara (1962), González (1963), Davidson (1971), Davidson & Vicente (1973), Thiele (1980), Charrier (1981*a*) and Charrier *et al.* (2002).

Rivano & Sepúlveda 1991; Rivano 1996; Vergara *et al.* 1995) and Altos de Hualmapu formations (Bravo 2001). The Arqueros, Lo Prado and La Lajuela formations are conformably overlain by thick continental volcanic and volcaniclastic deposits of the Quebrada Marquesa (Rivano & Sepúlveda 1991; Emparan & Calderón 2014), Veta Negra Formation (Piracés 1977; Nasi & Thiele 1982; Vergara *et al.* 1995) and El Culenar Beds (Bravo 2001), respectively. These extremely thick successions form a narrow band of almost continuous outcrops up to almost 36°S (Fig. 3). The stratigraphic position of the Veta Negra Formation and the age of the oldest granitoids that intrude this unit bracket its age to the Berriasian–Albian (Vergara *et al.* 1995). Notwithstanding the stratigraphic position of the Veta Negra Formation, radioisotopic age determinations in this unit indicate that it is slightly older (*c.* 119 Ma; Aguirre *et al.* 1999; Fuentes *et al.* 2001, 2005) than the older lavas of the northern equivalent Arqueros Formation (117–115 Ma) (Morata & Aguirre 2003), suggesting a northward progression of volcanism and tectonic extension (Morata & Aguirre 2003; Morata *et al.* 2008).

The rather deep depositional conditions detected for the lower Lo Prado marine deposits and the several thousand metres-thick pile encompassed by the Lo Prado and Veta Negra formations indicate intense subsidence in the forearc basin (Vergara *et al.* 1995). Additionally, the rather primitive geochemical composition of the Lo Prado rocks with low MgO and high K content, that fall in the classification of high-K and shoshonitic porphyric basaltic andesites and andesites, and their low initial Sr ratios (*c.* 0.7036) are indicative of intense crustal extension in the basin during Early Cretaceous time (Morata & Aguirre 2003; Parada *et al.* 2005). Similarly, the flood-basalt-type flows of the overlying Veta Negra lavas (Äberg *et al.* 1984), the presence in this formation of approximately north–south-orientated dyke swarms suggestive of fissural eruptions parallel to the strike of the basin (Vergara *et al.* 1995), and its geochemical features (low La/Yb ratios, low $^{87}Sr/^{86}Sr$ ratio of 0.70374 and more primitive Sr–Nd ratios than those of the Jurassic lavas), indicating an attenuated crust (Vergara *et al.* 1995; Morata & Aguirre 2003), are additional evidence for extensional tectonic conditions during Early Cretaceous times in the Lo Prado forearc basin. This basin corresponds to the aborted marginal basin of Äberg *et al.* (1984) and the intra-arc basin of Charrier (1984).

On the eastern flank of the Coastal Cordillera, the 3000 m-thick Las Chilcas Formation overlies with an apparently conformable contact the Veta Negra Formation (Wall *et al.* 1999). The lower volcanic portion of this formation has been dated (U–Pb) at 109.6 $\pm$ 0.1 and 106.5 $\pm$ 0.2 Ma (Wall *et al.* 1999), while lavas from its upper portion yielded K–Ar ages in plagioclase of 95 $\pm$ 3 Ma (Gallego 1994). Based on these ages, we suggest that the Las Chilcas Formation formed during the transition from the Early to the Late period of Andean evolution. The lower portion, consisting of basaltic and andesitic lavas and dacitic and rhyolithic pyroclastics, developed in apparent conformity with the underlying Veta Negra Formation, would be the continuation of the volcanic activity developed in the Lo Prado forearc basin, whereas the coarse conglomerates of its upper part would correspond to syn-orogenic deposits associated with the Peruvian orogeny. We discuss this point below.

Lo Prado magmatic arc. Early Cretaceous plutonic rocks form an almost continuous swath of hypabissal dioritic to granitic plutons, which mostly intrude the Early Cretaceous deposits mentioned above (Rivano & Sepúlveda 1991; Gana & Tosdal 1996; Rivano *et al.* 1993; Emparan & Calderón 2014). K–Ar age determinations on these plutons yielded ages 134–86 Ma (Parada *et al.* 1988; Bravo 2001). Recent $^{40}Ar/^{39}Ar$ dates in the northward prolongation of this swath, immediately north of the here considered region, yielded ages between 139 and 100 Ma (Valanginian–Albian) (Emparan & Calderón 2014). Low Sr initial ratios obtained on Early Cretaceous granitoids in the northern part of the region (31°–32°S) indicate an upper mantle origin, with virtually no continental crust involvement for these magmas (Parada *et al.* 1988; Creixell *et al.* 2011). This conclusion confirms the idea that the crust was thin and the tectonic conditions were extensional during development of the forearc basin, as well as in the Principal Cordillera, where thermal subsidence dominated the retroarc basins.

Arc volcanic rocks are also exposed further east and only in the northern part of the region (north of 32°S). These have been assigned to the Pucalume Formation, unless they correspond to backarc volcanic activity (Charrier *et al.* 2007). In the Aconcagua area the Late Jurassic–Early Cretaceous successions are interbedded with backarc basalts and pyroclastic deposits (Cristallini & Ramos 1996).

Backarc basin (Mendoza–Neuquén basin). Backarc basin deposits in this region are exposed in Chile in the High Andes close to the international boundary and extend eastwards into western Argentina (Fig. 3). These generally consist mostly of sedimentary marine facies; however, at some localities they interfinger with volcanic deposits that, depending on their location, are interpreted as the easternmost arc deposits or to products of backarc volcanic activity.

In the high cordillera, in northern part of the region, between 31 and 32°S, volcanic deposits of the Late Jurassic Algarrobal Formation are exposed. These deposits interfinger and are covered by the conglomeratic Mostazal Formation (Mpodozis & Cornejo 1988; Oliveros *et al.* 2012), which is a western lateral facies of the Kimmeridgian, finer-grained, continental Tordillo Formation exposed next to the international border, between 31 and 33°S (Rivano & Sepúlveda 1991; Rivano *et al.* 1993; Lo Forte *et al.* 1996; Aguirre-Urreta & Lo Forte 1996). The great distance (>80 km) that separates these volcanic deposits from those of the arc in this region suggests that they correspond to backarc volcanism, as has been observed in some regions along the central Argentina–Chilean Andes (Charrier *et al.* 2007; Mescua *et al.* 2008;

Mpodozis & Ramos 2008; Oliveros *et al.* 2012, among others).

Second-stage backarc marine sedimentary deposits in the northern part of the region consist of the Early Crertaceous Río Tascadero Formation (Mpodozis & Cornejo 1988; Rivano & Sepúlveda 1991). This unit forms a NNW-orientated swath that extends south-southeastwards into Argentina. Southwards, on the western flank of the cordillera, at 31°30′S, there is another similarly orientated swath, extending also into Argentina and consisting predominantly of volcanic and volcaniclastic deposits with mostly coarse detritic intercalations (breccias, conglomerates, and sandstones), and minor and finer marine fossiliferous calcareous sandstones, assigned to the Los Pelambres Formation (Rivano & Sepúlveda 1991).

Similar deposits exposed along the international border and next to it on the eastern flank of the cordillera at 33°S have been assigned to the Juncal Formation (Ramos *et al.* 1990; Aguirre-Urreta & Lo Forte 1996; Cristallini & Ramos 1996). Further east, the volcanic intercalations rapidly disappear eastwards, indicating that the source of the lavas and coarse volcaniclastic sediments was located to the west. Their source can either be the volcanic Lo Prado arc or volcanic edifices developed in the backarc basin to the east of the main magmatic arc. Because of the considerable distance separating the volcanic arc in the Coastal Cordillera and the volcanic deposits exposed along the axis of the Principal Cordillera, we favour the existence of volcanic activity in the backarc at this time coexisting with marine sedimentation. If this interpretation is correct it would emphasize the importance of volcanism in the backarc during the early period of the Andean Cycle (Ramos 1999; Charrier *et al.* 2007; Oliveros *et al.* 2012; Rossel *et al.* 2013).

Further south, between 33 and 36°15′S, along the western side of the Principal Cordillera (Fig. 3), but with a more external position than the previously mentioned units, Late Jurassic (Kimmeridgian) to late Early Cretaceous (Aptian–Albian), red continental and marine backarc deposits have been assigned to the upper member of the Lagunillas (Aguirre 1960) and Río Damas (Klohn 1960) formations, and the overlying marine San José (Aguirre 1960), Lo Valdés (González 1963; Hallam *et al.* 1986) and Baños del Flaco (Klohn 1960; González & Vergara 1962; Covacevich *et al.* 1976; Charrier 1981*a*; Arcos 1987) formations, and the red, detritic, continental Colimapu Formation (Klohn 1960) (see Fig. 6). These form a continuous, although considerably thrusted and folded, swath of outcrops that extends further east into Argentina. The marine rocks consist of thick, richly fossiliferous successions of predominantly calcareous neritic to shallow (external platform) sediments. Lavas in the Lo Valdés Formation form a thin intercalation in its lower portion (Biró-Bagóczky 1964), and volcanic intercalations in the Baños del Flaco Formation, a few kilometres to the south of the previous locality (*c.* 34°S), form a 440 m-thick succession of volcanic breccias and silicic lavas between marine fossiliferous sediments of Tithonian–Neocomian age (Charrier 1981*b*). In these formations the volcanic intercalations and volcanic components in the detritic deposits rapidly disappear eastwards, indicating again that the source of the lavas and coarse volcaniclastic sediments was located towards the west. At Termas del Flaco, in the Tinguiririca river valley, at 35°S, only the lowest portion of the Baños del Flaco is exposed. Its upper portion, and probably also the overlying Colimapu Formation, have been eroded in this place (Charrier *et al.* 1996). The final regressive episode led to the deposition of a second, generally thin band of gypsum ('Yeso Secundario' or 'Yeso Barremiano') at the base of the 1500 m-thick, red detrital Colimapu Formation (Klohn 1960; González & Vergara 1962; González 1963; Charrier 1981*b*), which corresponds to the generally fine-grained continental deposits with thin calcareous intercalations containing ostracodes that followed the regression in Aptian–Albian times. In the Maule river valley (36°S), a recent dating with detritic zircons yielded an Aptian maximum age for deposition of these deposits (Astaburuaga 2014). This formation is a lateral equivalent of the Huitrín–Rayoso Formation in western Argentina (Fig. 6).

At the end of the first Andean stage, a major plate reorganization associated with a great increase in generation of oceanic crust in the proto-Pacific (Larson 1991) and rapid westward drift of South America modified the tectonic conditions in the continental margin of South America. This geodynamic event, known as the Peruvian orogeny (Steinmann 1929; see also Groeber 1951; Charrier & Vicente 1972; Vicente *et al.* 1973; Ramos 1988*b*, 2010; Reutter 2001; Tunik *et al.* 2010), caused along western South America uplift of the continental margin, the marine regression referred above and definite emersion in the backarc basin, compressive deformation of the existing units, and crustal thickening. As a result of this phase, the first Andean mountain range was formed.

Late period (early Late Cretaceous: Present)

The Peruvian orogeny separates the Early and Late periods into which Coira *et al.* (1982) subdivided the evolution of the Andean tectonic cycle. After this episode the palaeogeographic organization in this region of the Andes changed completely: the backarc basin was inverted, the magmatic arc shifted considerably eastwards, a new mountain range was developed, a continental retroarc foreland basin was formed to the east of the arc instead of a backarc basin, and a rather wide forearc region west of the arc was produced as a result of eastward arc migration. Oblique subduction also prevailed at this time, although the movement of the oceanic plates towards the continent was mostly northeastward orientated, producing dextral displacement along trench-parallel faults. Moreover, some authors suggest from plan view reconstructions an orthogonal subduction for this moment, thus, dextral displacement could be less important (Arriagada *et al.* 2008; Martinod *et al.* 2010). The Late Period has been subdivided into two stages separated from each other by a major orogenic phase that occurred in middle Eocene, the Incaic orogeny (Fig. 1). Each one of these stages can be, in turn, subdivided into two substages by orogenic episodes that occurred at approximately the Cretaceous–Cenozoic boundary ('K–T' orogeny; Cornejo *et al.* 2003) and the Oligocene–Miocene boundary (Pehuenche orogeny; Fig. 1), respectively.

First stage (early Late Cretaceous–middle Eocene)

During the first stage, in the region between 31 and 37°S, a high sea-level stand in latest Cretaceous–earliest Cenozoic times caused a slight marine ingression along the western border of the present day Coastal Cordillera, and an extended marine incursion of Atlantic origin, on the eastern side of the mountain range that reached the axis of the present-day Principal Cordillera. This marine ingression from the Atlantic side was favoured by the tectonic loading and subsequent subsidence that developed a long foredeep along the eastern foothills of the Andes (Aguirre-Urreta *et al.* 2011).

For a better understanding of the following description of geological units, we will describe them separately in two different segments: a northern (31°–34°S) and a southern segment (34°–37°S).

Northern segment. The arc is represented by two parallel, close to each other, series of small and medium-sized plutonic outcrops located along the eastern flank of the Coastal Cordillera, immediately to the east of the previous arc representatives (Fig. 3). These outcrops can be followed up to 34°S, where they disappear or have not been identified. They consist of monzodiorites and subordinated granodiorites, gabbros, diorites and hypabissal andesitic and dioritic bodies (Rivano & Sepúlveda 1991; Rivano *et al.* 1993; Sellés & Gana 2001), and have been included by these authors in the Cogotí superunit, and more recently in the Illapel Plutonic Complex by Morata *et al.* (2010) and Ferrando *et al.* (2014).

Stratified deposits corresponding to this stage are represented, between 31 and 33°S, by the following Late Cretaceous volcanic, volcaniclastic and sedimentary stratigraphic units: (a) upper part of the Las Chilcas; (b) the Viñita and its equivalent the Salamanca; and (c) the Lo Valle formations, with ages ranging from 95.3 to 64.6 ± 5 Ma (Drake *et al.* 1976; Rivano & Sepúlveda 1991; Rivano *et al.* 1993; Gallego 1994; Mpodozis *et al.* 2009; Jara & Charrier 2014). The coarse and thick conglomeratic deposits of the upper Las Chilcas Formation, with a marine calcareous intercalation and some basaltic and andesitic–basaltic lavas at the top, would correspond to syn-orogenic deposits accumulated in a retroarc foreland basin developed with the Peruvian orogeny, which was deep enough to be invaded by the sea, and volcanic-arc deposits in its eastern and western border, respectively.

In fact, in this region, apatite fission track ages indicate for the western Coastal Cordillera the existence of a cooling event that began at 106–98 Ma (Gana & Zentilli 2000). This age is complemented by studies in the Caleu pluton on the eastern Coastal Cordillera indicating that crystallization occurred in the interval 94.2–97.3 Ma and that cooling occurred until about 90 Ma (Parada *et al.* 2005; Ferrando *et al.* 2014). These data have been confirmed by Willner *et al.* (2005), who reported for the eastern and western series of the metamorphic complex a cooling event between 113 and 80 Ma. This event is probably related to an exhumation process associated with uplift that can be associated with the Peruvian orogeny. Considering that it coincides with the age of the Las Chilcas Formation, we propose that the Las Chilcas Formation formed during the end of the Early period of Andean evolution and the beginning of the Late period, and represents the transition from an extensional to a compressional tectonic regime. A similar view has been proposed for the Caleu pluton (Parada *et al.* 2005). The calc-alkaline, silicic pyroclastic deposits, intermediate lavas and continental sediments of the Lo Valle Formation (Thomas 1958; Godoy 1982; Moscoso *et al.* 1982; Rivano 1996; Gana & Wall 1997) cover unconformably the Las Chilcas Formation. The Lo Valle Formation represents the deposits of the Late Cretaceous volcanic arc. K–Ar and Ar–Ar age determinations from samples collected at 33°S yielded 70.5 ± 2.5, 64.6 ± 5, 72.4 ± 1.4 and 71.4 ± 1.4 Ma (Vergara & Drake 1978; Drake *et al.* 1976; Gana & Wall 1997). According to these ages the unconformity that separates the Las Chilcas Formation from the overlying Lo Valle Formation represents a 20 Ma hiatus (Gana & Wall 1997).

Southern segment. Further south, between 33 and 37°S, Late Cretaceous to Palaeogene deposits are exposed on the western and eastern flanks of the Coastal Cordillera, and in the Principal Cordillera. On the western flank of the Coastal Cordillera to south of Santiago, deposits of both Late Cretaceous to early Paleocene age and of late Paleocene (?) to Eocene age have been reported. The Late Cretaceous to Paleocene outcrops consist of fossiliferous marine plataformal deposits related to the eustatic high stand developed at this time, and are exposed in the following localities, from north to south: Algarrobo (Levi & Aguirre 1960; Tavera 1980; Wall *et al.* 1996; Yury-Yáñez *et al.* 2012), Topocalma (Charrier 1973; Cecioni 1978; Tavera 1979), Faro Carranza, south of Constitución (Chanco Formation; Cecioni 1983), and in the Arauco region, at the latitude of Concepción (*c.* 37°S) (Quiriquina Formation; Steinmann *et al.* 1895; Wetzel 1930; Muñoz-Cristi 1946, 1956; Biró-Bagóczky 1982; Stinnesbeck 1986; Finger *et al.* 2007; Salazar *et al.* 2010; Buatois & Encinas 2011). The Quiriquina Formation overlies the late Palaeozoic metamorphic complex and is unconformably overlain by the late Paleocene (?) to Eocene Concepción Group.

In the coastal region at the latitude of Concepción, late Paleocene (?)–Eocene deposits of the Concepción Group comprise alternations of continental and marine deposits accumulated in extensional basins formed along the coast in late Paleocene (?) to Eocene times. This outstanding succession containing hydrocarbon and important coal reserves is characterized by an alternation of transgressive and regressive episodes, controlled by eustatic changes, local subsidence and uplift of tectonic blocks (Wenzel *et al.* 1975; Pineda 1983*a*, *b*), and general uplift of the Andean range. It consists of the following formations, some of which interfinger with each other: Pilpilco (early Eocene, littoral marine sequence, partly continental), Curanilahue (early Eocene, a mainly continental sequence, coal-bearing strata), Boca Lebu (early Eocene, marine transgressive sequence), Trihueco (middle Eocene, a mainly continental sequence, coal-bearing strata) and Millongue (middle to late Eocene, marine sequence) (Tavera 1942; Muñoz-Cristi 1946, 1973; Pineda 1983*a*, *b*; Arévalo 1984; Finger *et al.* 2007). Along the eastern flank of the Coastal Cordillera up 35°15′S, the Late Cretaceous Lo Valle Formation is further exposed (Bravo 2001).

In the Principal Cordillera at 35°S, upward fining and thinning red-coloured fluvial deposits that unconformably rest on Jurassic terms of the Baños del Flaco Formation and unconformably underlie early Oligocene mammal bearing levels of the Abanico Formation have been informally named Brownish-red Clastic Unit by Charrier *et al.* (1996). Similar deposits crop out next to the water divide at 36°S overlying Middle to Late Jurassic rocks of the Nacientes del Teno Formation and underlying the Late Cenozoic volcanic deposits assigned to the Campanario Formation (Drake 1976; Hildreth *et al.* 1998). These have been included in the Estero Cristales Beds by Muñoz & Niemeyer (1984). According to their stratigraphic position, these deposits can be assigned a Late Cretaceous age and correlated with the Late Cretaceous Neuquén Group on the eastern side of the cordillera (Charrier *et al.* 1996; Mescua 2011). On the western side of the cordillera, these units can be correlated with the upper Las Chilcas and the Viñita formations, further north. In westernmost Argentina, between 33 and 38°S on the eastern side of the Principal Cordillera, marine deposits of the Saldeño Formation (Tunik 2003) and the Malargüe Group (Bertels 1969, 1970; Aguirre-Urreta *et al.* 2011) testify to the far-reaching nature of the Late Cretaceous to early Cenozoic Atlantic transgression. The absence of these deposits in Chile suggests the existence of a relief that stopped the advance of the sea further west.

Along the western flank of the Andes, in Argentina between 35 and 38°S, the Late Cretaceous, 1500 m-thick red fluvial detritic deposits of the Neuquén Group, and the overlying Bajada del Agrio Group correspond to the retroarc foreland deposits related to the Peruvian orogeny (Ramos 1981; Ramos & Folguera 2005; Tunik *et al.* 2010; Di Giulio *et al.* 2012) (Fig. 1). New U–Pb detrital zircons age determinations indicate an early phase of westward-sourced deposits followed by deposition of sediments originated to the east of the retroarc foreland basin associated with uplift of the peripheral bulge as a consequence of the Late Cretaceous thrust front migration (Di Giulio *et al.* 2012).

In middle Eocene, the Incaic orogeny put an end to this stage. This event coincides with the peak of high convergence rate associated with a considerable reduction of the obliquity of convergence after 45 Ma (Pardo-Casas & Molnar 1987).

Second stage (middle Eocene–Present)

The northern part of the considered region, between 31 and 33°S, is located in the southern part of the flat-slab segment, where the Central Depression and the volcanic arc are not developed. This is the region where the Frontal Cordillera, the Precordillera and the Pampean ranges are developed (Fig. 2). The southern part, instead, between 33 and 37°S, is located in the transition to and in the normal subduction segment, where the Central Depression and the volcanic arc (along the axis of the Principal Cordillera) have developed. In this stage, the Maipo orocline occurred in close relationship with the Pampean flat-slab. Palaeomagnetic rotations are observed within the normal subduction segment (Arriagada *et al.* 2013). In the considered region, second-stage deposits are located in all morphostructural units. We will describe the deposits from west to east.

Western Coastal Cordillera. No Oligocene deposits exist along the coastal region in Chile, probably because of the eustatic low stand at this time. Between 33°40′ and 34°15′S, exposures of Miocene marine sediments are known as the Navidad Formation *sensu* Darwin (1846) and Tavera (1979). Recent work subdivided these deposits into the Navidad, Licancheo and Rapel formations (Encinas *et al.* 2006*a*). The Navidad Formation has been assigned a late Miocene age and the Licancheo and Rapel formations a Pliocene age by Finger *et al.* (2003) and Encinas *et al.* (2006*a*), whereas Gutiérrez *et al.* (2013) assigned an early to middle Miocene age to the Navidad Formation and a late Miocene age to the Licancheo and Rapel formations. The latter is overlain by the late Miocene to Pliocene, transitional marine to continental, richly tuffaceous La Cueva Formation (Tavera 1979), which interfingers and is overlain to the east by continental deposits of the Potrero Alto Beds of uncertain Miocene–Pliocene to Pleistocene age (Wall *et al.* 1996). According to Encinas *et al.* (2006*a*), the Navidad Formation was deposited on a rapidly subsiding basin, which reached depths of 1500 m; in contrast, Gutiérrez *et al.* (2013) favour a shallow coastal to outer shelf environment for this formation. The Navidad Formation can be correlated with the Ranquil Formation, to the south at 37°S.

The source of sediments in the Navidad basin based on the analysis of heavy mineral assemblages is the nearshore basement rocks (metamorphic and intrusive units) in the Coastal Cordillera and the central Chilean forearc (Rodríguez *et al.* 2012). Sediment supply from the latter began with erosion at the present-day eastern Central Depression (western Abanico Formation), later at the eastern Central Depression–western Principal Cordillera border (Miocene plutons), and finally in the western Principal Cordillera (Farellones Formation) (Rodríguez *et al.* 2012). The eastwards shift of the sediment source indicates the slow and gradual retreat experienced by the nick-points, which, according to Farías *et al.* (2008), arrived in the western Principal Cordillera between 2 and 6 myr after onset of surface uplift, at *c.* 7.6 Ma, and >2 myr later in the eastern Principal Cordillera.

Along the coast of central Chile, Plio-Pleitocene events are widely documented by: (a) marine deposits of the upper Coquimbo Formation (at 30°S) and correlatives, like the Pliocene upper La Cueva formations (at 34°S) and further south the Tubul Formation (at 37°S) in the Arauco region; (b) fluvial deposits exposed in coastal–near river drainages, like the Confluencia and Caleta Horcón formations (Rivano 1996), and the Potrero Alto Beds; and (c) shoreline and fluvial geomorphic features that testify to a considerable uplift of the forearc. Five well-preserved marine terraces (wave-cut platforms) (Darwin 1846; Paskoff 1970, 1977; Fuenzalida *et al.* 1965; Ota *et al.* 1995; Saillard *et al.* 2009, 2012) and pedimentary surfaces developed in fluvial drainages connected with the marine terraces (Rodríguez *et al.* 2013) have been reported. Cosmogenic datings on these features yielded 6, 122, 232, 321 and 690 ka, and allow reconstruction of a non-steady history of uplift to *c.* 100–150 m during interglacial periods after 400 ± 100 ka (Saillard *et al.* 2009; Regard *et al.* 2010; Rodríguez *et al.* 2013).

Central Depression. Until recently, this morphostructural feature, which is developed south of 33°S, has been considered to be of tectonic origin (i.e. Carter & Aguirre 1965) and related to the subduction of the Juan Fernández Ridge (i.e. Jordan *et al.* 1983*b*). However, based on analyses of uplift markers and nick-point progression supported by geochronological and thermochronological dating, it has been recently interpreted as an erosional feature (Farías *et al.* 2008). However, the Quaternary alluvial and fluvial deposits derived from the Principal Cordillera that build up the *c.* 400 m thick infill, as well as new tectonic evidence, show that the Central Depression is tectonically controlled (see Giambiagi *et al.* 2014). Explosive volcanic activity in the volcanic arc produced abundant lahar and volcanic avalanche deposits such as La Cueva Formation in the coastal region (Encinas *et al.* 2006*b*). Between 33°30′ and 37°S, tuff and ash-flow deposits covered the Central Depression, that is, the Pudahuel–Machalí Ignimbrite (Stern *et al.* 1984), Teno (MacPhail & Saa 1967; Marangunic *et al.* 1979), Tinguiririca (Abele 1982) and Laja (MacPhail 1966) lahars.

The origin of the Pudahuel–Machalí Ignimbrite (Stern *et al.* 1984) has been associated with the Maipo Caldera, in the high Andes, at 34°S. The ignimbrite flow was channelized along the main river valleys towards the coastal region, and into Argentina, along the Yaucha and Papagayos valleys. The tuff deposits in Pudahuel, next to Santiago, and Machalí, east of Rancagua, yielded apatite fission track ages of 0.44 ± 0.08 and 0.47 ± 0.007 Ma, respectively (Stern *et al.* 1984).

Principal and Frontal Cordillera. In the northernmost part of the region (31°–32°S), Oligocene plutonic rocks (El Maitén–Junquillar and Bocatoma units) form extensive outcrops that intrude Permo-Triassic volcanics of the Choiyoi Group and younger Mesozoic units (Fig. 3) (Mpodozis & Cornejo 1988; Martin *et al.* 1997; Bissig *et al.* 2001). Further south, these outcrops disappear and two alignments of scattered intrusives of early and middle to late Miocene age (the latter to the east of the former) are exposed along the western flank of the Principal Cordillera. The La Obra and the San Gabriel plutons in the Maipo river valley next to Santiago belong to this group of intrusives. Some of these plutonic bodies are associated with supergiant late Miocene to Pliocene porphyry Cu–Mo ore bodies such as Los Pelambres, Río Blanco–Los Bronces and El Teniente. These ore deposits developed within hydrothermal alteration zones linked to multiphase stocks, breccia pipes and diatreme structures in rocks of Oligocene to Miocene age (Cuadra 1986; Serrano *et al.* 1996; Vivallo *et al.* 1999; Camus 2002, 2003; Skewes *et al.* 2002; Maksaev *et al.* 2004; Charrier *et al.* 2009; Mpodozis & Cornejo 2012).

Some of the stratified units of this stage exposed between 31 and 33°S have been previously considered to represent much older ages. Recent studies have shown that they formed essentially during Oligocene to Miocene times (Mpodozis *et al.* 2009; Jara & Charrier 2014; Jara *et al.* 2014). According to this age and their volcanic and volcaniclastic nature with only subordinated sedimentary intercalations, they can be correlated with similar deposits exposed between 29 and 30°S on the eastern flank of the cordillera in the Valle del Cura region (Winocur *et al.* 2014), and with the Abanico and Farellones formations well exposed 33°S along the western flank of the Principal Cordillera and to the north (Fig. 3).

The dominantly volcanic, middle–late Eocene to Oligocene Abanico Formation, and the Miocene Farellones Formation make up the pre-Pliocene Cenozoic deposits in the Principal Cordillera of Central Chile (31°–36°S) (Aguirre 1960; Klohn 1960; González & Vergara 1962; Charrier 1973, 1981*a*, *b*; Thiele 1980; Charrier *et al.* 2002; Godoy 2011). The Abanico Formation consists of a locally strongly folded, *c.* 3000 m-thick succession of volcanic, pyroclastic volcaniclastic and sedimentary deposits including abundant subvolcanic intrusions of the same age (Vergara *et al.* 2004), with a well-developed paragenesis of low-grade metamorphic minerals (Padilla & Vergara 1985; Levi *et al.* 1989; Aguirre *et al.* 2000; Fuentes *et al.* 2001, 2005; Bevins *et al.* 2003; Fuentes 2004; Muñoz *et al.* 2006, 2010). The outcrops of this formation form two north–south orientated swaths separated by the Farellones Formation (Fig. 3) (Sernageomin 2002). This formation contains abundant mammalian rests (Flynn *et al.* 2007; Charrier *et al.* 2012). At the western side of the Abanico outcrops, 34.3 ± 2.2 Ma old basal Abanico deposits unconformably overlie the 72.4 ± 1.4 and 71.4 ± 1.4 Ma old Lo Valle Formation (Gana & Wall 1997). At the eastern side of the Abanico exposures, the oldest age obtained for the base of the Abanico Formation is 37.67 ± 0.31 Ma (Charrier *et al.* 1996). The Abanico Formation was deposited in an extensional basin formed while the crust was relatively thin, persisting throughout the Oligocene epoch, and underwent subsequent tectonic inversion in late Oligocene to early Miocene time (Pehuenche orogeny, see Fig. 1). This diachronic extensional event has not been recognized in northern Chile (Charrier *et al.* 2009, 2013) and seems to have been concentrated between 28 and 39°S, and probably extended further south, up to 43°S (Godoy 2011).

The younger Farellones Formation is a 2400 m thick, gently folded, almost entirely volcanic unit forming a continuous north–south trending swath between approximately 32 and 35°S (Fig. 3) (Thiele 1980; Charrier 1981*a*, *b*; Vergara *et al.* 1988). The deposits of the Farellones Formation typically cover the Abanico Formation, up to 35°S, where this formation is not exposed any more. The views about the contact are controversial (Charrier *et al.* 2002; 2007). It has generally been reported as unconformable (Aguirre 1960; Klohn 1960; Jaros & Zelman 1967; Charrier 1973, 1981*a*, *b*; Thiele 1980; Quiroga 2013). Growth strata have been observed at several localities between the upper Abanico and the lower Farellones deposits (Fock *et al.* 2006; Quiroga 2013). The contractional event evidenced by the growth strata has been associated with the inversion of pre-existing normal faults that participated in the development of the Abanico basin (Charrier *et al.* 2002; Fock *et al.* 2006; Farías *et al.* 2010). Inversion along the eastern side of the basin linked to El Diablo fault triggered the development of the east-vergent thrust–fold belt systems during middle Miocene on the eastern flank of the Principal Cordillera (Ramos *et al.* 1996*b*; Giambiagi *et al.* 2003*a*; Mescua 2011; Muñoz-Saez *et al.* 2014; Giambiagi *et al.* 2014). Furthermore, inversion along the San Ramón Fault on the western side of the Abanico basin caused west-vergent thrusting of the Abanico Formation deposits over the Central Depression (Rauld 2002; Armijo *et al.* 2010). Recent activity has been detected on the San Ramón Fault (Vargas & Rebolledo 2012).

South of 36°S, the prolongation of the younger part of Abanico Formation is the Cura–Mallín Formation (Niemeyer & Muñoz 1983; Muñoz & Niemeyer 1984; Charrier *et al.* 2002; Radic *et al.* 2002; Flynn *et al.* 2008). This formation accumulated in the southern prolongation of the Abanico Extensional basin (Elgueta 1990; Vergara *et al.* 1997; Jordan *et al.* 2001; Charrier *et al.* 2002; Radic *et al.* 2002; Croft *et al.* 2003; Flynn *et al.* 2008) that in this region was inverted during late Miocene times (Burns & Jordan 1999; Radic *et al.* 2002).

The Cura–Mallín Formation is conformably overlain by the andesitic and conglomeratic Trapa–Trapa Formation, which in turn is unconformably overlain by the late Miocene Campanario Formation, which is a southern equivalent of the upper Farellones Formation and the Pliocene Cola de Zorro Formation (González & Vergara 1962; Muñoz & Niemeyer 1984; Astaburuaga 2014). A nearly coeval stratigraphic series has been recognized in the Andacollo region on the Argentine side of the Andes at 37°S (Jordan *et al.* 2001), where these authors applied the same formational names as used in Chile. These Argentine deposits unconformably overlie the early Cenozoic Serie Andesítica, and are overlain by the late Miocene sedimentary and volcaniclastic Pichi Neuquén Formation.

Scattered Plio-Pleistocene volcanic activity on the western Principal Cordillera has been reported for areas located next to the El Teniente ore deposit at 34°S (Camus 1977; Charrier & Munizaga 1979; Charrier 1981*b*; Cuadra 1986; Godoy & Lara 1994; Gómez 2001) and Sierras de Bellavista at 34°45′S (Klohn 1960; Vergara 1969; Charrier 1973; Malbran 1986; Eyquem 2009). These volcanic centres form a north–south alignment suggesting a tectonic control for this activity. Finally, the volcanoes of the present-day magmatic arc lie east of the eastern outcrops of the Abanico Formation, covering Mesozoic units and forming the northern part of the Southern Volcanic Zone (Stern *et al.* 2007). From north to south the most important of these volcanoes are named Tupungato, San José, Maipo and Maipo caldera, Tinguiririca, Planchón–Peteroa, Descabezado Grande, Cerro Azul, Descabezado Chico, San Pedro, Longaví and Chillán, some of which are aligned with the El Diablo fault (see Fig. 3). Isotopic studies on late Neogene magmatic rocks from the Chilean Principal Cordillera reveal a source contamination probably resulting from the deep westwards underthrusting of the basement beneath the orogen, a process that is coeval with thickening and uplifting events in the Andes (Muñoz *et al.* 2013).

Thermochronometric studies oriented to constrain the tectonic-related exhumation history in central Chile, between 28.5° and 32°S, reveal that uplift of the Coastal Cordillera occurred mostly in Palaeogene times (apatite fission track (AFT) ages between *c.* 60 and 40 Ma and apatite He (AHe) ages around 30 Ma) and that little exhumation occurred during the rest of the Neogene in that region, while exhumation ages from the Frontal Cordillera are younger AFT ages between *c.* 40 and 8 Ma and AHe ages from *c.* 20 to 6 Ma). Thermal modelling of AFT and AHe data allows recognition of three main episodes of accelerated cooling affecting different areas of the Frontal Cordillera: *c.* 30, *c.* 22–17 and *c.* 7 Ma. The first of them coincides with the early stages of development of a late Oligocene extensional intra-arc basin along the eastern Frontal Cordillera, between 29 and 30°S, and is interpreted as a consequence of tectonic exhumation. The early and late Miocene periods of accelerated cooling along the Frontal Cordillera correlate with periods of contractional deformation widely recognized throughout the Central Andes and, thus, interpreted as a consequence of surface-uplift (Rodríguez 2013; Rodríguez *et al.* 2014).

^{10}Be content in bed-load from different rivers and across a major climatic gradient on the western flank of the mountain range in central Chile has been analysed in order to determine erosion rates associated with uplift (Carretier *et al.* 2013). This study confirms the primary role of slope as a control of erosion even under contrasting climates and supports the view that the influence of runoff variability on millennial erosion rates increases with aridity. However, even if current erosion rates are decoupled from precipitation rates, climate still plays a fundamental role by accelerating the erosion response to uplift (Carretier *et al.* 2014).

Foreland. In Neogene times in the Andean foreland some processes related to shallowing and steepening of the subducting slab occurred, which are described next.

Pampean flat-slab subduction. The magmatic arc that was developed during previous stages of the Andean cycle along the western slope of the Andes expanded and shifted during late Miocene to the Quaternary to the Argentine side between 31 and 33°30′S latitude (Fig. 7) associated with a period of shallowing of the subduction zone (Jordan *et al.* 1983*a*, *b*).

Magmatic activity ended in the Principal Cordillera at about 8.6 Ma and in Sierras Pampeanas at 1.9 Ma with the last subduction-related volcanism more than 750 km away from the trench (Ramos *et al.* 2002). The first migration of the volcanic arc at these latitudes is recorded in the Aconcagua volcanic rocks. Huge amounts of andesitic and dacitic rocks were erupted at about 15.8 ± 0.4 and 8.9 ± 0.5 Ma in the Aconcagua massif on the eastern side of the Principal Cordillera, at 33°S (see Fig. 3). This area constitutes the new volcanic front 50 km east of the Farellones arc in the western slope. The retroarc magmatism of Paramillos,

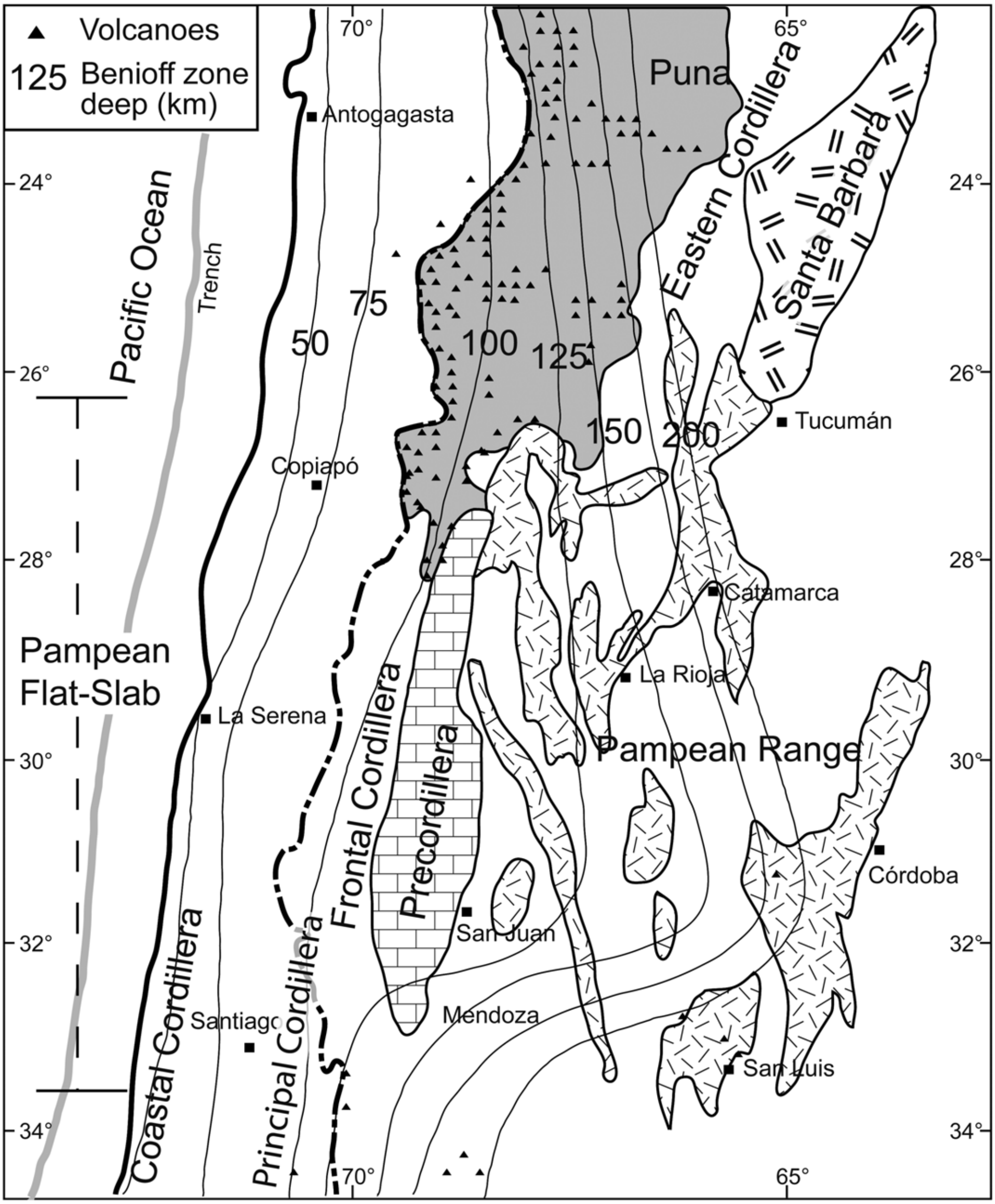

Fig. 7. The Pampean flat-slab segment with the different geological provinces in the foreland, the Quaternary volcanic arc and the isobath to the subducted oceanic slab (after Ramos *et al.* 2002).

west of the city of Mendoza, was shut off at 15.2 Ma, almost at the same time that the migration took place (Ramos *et al.* 1996*b*). Geochemical studies show a typical calc-alkaline signature of these volcanic rocks (Kay & Abbruzzi 1996).

The shifting of the magmatic arc was preceded by an important deformation in the western half of the Aconcagua fold-and-thrust belt (Fig. 3) (Ramos *et al.* 1996*a*). At about 8.6 Ma, the thin-skinned Aconcagua fold-and-thrust belt detached in Jurassic evaporites ceased. As a result of that, the orogenic front migrated about 25 km from Las Cuevas to Río de Las Vacas (Ramos *et al.* 1996*b*). Syn-orogenic deposits were preserved in isolated exposures between Principal and Frontal Cordilleras, in the Uspallata–Calingasta depression and in the present foreland basin in the foothills around Mendoza (Fig. 3). Magnetostratigraphic studies performed in the foothills show that sedimentation started at 15.7 Ma in the Mariño Formation with distal fluvial and eolian deposits with a low sedimentation rate. This unit was followed

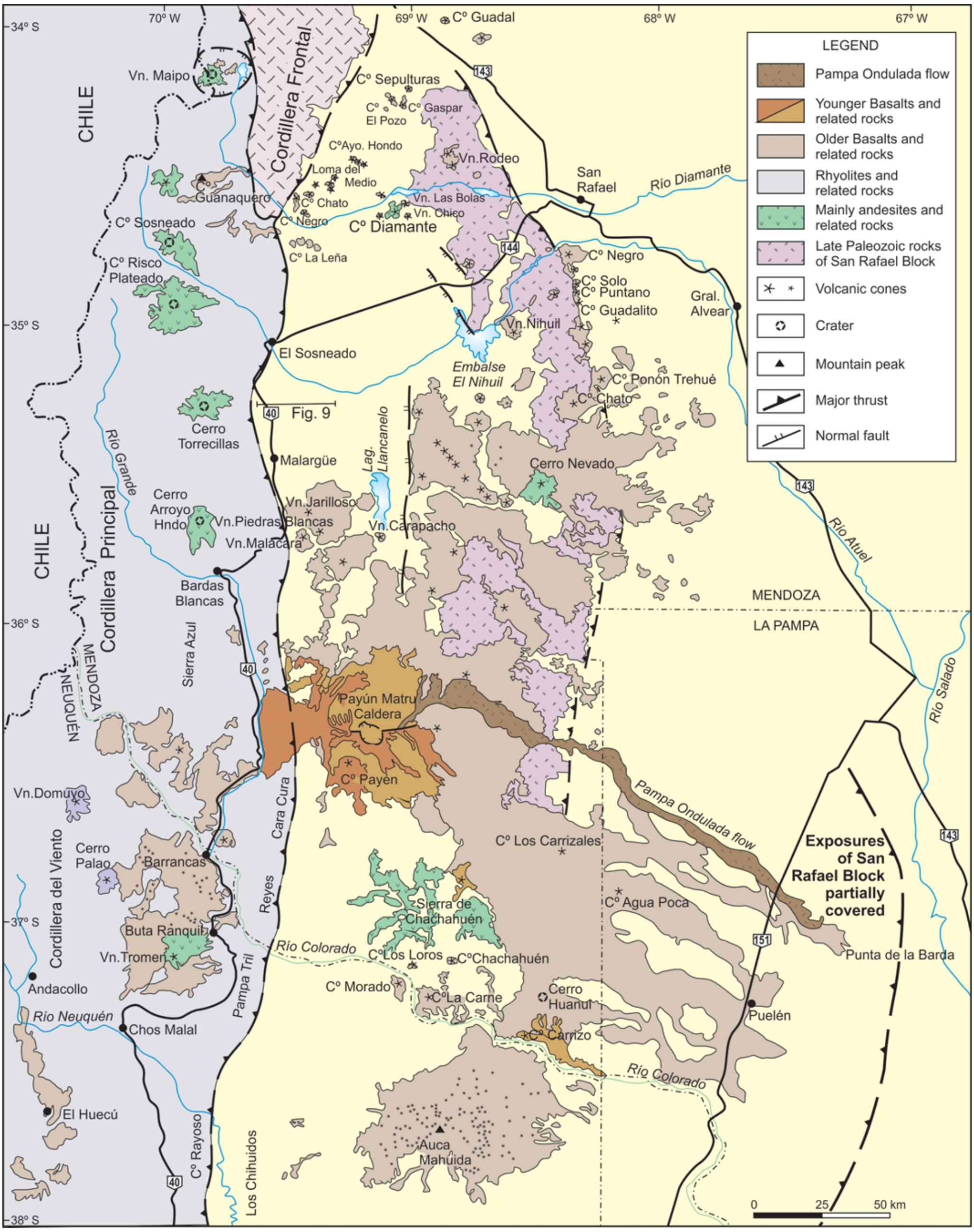

Fig. 8. The Miocene magmatic arc rocks, the Quaternary Payenia basaltic province and the Present thrust front (after Ramos & Folguera 2011).

by the conglomerates and sandstones of La Pilona Formation at 11.7 Ma, which exhibit a marked increase in accumulation rate with time (Irigoyen *et al.* 2000).

There is no magmatic activity in the Principal and Frontal Cordilleras. Magmatic arc rocks are concentrated in the Sierras Pampeanas between 8 and 6 Ma. Volcanic arc rocks are widespread in the Sierra de San Luis (Urbina & Sruoga 2009) and consist of high-K andesites and dacites with typical shoshonites in the Sierra del Morro, which recorded the latest eruption at 1.9 Ma along the flat-slab subduction segment (Ramos *et al.* 1991, 2002; Kay *et al.* 1991).

The magmatic expansion was accompanied by the development of a broken foreland where several late Cenozoic basins were formed related to tectonic loading and dynamic subsidence (Dávila *et al.* 2005).

The neotectonic activity is presently concentrated between Precordillera and Sierras Pampeanas, where large intracrustal earthquakes have occurred (Alvarado *et al.* 2009). Surface fault ruptures and other neotectonic features indicate important Quaternary deformation (Schmidt *et al.* 2011).

Payenia palaeoflat-slab subduction. South of 33°30′S latitude a different geological setting is observed (Fig. 8). The Principal Cordillera is flanked by the Frontal Cordillera up to 34°30′S, where south of this latitude the foothills of the Andes are in contact with an extensive basaltic plateau of Quaternary age between 34 and 37°S (Ramos & Folguera 2011). This basaltic plateau is known as the Payenia volcanic province.

The Principal Cordillera between 35 and 37.5°S latitudes recorded in the Miocene an important expansion of the magmatic arc from the Chilean slope to the foreland eastern foothills (Spagnuolo *et al.* 2012*b*; Folguera & Ramos 2011). After a period of extension during the Oligocene, where the within-plate alkaline basaltic rocks of Palauco Formation erupted, a series of granitic stocks were emplaced in the eastern slope of the Principal Cordillera. Subvolcanic bodies of calc-alkaline andesites with ages ranging from middle to late Miocene are found in the foreland extra-andean plains. The eruption of these rocks is also linked to another phase of contraction and deformation (Spagnuolo *et al.* 2012*b*). The within-plate basalts of the Payenia volcanic province are unconformably overlying previous deposits and extend over an area larger than 40 000 km^2 between 33°30′ and 38°S latitudes. The huge Payún Matru caldera is the main feature related to the Payenia retroarc basalts (Bertotto *et al.* 2009; Llambías *et al.* 2010). The basalts have an estimated volcanic volume of about 8387 km^3 erupted through more than 800 volcanic centres in the last *c.* 2 Ma (Ramos & Folguera 2011; Gudnason *et al.* 2012; Søager *et al.* 2013).

The sedimentary basin evolution at these latitudes during the Cenozoic shows the transit from a single foreland basin to a broken foreland basin associated with the uplift and exhumation of the San Rafael Block (Silvestro & Atencio 2009; Ramos *et al.* 2014). Geophysical studies have demonstrated that the steepening of a subducted slab is the more appropriate process to explain the extension and characteristics of the Payenia basaltic retroarc province (Burd *et al.* 2008).

Concluding remarks

The analysis of the geology of this sector of the southern Central Andes shows continuous subduction along the proto-Pacific margin of Gondwana and the present margin of South America during most of the Cenozoic. However, it is possible to identify an accretionary orogen during the Palaeozoic, with docking of different terranes, and a Meso-Cenozoic subduction with different tectonic regimes. These variations defined tectonic cycles with different processes, where extensional and compressive regimes alternate through time. The accretion of continental basement terranes produced the obduction of slices of oceanic crust, high-pressure–low-temperature metamorphism, and important shifting to the trench of the magmatic arcs. Periods of shallow subduction, partially combined in late Palaeozoic times with the processes of accretionary orogenesis, produced broken forelands under extreme contraction and subsequent extension and widespread rhyolitic volcanism. The Mesozoic was characterized by subduction with generalized extension until late Early Cretaceous, when evidence of contraction and orogeny led to the present Andean tectonic setting with dominant contraction. The development of segments with flat-slab subduction with no arc-magmatism alternates with segments where, after periods of flat subduction, the steepening of the subduction zone produced generalized extension and backarc basaltic magmatism.

All these processes indicate the complexities of the classic Andean tectonic setting, where the simple subduction of oceanic crust under continental crust controls the orogenesis. The analysed segment, one of the classical sectors of the Central Andes, with excellent exposures and where many of these processes have been first recognized, enhanced the importance of understanding the relationship among magmatism, metamorphism, sedimentation and deformation.

The authors thank the participants of the IGCP 586-Y 'Geodynamic Processes in the Andes, 32–34°S' for their invitation to prepare this introductory chapter to this book. They thank two anonymous reviewers for their valuable suggestions that considerably improved the manuscript and several colleagues who provided in-press manuscripts on subjects related to the considered region. The authors acknowledge: FONDECYT Project no. 1120272, 'Extension, inversion and propagation: key tectonic styles on the development of the Andean Cordillera of central Chile-Argentina (32–36°S)'.

References

Abele, G. 1982. El lahar Tinguiririca: su significado entre los lahares chilenos. *Informaciones Geográficas*, **29**, 21–34.

Äberg, G., Aguirre, L., Levi, B. & Nyström, J. O. 1984. Spreading subsidence and generation of ensialic marginal basin: an example from the Early Cretaceous of Central Chile. *In*: Kokelaar, B. P. & Howells, M. F. (eds) *Marginal Basin Geology*. Geological Society, London, Special Publications, **16**, 185–193.

Aceñolaza, G. & Tosselli, A. C. 1976. Consideraciones estratigráficas y tectónicas sobre el Paleozoico inferior del Noroeste Argentino. *In*: *II Congreso Latinoamericano de Geología*, Caracas, 1973, **2**, 755–764.

Aguirre, L. 1960. Geología de los Andes de Chile Central, provincia de Aconcagua. *Boletín del Instituto de Investigaciones Geológicas*, **9**, 1–70.

Aguirre, L. & Egert, E. 1965. *Cuadrángulo Quebrada Marquesa, Provincia de Coquimbo*. Instituto de Investigaciones Geológicas, Santiago, Carta Geológica de Chile, escala 1:50.000, Carta 15.

Aguirre, L. & Egert, E. 1970. *Cuadrángulo Lambert (La Serena), Provincia de Coquimbo*. Instituto de Investigaciones Geológicas, Santiago, Carta Geológica de Chile, escala 1:50.000, Carta 23.

Aguirre, L., Hervé, F. & Godoy, E. 1972. Distribution of metamorphic facies in Chile, an outline. *Kristallinikum*, **9**, 7–19.

Aguirre, L., Charrier, R. *et al.* 1974. Andean Magmatism: its paleogeographical and structural setting in the central part (30–35°S) of the Southern Andes. *Pacific Geology*, **8**, 1–38.

Aguirre, L., Féraud, G., Morata, D., Vergara, M. & Robinson, D. 1999. Time interval between volcanism and burial metamorphism and rate of basin subsidence in a Cretaceous Andean extensional setting. *Tectonophysics*, **313**, 433–447.

Aguirre, L., Robinson, D., Bevins, R. E., Morata, D., Vergara, M., Fonseca, E. & Carrasco, J. 2000. A low-grade metamorphic model for the Miocene volcanic sequences in the Andes of central Chile. *New Zealand Journal of Geology and Geophysics*, **43**, 83–93.

Aguirre-Urreta, B., Tunik, M., Naipauer, M., Pazos, P., Ottone, E., Fanning, M. & Ramos, V. A. 2011. Malargüe Group (Maastrichtian–Danian) deposits in the Neuquén Andes, Argentina: implications for the onset of the first Atlantic transgression related to Western Gondwana break-up. *Gondwana Research*, **19**, 482–494.

Aguirre-Urreta, M. B. & Lo Forte, G. L. 1996. Los depósitos tithoneocomianos. *In*: Ramos, V. A. (ed.) *Geología de la región del Aconcagua, provincias de San Juan y Mendoza, República Argentina*. Dirección Nacional del Servicio Geológico, Buenos Aires, Anales, **24**, 179–230.

Alonso, J. L., Gallastegui, J., García-Sansegundo, J., Farias, P., Rodríguez Fernández, L. R. & Ramos, V. A. 2008. Extensional tectonics and gravitational collapse in an Ordovician passive margin: the Western Argentine Precordillera. *Gondwana Research*, **13**, 204–215.

Alvarado, P., Pardo, M., Gilbert, H., Miranda, F., Anderson, M., Saez, M. & Beck, S. 2009. Flat-slab subduction and crustal models for the seismically active Sierras Pampeanas región of Argentina. *In*: Kay, S. M., Ramos, V. A. & Dickinson, W. R. (eds) *Backbone of the Americas: Shallow Subduction, Plateau Uplift, and Ridge and Terrane Collision*. Geological Society of America, Boulder, CO, Memoirs, **204**, 261–278.

Álvarez, P. P. 1996. Los depósitos triásicos y jurásicos de la Alta Cordillera de San Juan. *In*: Ramos, V. (ed.) *Geología de la Región del Aconcagua, provincias de San Juan y Mendoza*. Subsecretaría de Minería de la Nación, Dirección Nacional del Servicio Geológico, Buenos Aires, Anales, **24**, 59–137.

Álvarez, P. P. & Ramos, V. A. 1999. The Mercedario Rift System in the Principal Cordillera of Argentina and Chile (32°SL). *Journal of South American Earth Sciences*, **12**, 17–31.

Álvarez, P. P., Aguirre-Urreta, M. B., Godoy, E. & Ramos, V. A. 1997. Estratigrafía del Jurásico de la Cordillera Principal de Argentina y Chile (33°45′–34°00′LS). *In*: *VIII Congreso Geológico Chileno Antofagasta*. Antofagasta, **1**, 425–429.

Arévalo, A. 1984. *Geología de subsuperficie del área al sur del río Lebu, VIII Región*. Thesis, Departamento de Geología, Universidad de Chile, Santiago.

Arcos, R. 1987. *Geología del Cuadrángulo Termas del Flaco, provincia de Colchagua, VI Región, Chile*. Thesis, Departamento de Geología, Universidad de Chile.

Armijo, R., Rauld, R., Thiele, R., Vargas, G., Campos, J., Lacassin, R. & Kausel, E. 2010. The West Andean Thrust, the San Ramón Fault, and the seismic hazard for Santiago, Chile. *Tectonics*, **29**, TC2007, http://dx.doi.org/10.1029/2008TC002427

Arriagada, C., Roperch, P., Mpodozis, C. & Cobbold, P. R. 2008. Paleogene building of the Bolivian Orocline: tectonic restoration of the Central Andes in 2-D map view. *Tectonics*, **27**, TC6014, http://dx.doi.org/10.1029/2008TC002269

Arriagada, C., Ferrando, R., Córdova, L., Morata, D. & Roperch, P. 2013. The Maipo Orocline: a first scale structural feature in the Miocene to recent geodynamic evolution in the Central Andes. *Andean Geology*, **40**, 419–137.

Astaburuaga, D. 2014. *Geología estructural y configuración del límite Mesozoico-Cenozoico de la Cordillera Principal entre 35°30′y 36°S, Región del Maule, Chile*. Master's thesis, Departamento de Geología, Universidad de Chile.

Astini, R. A. 1996. Las fases diastróficas del Paleozoico Medio en la Precordillera del oeste argentino. *In*: *Evidencias estratigráficas. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos*, Buenos Aires, **5**, 509–526.

Astini, R. A., Benedetto, J. L. & Vaccari, N. E. 1995. The early Paleozoic evolution of the Argentina Precordillera as a Laurentian rifted, drifted, and collided terrane: a geodynamic model. *Geological Society of America, Bulletin*, **107**, 253–273.

Astini, R., Ramos, V. A., Benedetto, J. L., Vaccari, N. E. & Cañas, F. L. 1996. La Precordillera: un terreno exótico a Gondwana. *In*: *XIII Congreso Geológico Argentino y III Congreso Exploración de Hidrocarburos*, Buenos Aires, **5**, 293–324.

Astini, R. A., Martina, F. & Dávila, F. M. 2011. La Formación Los Llantenes en la Precordillera de Jagüé (La Rioja) y la identificación de un episodio de extensión en la evolución temprana de las cuencas del Paleozoico superior en el oeste argentino. *Andean Geology*, **38**, 245–267.

Ávila, J. N., Chemale, F., Jr, Mallmann, G., Kawashita, K. & Armstrong, R. 2006. Combined stratigraphic and isotopic studies of Triassic strata, Cuyo Basin, Argentine Precordillera. *Geological Society of America Bulletin*, **118**, 1088–1098.

Barredo, S., Chemale, F., Marsicano, C., Ávila, J. N., Ottone, E. G. & Ramos, V. A. 2012. Tectonosequence stratigraphy and U–Pb zircon ages of the Rincón Blanco depocenter, northern Cuyo Rift, Argentina. *Gondwana Research*, **21**, 624–636.

Bell, M. & Suárez, M. 1995. Slope apron deposits of the Lower Jurassic Los Molles Formation, Central Chile. *Revista Geologica de Chile*, **22**, 103–114.

Benedetto, J. L., Sánchez, T. M., Carrera, M. G., Brussa, E. D. & Salas, M. J. 1999. Paleontological constraints in successive paleogeographic positions of Precordillera terrane during the Early Paleozoic. *In*: Ramos, V. A. & Keppie, D. (eds) *Laurentia-Gondwana Connections Before Pangea*. Geological Society of America, Boulder, CO, Special Papers, **336**, 21–42.

Bertels, A. 1969. Estratigrafía del límite Cretácico-Terciario en Patagonia septentrional. *Revista Asociación Geológica Argentina*, **24**, 41–54.

Bertels, A. 1970. Micropaleontología y estratigrafía del límite Cretácico-Terciario en Huantraico (Provincia del Neuquén, Parte II). *Ameghiniana*, **4**, 253–298.

Bertotto, G. W., Cingolani, C. & Berg, E. 2009. Geochemical variations in Cenozoic back-arc basalts at the border of La Pampa and Mendoza provinces, Argentina. *Journal of South American Earth Sciences*, **28**, 360–373.

Bevins, R. E., Robinson, D., Aguirre, L. & Vergara, M. 2003. Episodic burial metamorphism in the Andes – a viable model? *Geology*, **31**, 705–708.

Biró-Bagóczky, L. 1964. *Estudio sobre el límite Titoniano y el Neocomiano en la Formación Lo Valdés, Provincia de Santiago, principalmente en base a ammonoideos, Región Metropolitana, Chile*. Thesis, Departamento de Geología, Universidad de Chile.

Biró-Bagóczky, L. 1982. Revisión y redefinición de los "Estratos de Quiriquina", Campaniano-Maastrichtiano, en su localidad tipo en la Isla Quiriquina, 36° 35′ Lat. S, Chile, Sudamérica, con un perfil complementario en Cocholgüe. *In*: *III Congreso Geológico Chileno*, Concepción, **1**, A 29–64.

Bissig, T., Lee, J. K. W., Clark, A. H. & Heather, K. B. 2001. The Cenozoic history of magmatic activity and hydrothermal alteration in the central Andean flat-slab region: new $^{40}Ar/^{39}Ar$ constraints from the El Indio–Pascua Au (-Ag, Cu) belt, 29°20′–30°30′S. *International Geology Review*, **43**, 312–340.

Bjerg, E. A., Gregori, D. A., Losada Calderon, A. & Labudia, C. H. 1990. Las metamorfitas del faldeo oriental de la Cuchilla de Guarguaraz, Cordillera Frontal, Provincia de Mendoza. *Revista de la Asociación Geológica Argentina*, **45**, 234–245.

Bordonaro, O. 1980. El Cámbrico de la quebrada de Zonda, Provincia de San Juan. *Revista de la Asociación Geológica Argentina*, **35**, 26–40.

Bordonaro, O. 1992. El Cámbrico de Sudamérica. *In*: Gutiérrez Marco, J. C., Saavedra, J. & Rábano, I. (eds) *Paleozoico inferior de Ibero América*. Universidad de Extremadura, Mérida, 69–84.

Bravo, P. 2001. *Geología del borde oriental de la Corillera de la Costa entre los ríos Mataquito y Maule, VII Región*. Thesis, Departamento de Geología, Universidad de Chile.

Buatois, L. A. & Encinas, A. 2011. Ichnology, sequence stratigraphy and depositional evolution of an Upper Cretaceous rocky shoreline in central Chile: Bioerosion structures in a transgressed metamorphic basement. *Cretaceous Resource*, **32**, 203–212.

Buggish, W., von Gosen, W., Henjes-Kunst, F. & Krumm, S. 1994. The age of Early Paleozoic deformation and metamorphism in the Argentine Precordillera – evidence from K–Ar data. *Zentralblatt fur Geologie und Palaontologie, Teil*, **1**, 275–286.

Burd, A. I., Booker, J. R., Pomposiello, M. C., Favetto, A., Larsen, J., Giordanengo, G. & Orozco Bernal, L. 2008. Electrical conductivity beneth the Payún Matrú volcanic field in the Andean back-arc of Argentina near 36,5°S: insights into the magma source. *In*: *VII Internatinal Symposium on Andean Geodynamics*, Nice, Extenden Abstract, 90–93.

Burns, W. M. & Jordan, T. E. 1999. Extension in the Southern Andes as evidenced by an Oligo-Mioceneage intra-arc basin. *In*: *IV International Symposium on Andean Geodynamics (ISAG)*, Göttingen, 115–118.

Cahill, T. & Isacks, B. 1992. Seismicity and shape of the subducted Nazaca Plate. *Journal of Geophysical Research*, **97**, 17 503–17 529.

Caminos, R. 1965. Geología de la vertiente oriental del Cordón del Plata, Cordillera Frontal de Mendoza. *Revista de la Asociación Geológica Argentina*, **20**, 351–392.

Caminos, R. 1979. Cordillera Frontal. *In*: Turner, J. C. M. (ed.) *Geología Regional Argentina*. Academia Nacional de Ciencias, Córdoba, Argentina, **1**, 397–453.

Camus, F. 1977. Geología del área de emplazamiento de los depósitos de cuarzo Olla Blanca, provincia de Cachapoal. *Revista Geológica de Chile*, **4**, 43–54.

Camus, F. 2002. The Andean porphyry systems. *In*: Cooke, D. R. & Pongratz, J. (eds) *Giant Ore Deposits: Characteristics, Genesis and Exploration*. CODES, Australia, Special Publications, **4**, 5–21.

Camus, F. 2003. *Geología de los sistemas porfíricos en los Andes de Chile*. Servicio Nacional de Geología y Minería, Santiago.

Cañas, F. L. 1999. Facies and sequences of the Late Cambrian-Early Ordovician carbonates of the Argentine Precordillera: a stratigraphic comparison with Laurentian platforms. *In*: Ramos, V. A. & Keppie, J. D. (eds) *Laurentia–Gondwana Connections before Pangea*. Geological Society of America, Boulder, CO, Special Papers, **336**, 43–62.

Carretier, S., Regard, V. *et al.* 2013. Slope and climate variability control of erosion in the Andes of central Chile. *Geology*, **41**, 195–198.

Carretier, S., Tolorza, V. *et al.* 2014. Erosion in the Chilean Andes between 27°S and 39°S: tectonics, climatic and geomorphic control. *In*: Sepúlveda, S. A., Giambiagi, L. B., Moreiras, S. M., Pinto, L., Tunik, M., Hoke, G. D. & Farías, M. (eds) *Geodynamic Processes in the Andes of Central Chile and Argentina*. Geological Society, London, Special Publications, **399**. First published online April 9, 2014, http://dx.doi.org/10.1144/SP399.16

Carter, W. & Aguirre, L. 1965. Structural Geology of Aconcagua province and its relationship to the central Valley Graben, Chile. *Geological Society of America Bulletin*, **76**, 651–664.

Casamiquela, R. M. & Fasola, A. 1968. Sobre pisadas de dinosauriosdel Cretácico Inferior de Colchagua (Chile). *Boletín Departamento de Geología, Universidad de Chile*, **30**, 1–24.

Casquet, C., Rapela, C. *et al.* 2012. A history of Proterozoic terranes in southern South America: from Rodinia to Gondwana. *Geoscience Frontiers*, **3**, 137–145.

Cecioni, G. 1978. Petroleum possibilities of the Darwin's Navidad Formation near Santiago, Chile. *Publicación Ocasional del Museo Nacional de Historia Natural, Chile*, **25**, 3–28.

Cecioni, G. 1983. Chanco Formation, a potential Cretaceous reservoir, central Chile. *Journal of Petroleum Geology*, **6**, 89–93.

Cecioni, G. & Westermann, G. E. G. 1968. The Triassic–Jurassic marine transition of coastal central Chile. *Pacific Geology*, **1**, 41–75.

Charrier, R. 1973. Geología de las Provincias O'Higgins y Colchagua. *Instituto de Investigación de Recursos Naturales, Santiago*, **7**, 11–69.

Charrier, R. 1977. Geology of region of Huentelauquén, Coquimbo Province, Chile. *In*: Ishikawa, T. & Aguirre, L. (eds) *Comparative Studies on the Geology of the Circum-Pacific Orogenic Belt in Japan and Chile*. First Report. Japanese Society for Promotion of Science, Tokyo, 81–94.

Charrier, R. 1979. El Triásico de Chile y regiones adyacentes de Argentina: una reconstrucción paleogeográfica y paleoclimática. *Comunicaciones*, **26**, 1–37.

Charrier, R. 1981*a*. Mesozoic and Cenozoic stratigraphy of the Central Argentinian Chilean Andes (32° 35°S) and chronology of their tectonic evolution. *Zentralblatt fur Geologie und Palaontologie*, Teil **1**, 344–355.

Charrier, R. 1981*b*. *Geologie der chilenischen Hauptkordillere zwischen 34°30p südlicher Breite und ihre tektonische, magmatische und paleogeographische Entwicklung*. Berliner Geowissenschaftliche Abhandlungen (A), Berlin, **36**.

Charrier, R. 1982. La Formación Leñas-Espinoza: redefinición, petrografía y ambiente de sedimentación. *Revista Geológica de Chile*, **17**, 71–82.

Charrier, R. 1984. Areas subsidentes en el borde occidental de la cuenca de tras arco jurásico cretácica, Cordillera Principal Chilena entre 34° y 34°30′S. *In*: *IX Congreso Geológico Argentino*. Bariloche, Argentina, Actas, **2**, 107–124.

Charrier, R. & Vicente, J. C. 1972. Liminary and Geosyncline Andes: major orogenic phases and synchronical evolution of the Central and Austral sectors of the Southern Andes. *Conferencia sobre Problemas de la Tierra Sólida, Buenos Aires*, **2**, 451–470.

Charrier, R. & Munizaga, F. 1979. Edades K–Ar de volcanitas cenozoicas del sector cordillerano del río Cachapoal, Chile (34° 15′ de latitud Sur). *Revista Geológica de Chile*, **7**, 41–51.

Charrier, R. & Muñoz, N. 1994. Jurassic–Cretaceous paleogeographic evolution of the Chilean Andes at 23°–24°S and 34°–35°S latitude: a comparative analysis. *In*: Reutter, K. J., Scheuber, E. & Wigger, P. (eds) *Tectonics of the Southern Central Andes*. Springer, Heidelberg, 233–242.

Charrier, R., Wyss, A. R. *et al.* 1996. New evidence for late Mesozoic–Early Cenozoic evolution of the Chilean Andes in the Upper Tinguiririca valley (35°S), Central Chile. *Journal of South American Earth Sciences*, **9**, 393–422.

Charrier, R., Baeza, O. *et al.* 2002. Evidence for Cenozoic extensional basin development and tectonic inversion south of the flat-slab segment, southern Central Andes, Chile, (33°–36° S.L.). *Journal of South American Earth Sciences*, **15**, 17–139.

Charrier, R., Pinto, L. & Rodríguez, M. P. 2007. Tectonostratigraphic evolution of the Andean Orogen in Chile. *In*: Moreno, T. & Gibbons, W. (eds) *The Geology of Chile*. Geological Society, London, 21–114.

Charrier, R., Farías, M. & Maksaev, V. 2009. Evolución tectónica, paleogeográfica y metalogénica durante el Cenozoico en los Andes de Chile norte y central e implicaciones para las regiones adyacentes de Bolivia y Argentina. *Revista de la Asociación Geológica Argentina*, **65**, 5–35.

Charrier, R., Croft, D. A., Flynn, J. J., Pinto, L. & Wyss, A. R. 2012. Mamíferos fósiles cenozoicos en Chile: implicancias paleontológicas y tectónicas. Continuación de investigaciones iniciadas por Darwin en América del Sur. *In*: Veloso, A. & Spotorno, A. (eds) *Darwin y la evolución: avances en la Universidad de Chile*. Editorial Universitaria, Santiago de Chile, 281–316.

Charrier, R., Hérail, G., Pinto, L., García, M., Riquelme, R., Farías, M. & Muñoz, N. 2013. Cenozoic tectonic evolution in the Central Andes in northern Chile and west-central Bolivia. Implications for paleogeographic, magmatic and mountain building evolution. *International Journal of Earth Sciences*, **102**, 235–264, http://dx.doi.org/10.1007/s00531-012-0801-4

Chernicoff, J. & Ramos, V. A. 2003. El basamento de la Sierra de San Luis: nuevas evidencias magnéticas y sus implicancias tectónicas. *Revista de la Asociación Geológica Argentina*, **58**, 511–524.

Chernicoff, C. J., Zappettini, E. O., Santos, J. O. S., Godeas, M. C., Belousova, E. & McNaughton, N. K. 2012. Identification and isotopic studies of early Cambrian magmatism (El Carancho Igneous Complex) at the boundary between Pampia terrane and the Río de la Plata craton, La Pampa province, Argentina. *Gondwana Research*, **21**, 378–393.

Coira, B. L., Davidson, J. D., Mpodozis, C. & Ramos, V. A. 1982. Tectonic and magmatic evolution of the Andes of Northern Argentina and Chile. *Earth Science Reviews*, **18**, 303–332.

Collo, G., Astini, R. A., Cardona, A., Do Campo, M. D. & Cordani, U. 2008. Edad del metamorfismo de las unidades con bajo grado de la región central del Famatina: La impronta del ciclo orogénico oclóyico. *Revista Geológica de Chile*, **35**, 191–213.

Collo, G., Astini, R. A., Cawood, P. A., Buchan, C. & Pimentel, M. 2009. U–Pb detrital zircon ages and Sm–Nd isotopic features in low-grade metasedimentary rocks of the Famatina belt: implications for late Neoproterozoic-early Palaeozoic evolution of the proto-Andean margin of Gondwana. *Journal of the Geological Society*, **166**, 303–319.

Coloma, F., Salazar, E. & Creixell, C. 2012. Nuevos antecedentes acerca de la construcción de los plutones Pérmicos y Permo-Triásicos en el valle del río Tránsito, región de Atacama, Chile. *In*: *XIII Congreso Geológico Chileno*, Antofagasta, Tematic Session 3: Magmatism and Metamorphism, 324–326, digital abstract.

Cornejo, P., Matthews, S. & Pérez, C. 2003. The 'K–T' compressive deformation event in northern Chile (24°–27°S). *In*: *X Congreso Geológico Chileno*, Concepción, Tematic Session 1: Tectonics, 13 p., digital.

Cortés, J. M. & Kay, S. M. 1994. Una dorsal oceánica como origen de las lavas almohadilladas del Grupo Ciénaga del Medio (Silúrico-Devónico) de la Precordillera de Mendoza. *In*: *VII Congreso Geológico Chileno*, Concepción, Actas, **I**, 1005–1009.

Covacevich, V., Varela, J. & Vergara, M. 1976. Estratigrafía y sedimentación de la Formación Baños del Flaco al sur del rio Tinguiririca, Cordillera de los Andes, provincia de Curicó, Chile. *In*: *I Congreso Geológico Chileno*, Santiago, **1**, A191–A211.

Cowan, D. S. 1985. Structural styles in Mesozoic and Cenozoic melanges in the western Cordillera of North-America. *Geological Society of America Bulletin*, **96**, 451–462.

Creixell, C., Parada, M. A., Morata, D., Vásquez, P., Pérez de Arce, C. & Arriagada, C. 2011. Middle–Late Jurassic to Early Cretaceous transtension and transpression during arc building in central Chile: evidence from mafic dike swarms. *Andean Geology*, **38**, 16–42.

Cristallini, E. O. & Ramos, V. A. 1996. Los depósitos continentales cretácicos y volcanitas asociadas. *In*: Ramos, V. A. (ed.) *Geología de la Región del Aconcagua, Provincias de San Juan y Mendoza*. Dirección Nacional del Servicio Geológico, Buenos Aires, Argentina, Anales, **24**, 231–274.

Croft, D. A., Radic, J. P., Zurita, E., Charrier, R., Flynn, J. & Wyss, A. R. 2003. A Miocene toxodontid (Mammalia: notoungulata) from the sedimentary series of the Cura-Mallín Formation, Lonquimay, Chile. *Revista Geológica de Chile*, **30**, 285–298.

Cuadra, P. 1986. Geocronología K–Ar del yacimiento El Teniente y áreas adyacentes. *Revista Geológica de Chile*, **27**, 3–26.

Cucchi, R. J. 1972. Edades radimétricas y correlación de metamorfitas de la Precordillera, San Juan–Mendoza, Rep. Argentina. *Revista de la Asociación Geológica Argentina*, **26**, 503–515.

Dalla Salda, L. H., Cingolani, C. & Varela, R. 1992*a*. Early Palaeozoic Orogenic belt of the Andes in southwestern South-America – result of Laurentia–Gondwana collision. *Geology*, **20**, 617–620.

Dalla Salda, L., Dalziel, I. W. D., Cingolani, C. A. & Varela, R. 1992*b*. Did the Taconic Appalachians continue into southern South America? *Geology*, **20**, 1059–1062.

Dahlquist, J. A., Pankhurst, R. J. *et al.* 2013. Hf and Nd isotopes in Early Ordovician to Early Carboniferous granites as monitors of crustal growth in the Proto-Andean margin of Gondwana. *Gondwana Research*, **23**, 1617–1630.

Darwin, C. 1846. *Geological Observations on South America; Part III, The Geology of the Voyage of the Beagle*. Smith Elder, London.

Davidson, J. 1971. *Tectónica y paleogeografía de la Cordillera Principal en el área de las Nacientes del Teno, Curicó, Chile*. Thesis, Departamento de Geología, Universidad de Chile.

Davidson, J. & Vicente, J. C. 1973. Características paleogeográficas y estructurales del área fronteriza de las nacientes del Teno (Chile) y Santa Elena (Argentina), (Cordillera Principal, 35° a 35°15′ de Latitud Sur). *In*: *V Congreso Geológico Argentino*. Carlos Paz, Argentina, Actas, **5**, 11–55.

Dávila, F. M., Astini, R. A. & Jordan, T. E. 2005. Cargas subcorticales en el antepaís andino y la planicie pampeana: evidencias estratigráficas, topográficas y geofísicas. *Revista de la Asociación Geológica Argentina*, **60**, 775–786.

Davis, J. S., Roeske, S. M., McClelland, W. C. & Snee, L. W. 1999. Closing the ocean between the Precordillera terrane and Chilenia: early Devonian ophiolite emplacement and deformation in the southwest Precordillera. *In*: Ramos, V. A. & Keppie, J. D. (eds) *Laurentia-Gondwana Connections before Pangea*. Geological Society of America, Boulder, CO, Special Papers, **336**, 115–138.

Deckart, K., Hervé, F., Fanning, C. M., Ramìrez, V., Calderón, M. & Godoy, E. 2014. U–Pb geochronology and Hf–O isotopes of zircons from the Pennsylvanian Coastal Batholith, south-central Chile. *Andean Geology*, **41**, 49–82.

Dedios, P. 1967. *Cuadrángulo Vicuña, Provgincia de Coquimbo*. Instituto de Investigaciones Geológicas, Santiago, Carta, **16**.

De la Cruz, R. & Suárez, M. 1997. El Jurásico de la cuenca de Neuquén en Lonquimay, Chile: formación Nacientes del Biobio (38°–39°S). *Revista Geológica de Chile*, **24**, 3–24.

Díaz-Martínez, E., Mamet, B., Isaacson, P. E. & Grader, G. W. 2000. Permian marine sedimentation in northern Chile: new paleontological evidence from the Juan de Morales Formation, and regional paleogeographic implications. *Journal of South American Earth Sciences*, **13**, 511–525.

Di Giulio, A., Ronchi, A., Sanfilippo, A., Tiepolo, M., Pimentel, M. & Ramos, V. A. 2012. Detrital zircon provenance from the Neuquén Basin (south-central Andes): Cretaceous geodynamic evolution and sedimentary response in a retroarc-foreland basin. *Geology*, **40**, 559–562.

Drake, R. E. 1976. Chronology of Cenozoic igneous and tectonic events in the Central Chilean Andes-latitudes 35°30′–36°00′S. *Journal of Volcanology and Geothermal Research*, **1**, 265–284.

Drake, R. E., Curtis, G. & Vergara, M. 1976. Potassium–argon dating of igneous activity in the central Chilean Andes – latitude 33°S. *Journal of Volcanology and Geothermal Research*, **1**, 285–295.

Elgueta, S. 1990. Sedimentación marina y paleogeografía del Terciario Superior de la Cuenca de Temuco, Chile. *In*: *II Simposio sobre el Terciario en Chile*. Concepción, Chile, Actas, **1**, 85–96.

Emparan, C. & Calderón, G. 2014. *Geología del Área Ovalle-Peña Blanca, Región de Coquimbo*. Servicio Nacional de Geología y Minería, Santiago.

Emparan, C. & Pineda, G. 1999. *Área Condoriaco-Rivadavia, Región de Coquimbo*. Servicio Nacional de Geología y Minería, Santiago, Mapas Geológicos, **12**.

Emparan, C. & Pineda, G. 2006. *Geología del Área Andacollo-Puerto Aldea, Región de Coquimbo*. Servicio Nacional de Geología y Minería, Santiago, Carta Geológica de Chile, Serie Geología Básica, **96**.

Encinas, A., Le Roux, J., Buatois, L. A., Nielsen, S. N., Finger, K. L., Fourtanier, E. & Lavenu, A. 2006*a*. Nuevo esquema estratigráfico para los depósitos marinos mio-pliocenos del área de Navidad (33°00′–34°30′S), Chile central. *Revista Geológica de Chile*, **33**, 221–246.

Encinas, A., Maksaev, V., Pinto, L., Le Roux, J., Munizaga, F. & Zentilli, M. 2006*b*. Pliocene lahar deposits in the Coastal Cordillera of central Chile: implications for uplift, avalanche deposits, and porphyry copper systems in the Main Andean Cordillera. *Journal of South American Earth Sciences*, **20**, 369–381.

Escayola, M. P., Ramé, G. A. & Kraemer, P. E. 1996. Caracterización y significado geotectónico de las fajas ultramáficas de las Sierras Pampeanas de Córdoba. *In*: *XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos*. Mendoza, Argentina, **3**, 421–438.

Escayola, M. P., Pimentel, M. & Armstrong, R. 2007. Neoproterozoic backarc basin: sensitive high-resolution ion microprobe U–Pb and Sm–Nd isotopic evidence from the Eastern Pampean Ranges, Argentina. *Geology*, **35**, 495–498.

Eyquem, D. 2009. *Volcanismo cuaternario de Sierras de Bellavista. Comparación geoquímica con el magmatismo contemporáneo del arco comprendido entre los 34°30′ y los 35°30′S*. Thesis, Departamento de Geología, Universidad de Chile, Santiago.

Farías, M., Charrier, R. *et al*. 2008. Late Miocene high and rapid surface uplift and its erosional response in the Andes of central Chile (33°–35°S). *Tectonics*, **27**, TC1005, http://dx.doi.org/10.1029/2006TC002046

Farías, M., Comte, D. *et al*. 2010. Crustal scale architecture in central Chile based on seismicity and surface geology: implications for Andean mountain building. *Tectonics*, **29**, TC3006, http://dx.doi.org/10.1029/2009TC002480

Fernández-Seveso, F. & Tankard, A. J. 1995. Tectonics and stratigraphy of the Late Paleozoic Paganzo basin of western Argentina and its regional implications. *In*: Tankard, A. J., Suárez Soruco, R. & Welsink, H. J. (eds) *Petroleum Basins of South America*. American Association of Petroleum Geologists, Tulsa, OK, Memoirs, **62**, 285–301.

Ferrando, R., Roperch, P., Morata, D., Arriagada, C., Ruffet, G. & Córdoba, M. L. 2014. A paleomagnetic and magnetic fabric study of the Illapel Plutonic complex, Coastal Range, central Chile: implications for emplacement mechanism and regional tectonic evolution during the mid-Cretaceous. *Journal of South American Earth Science*, **50**, 12–26.

Finger, K., Encinas, A., Nielsen, S. & Peterson, D. 2003. Microfaunal indications of late Miocene deep-water basins off the central coast of Chile. *In*: *X Congreso Geológico Chileno*. Concepción, Tematic Session 3, 8 p., digital abstract.

Finger, K. L., Nielsen, S. N., DeVries, T. J., Encinas, A. & Peterson, D. E. 2007. Paleontologic evidence for sedimentary displacement in Neogene forearc basins of Central Chile. *Palaios*, **22**, 3–16, http://dx.doi.org/10.2110/palo.2005.p05-081r

Flynn, J. J., Wyss, A. R. & Charrier, R. 2007. South America's missing mammals. *Scientific American*, **296**, 68–75.

Flynn, J. J., Charrier, R., Croft, D. A., Gans, P. B., Herriott, T. M., Wertheim, J. A. & Wyss, A. R. 2008. Chronologic implications of new Miocene mammals from the Cura–Mallín and Trapa–Trapa Formations, Laguna del Laja area, south Central Chile. *Journal of South American Earth Sciences*, **26**, 412–423.

Fock, A., Charrier, R., Farías, M. & Muñoz, M. 2006. Fallas de vergencia Oeste en la Cordillera Principal de Chile Central: inversión de la cuenca de Abanico (33°–34°S). *In*: Hongn, F., Becchio, R. & Seggiario, R. (eds) *XII Reunión sobre microtectónica y geología estructural*. Revista de la Asociación Geológica Argentina, Serie D, Publicación Especial, Buenos Aires, Argentina, **9**, 48–55.

Folguera, A. & Ramos, V. A. 2011. Repeated eastward shifts of arc magmatism in the Southern Andes: a revision to the long-term patter of Andean uplift and magmatism. *Journal of South American Earth Sciences*, **32**, 531–546, http://dx.doi.org/10.1016/j.jsames.2011.04.003

Frutos, J. 1981. Andean tectonic as consequence of sea-floor spreading. *Tectonophysics*, **72**, 21–32.

Fuentes, F. 2004. *Petrología y metamorfismo de muy bajo grado de unidades volcánicas oligo-miocenas en la ladera occidental de los Andes de Chile Central (33°S)*. PhD thesis, Universidad de Chile.

Fuentes, F., Féraud, G., Aguirre, L. & Morata, D. 2001. Convergent strategy to date metamorphic minerals in subgreenschit facies metabasites by the $^{40}Ar/^{39}Ar$ method. *In*: *III South American Symposium on Isotope Geology*. Pucón, Chile, electronic abstracts, 34–36.

Fuentes, F., Féraud, G., Aguirre, L. & Morata, D. 2005. ^{40}Ar/^{39}Ar dating of volcanism and subsequent very low-grade metamorphism in a subsiding basin: example of the Cretaceous lava series from central Chile. *Chemical Geology*, **214**, 157–177.

Fuenzalida, H. 1940. Algunos afloramientos Paleozoicos de la desembocadura del Choapa. *Boletín del Museo Nacional de Historia Natural*, **28**, 37–64.

Fuenzalida, H., Cooke, R., Paskoff, R., Segerstrom, K. & Weischet, W. 1965. High stands of Quaternary sea level along the Chilean coast. *In*: Wright, H. E. & Frey, D. (eds) *International Studies on the Quaternary*. *Papers Prepared on the Occasion of the VII Congress of the International Association for Quaternary Research Boulder*, Colorado. Geological Society of America, Boulder, CO, Special Papers, **84**, 473–496.

Gallego, A. 1994. *Paleoambiente y mecanismo de depositación de la secuencia sedimentaria que aflora en el sector de Polpaico, Región Metropolitana, Chile*. Thesis, Departamento de Geología, Universidad de Chile, Santiago.

Gana, P. 1991. Magmatismo bimodal del Triásico Superior – Jurásico Inferior, en la Cordillera de la Costa, Provincias de Elqui y Limarí, Chile. *Revista Geológica de Chile*, **18**, 55–67.

Gana, P. & Tosdal, R. M. 1996. Geocronología U–Pb y K–Ar en intrusivos del Paleozoico y Mesozoico de la Cordillera de la Costa, región de Valparaíso, Chile. *Revista Geológica de Chile*, **23**, 151–164.

Gana, P. & Wall, R. 1997. Evidencias geocronológicas 40Ar/39Ar y K–Ar de un hiatus Cretácico Superior-Eoceno en Chile Central (33°–33°30′ S). *Revista Geológica de Chile*, **24**, 145–163.

Gana, P. & Zentilli, M. 2000. Historia termal y exhumación de intrusivos de la Cordillera de la Costa de Chile central. *In*: *IX Congreso Geológico Chileno*. Puerto Varas, Actas, **2**, 664–668.

García, C. 1991. *Geología del sector de quebrada El Teniente, Región de Coquimbo*. Thesis, Departamento de Geología, Universidad de Chile.

García-Sansegundo, J., Farías, P., Rubio-Ordóñez, A. & Heredia, N. 2014*a*. The Palaeozoic basement of the Andean Frontal Cordillera at 34° S (Cordón del Carrizalito, Mendoza Province, Argentina): geotectonic implications. *Journal of Iberian Geology*, **40**, 321–330. http://dx.doi.org/10.5209/rev_JIGE.2014.v40.n2.45299.

García-Sansegundo, J., Farias, P., Heredia, N., Gallastegui, G., Charrier, R., Rubio-Ordóñez, A. & Cuesta, A. 2014*b*. Structure of the Andean Paleozoic basement in the Chilean coast at 31° 30′ S: geodynamic evolution of a subduction margin. *Journal of Iberian Geology*, **40**, 293–308. http://dx.doi.org/10.5209/rev_JIGE.2014.v40.n2.45300

Gerbi, C., Roeske, S. M. & Davis, J. S. 2002. Geology and structural history of the southwest Precordillera margin, northern Mendoza Province, Argentina. *Journal of South American Earth Sciences*, **14**, 821–835.

Giambiagi, L. & Martínez, A. N. 2008. Permo-Triassic oblique extension in the Uspallata–Potrerillos area, western Argentina. *Journal of South American Earth Sciences*, **26**, 252–260.

Giambiagi, L., Mescua, J., Bechis, F., Martínez, A. & Folguera, A. 2011. Pre-Andean deformation of the Precordillera southern sector, Southern Central Andes. *Geosphere*, **7**, 219–239.

Giambiagi, L., Tassara, A. *et al.* 2014. Evolution of shallow and deep structures along the Maipo – Tunuyán transect (33°40′S): from the Pacific coast to the Andean foreland. *In*: Sepúlveda, S. A., Giambiagi, L. B., Moreiras, S. M., Pinto, L., Tunik, M., Hoke, G. D. & Farías, M. (eds) *Geodynamic Processes in the Andes of Central Chile and Argentina*. Geological Society, London, Special Publications, **399**. First published online February 27, 2014, http://dx.doi.org/10.1144/SP399.14

Giambiagi, L. B., Ramos, V. A., Godoy, E., Álvarez, P. P. & Orts, S. 2003*a*. Cenozoic deformation and tectonic style of the Andes, between 33° and 34° South Latitude. *Tectonics*, **22**, 1041–1051.

Giambiagi, L. B., Alvarez, P. P., Godoy, E. & Ramos, V. A. 2003*b*. The control of pre-existing extensional structures on the evolution of the southern sector of the Aconcagua fold and thrust belt, Southern Andes. *Tectonophysics*, **369**, 1–19.

Glodny, J., Lohrmann, J., Echtler, H., Gräfe, K., Seifert, W., Collao, S. & Figueroa, O. 2005. Internal dynamics of a paleoaccretionary wedge: insights from combined isotope tectonochronology and sandbox modelling of the south-central Chilean fore-arc. *Earth and Planetary Science Letters*, **231**, 23–39.

Glodny, J., Echtler, H. *et al.* 2006. Long-term geological evolution and mass flow balance of the South-Central Andes. *In*: Oncken, O., Chong, G., Franz, G., Giese, P., Götze, H. J., Ramos, V., Strecker, M. & Wigger, P. (eds) *The Andes – Active Subduction Orogeny*. Frontiers in Earth Sciences, Springer, Berlin, **1**, 401–442.

Glodny, J., Echtler, H., Collao, S., Ardiles, M., Burón, P. & Figueroa, O. 2008. Differential Late Paleozoic active margin evolution in South-Central Chile (37°S–40°S) – the Lanalhue Fault Zone. *Journal of South American Earth Sciences*, **26**, 397–411.

Godoy, E. 1982. Geología del área de Montenegro, Cuesta de Chacabuco, Región Metropolitana. El problema de la Formación Lo Valle. *In*: *II Congreso Geológico Chileno*, Concepción, **1**, A124–A146.

Godoy, E. 2011. Structural setting and diachronism in the Central Andean Eocene to Miocene volcano-tectonic basins. *In*: Salfity, J. A. & Marquillas, R. A. (eds) *Cenozoic Geology of the Central Andes of Argentina*. SCS, Salta, Argentina, 155–167.

Godoy, E. & Charrier, R. 1991. Antecedentes mineralógicos para el origen de las metabasitas y metacherts del Complejo Metamórfico del Choapa (Región de Coquimbo, Chile): un prisma de acreción Paleozoico Inferior. *In*: *VI Congreso Geológico Chileno*, Viña del Mar, Actas, 410–414.

Godoy, E. & Lara, L. 1994. Segmentación estructural andina a los 33°–34°: nuevos datos en la Cordillera Principal. *In*: *VII Congreso Geológico Chileno*, Concepción, **2**, 1344–1348.

Gómez, R. 2001. *Geología de las unidades volcanogénicas cenozoicas del área industrial de la Mina El Teniente, entre Colón y Coya, Cordillera Principal* *de Rancagua, VI Región*. Thesis, Departamento de Geología, Universidad de Chile.

González, O. 1963. Observaciones geológicas en el valle del Río Volcán. *Revista Minerales*, **17**, 20–61.

González, O. & Vergara, M. 1962. *Reconocimiento geológico de la Cordillera de los Andes entre los paralelos 35° y 38° latitud S*. Instituto de Geología, Universidad de Chile, Santiago, Publicación, **24**.

González-Bonorino, F. 1970. Series metamórficas del basamento cristalino de la Cordillera de la Costa de Chile Central. Departamento de Geología, Universidad de Chile. *Publicaciones*, **37**, 1–68.

González-Bonorino, F. 1971. Metamorphism of the crystalline basement of Central Chile. *Journal of Petrology*, **12**, 149–175.

González-Bonorino, F. & Aguirre, L. 1970. Metamorphic facies series of the crystalline basement of Chile. *Geologische Rundschau*, **59**, 979–993.

González-Menéndez, L., Gallastegui, G., Cuesta, A., Heredia, N. & Rubio-Ordóñez, A. 2013. Petrogenesis of Early Paleozoic basalts and gabbros in the western Cuyania terrane: constraints on the tectonic setting of the southwestern Gondwana margin (Sierra del Tigre, Andean Argentine Precordillera). *Gondwana Research*, **24**, 359–376.

Gordillo, C. E. 1984. Migmatitas cordieríticas de la Sierra de Córdoba, condiciones físicas de la migmatización. Academia Nacional de Ciencias. *Miscelánea*, **68**, 1–40.

Gregori, D. & Benedini, L. 2013. The Cordon del Portillo Permian magmatism, Mendoza, Argentina, plutonic and volcanic sequences at the western margin of Gondwana. *Journal of South American Earth Sciences*, **42**, 61–73.

Gregori, D. A., Fernández-Turiel, J. L., López-Soler, A. & Petford, N. 1996. Geochemistry of Upper Palaeozoic–Lower Triassic granitoids of the Central Frontal Cordillera (33°10′–33°45′), Argentina. *Journal of South American Earth Sciences*, **9**, 141–151.

Groeber, P. 1918. Estratigrafía del Dogger en la República Argentina. Estudio sintético comparativo. *Dirección General de Minas, Geología e Hidrogeología, Boletín*, **18**, Serie B (Geología), 1–81.

Groeber, P. 1922. Pérmico y Triásico en la costa de Chile. *Revista de la Sociedad Argentina de Ciencias Naturales*, **5**, 979–994.

Groeber, P. 1946. Observaciones geológicas a lo largo del meridiano 70°. 1, Hoja Chos Malal. *Revista de la Asociación Geológica Argentina*, **1**, 117–208. Reprint in Asociación Geológica Argentina, Serie C, Reimpresiones (1980) 1, 1–174.

Groeber, P. 1951. La Alta Cordillera entre las latitudes 34° y 29°30′. Instituto Investigaciones de las Ciencias Naturales. *Revista del Museo Argentino de Ciencias Naturales Bernardino Rivadavia (Ciencias Geológicas)*, **1**, 1–352.

Groeber, P. 1953. Mesozoico. *Geografía de la República Argentina, Sociedad Argentina de Estudios Geográficos GAEA, Buenos Aires*, **2**, 9–541.

Gromet, L. P. & Simpson, C. 2000. Cambrian orogeny in the Sierras Pampeanas, Argentina: ridge subduction or continental collision? *Geological Society of America Abstracts with Programs*, **32**, A-505.

Grosse, P., Söllner, F., Báez, M. A., Toselli, A. J., Rossi, J. N. & Rosa, J. D. 2009. Lower Carboniferous post-orogenic granites in central-eastern Sierra de Velasco, Sierras Pampeanas, Argentina: U–Pb monazite geochronology, geochemistry and Sr–Nd isotopes. *International Journal of Earth Sciences*, **98**, 1001–1025.

Gudnason, J., Holm, P. M., Søager, N. & Llambías, E. J. 2012. Geochronology of the late Pliocene to recent volcanic activity in the Payenia back-arc volcanic province, Mendoza, Argentina. *Journal of South American Earth Sciences*, **37**, 191–201.

Gulbranson, E. L., Montañez, I. P., Schmitz, M. D., Limarino, C. O., Isbell, J. L., Marenssi, S. A. & Crowley, J. L. 2010. High-precision U–Pb calibration of Carboniferous glaciation and climate history, Paganzo Group, NW Argentina. *Geological Society of America Bulletin*, **122**, 1480–1498.

Gutiérrez, N. M., Hinojosa, L. F., Le Roux, J. P. & Pedroza, V. 2013. Evidence for an Early–Middle Miocene age of the Navidad Formation (central Chile): paleontological, paleoclimatic and tectonic implications. *Andean Geology*, **40**, 66–78.

Hallam, A., Biró-Bagóczky, L. & Pérez, E. 1986. Facies analysis of the Valdés Formation (Tithonian–Hauterivian) of the High Cordillera of Central Chile, and the Paleogeographic evolution of the Andean Basin. *Geological Magazine*, **123**, 425–435.

Haller, M. J. & Ramos, V. A. 1984. Las ofiolitas famatinianas (Eopaleozoico) de las provincias de San Juan y Mendoza. *In*: *IX Congreso Geológico Argentino*, Bariloche, 66–83.

Haller, M. J. & Ramos, V. A. 1993. Las ofiolitas y otras rocas afines. *In*: Ramos, V. A. (ed.) *Geología y Recursos Naturales de Mendoza. Relatorio XII Congreso Geológico Argentino y II Congreso de Exploración de Hidrocarburos*. Buenos Aires, 31–40.

Heredia, N., Fernández, L. R. R., Gallastegui, G., Busquets, P. & Colombo, F. 2002. Geological setting of the Argentine Frontal Cordillera in the flat-slab segment (30° 00′–31° 30′ S latitude). *Journal of South American Earth Sciences*, **15**, 79–99.

Heredia, N., Farias, P., García-Sansegundo, J. & Giambiagi, L. 2012. The Basement of the Andean Frontal Cordillera in the Cordón del Plata (Mendoza, Argentina): geodynamic evolution. *Andean Geology*, **39**, 242–257.

Hervé, F. 1977. Petrology of the Crystalline Basement of the Nahuelbuta Mountains, Southcentral Chile. *In*: Ishikawa, T. & Aguirre, L. (eds) *Comparative Studies on the Geology of the Circum Pacific Orogenic Belt in Japan and Chile*. Japan Society for the Promotion of Science, Tokyo, 1–51.

Hervé, F. 1988. Late Palaeozoic subduction and accretion in Southern Chile. *Episodes*, **11**, 183–188.

Hervé, F., Munizaga, F., Godoy, E. & Aguirre, L. 1974. Late Paleozoic K/Ar ages of blueschists from Pichilemu, Central Chile. *Earth and Planetary Science Letters*, **23**, 261–264.

Hervé, F., Kawashita, K., Munizaga, F. & Basei, M. 1984. Rb–Sr isotopic ages from late Paleozoic metamorphic rocks of Central Chile. *Journal of the Geological Society London*, **141**, 877–884.

Hervé, F., Munizaga, F., Parada, M. A., Brook, M., Pankhurst, R. J., Snelling, N. J. & Drake, R. 1988. Granitoids of the Coast Range of central Chile: geochronology and geologic setting. *Journal of South American Earth Sciences*, **1**, 185–194.

Hervé, F., Fanning, C. M. & Pankhurst, R. J. 2003. Detrital zircon age patterns and provenance of the metamorphic complexes of southern Chile. *Journal of South American Earth Sciences*, **16**, 107–123.

Hervé, F., Faúndez, V., Calderón, M., Massonne, H.-J. & Willner, A. P. 2007. Metamorphic and plutonic basement complexes. *In*: Moreno, T. & Gibbons, W. (eds) *The Geology of Chile*. Geological Society, London, 5–20.

Hervé, F., Calderón, M., Fanning, C. M., Pankhurst, R. J. & Godoy, E. 2013. Provenance variations in the Late Paleozoic accretionary complex of central Chile as indicated by detrital zircons. *Gondwana Research*, **23**, 1122–1135.

Hervé, F., Fanning, C. M., Calderón, M. & Mpodozis, C. 2014. Early Permian to Late Triassic batholiths of the Chilean Frontal Cordillera (28°–31°S): SHRIMP U–Pb zircon ages and Lu–Hf and O isotope systematics. *Lithos*, **184–187**, 436–446.

Hildreth, W., Singer, B., Godoy, E. & Munizaga, F. 1998. The age and constitution of Cerro Campanario, a mafic stratovolcano in the Andes of Central Chile. *Revista Geológica de Chile*, **25**, 17–28.

Iannizzotto, N. F., Rapela, C. W., Baldo, E. G. A., Galindo, C., Fanning, C. M. & Pankhurst, R. J. 2013. The Sierra Norte–Ambargasta batholith: Late Ediacaran–Early Cambrian magmatism associated with Pampean transpressional tectonics. *Journal of South American Earth Sciences*, **42**, 127–143.

Irigoyen, M. V., Buchan, K. L. & Brown, R. L. 2000. Magnetostratigraphy of Neogene Andean foreland-basin strata, lat 33°S, Mendoza Province, Argentina. *Geological Society of America Bulletin*, **112**, 803–816.

Irwin, J. J., García, C., Hervé, F. & Brook, M. 1988. Geology of part of a long-lived dynamic plate margin – the Coastal Cordillera of north-central Chile, latitude 30°51′–31°S. *Canadian Journal of Earth Sciences*, **25**, 603–624.

Isacks, B. L. 1988. Uplift of the Central Andean Plateau and bending of the Bolivian Orocline. *Journal of Geophysical Research*, **93**, 3211–3231.

James, D. E. 1971. Plate tectonic model for the evolution of the Central Andes. *Geological Society of America Bulletin*, **82**, 3325–3346.

Jara, P. & Charrier, R. 2014. Nuevos antecedentes geocronológicos y estratigráficos para la Alta Cordillera de Chile central a ~32°10'S. Implicancias paleogeográficas y estructurales. *Andean Geology*, **41**, 174–209, http://dx.doi.org/10.5027/andgeoV41n1-a07

Jara, P., Likerman, J., Winocur, D., Guiglione, M. C., Cristallini, E. O., Pinto, L. & Charrier, R. 2014. Role of basin width variation in tectonic inversion: insight from analogue modelling and implications for the tectonic inversion of the Abanico Basin, 32°–34°S, Central Andes. *In*: Sepúlveda, S. A., Giambiagi, L. B., Moreiras, S. M., Pinto, L., Tunik, M., Hoke, G. D. & Farías, M. (eds) *Geodynamic Processes in the Andes of Central Chile and Argentina*. Geological Society, London, Special Publications, **399**. First published online February 27, 2014, http://dx.doi.org/10.1144/SP399.7

Jaros, J. & Zelman, J. 1967. *La relación estructural entre las formaciones Abanico y Farellones en la Cordillera del Mesón, Provincia de Aconcagua, Chile*. Departamento de Geología, Universidad de Chile, Santiago de Chile, **34**.

Jordan, T., Isacks, B., Ramos, V. A. & Allmendinger, R. W. 1983*a*. Mountain building model: the Central Andes. *Episodes*, **1983**, 20–26.

Jordan, T. E., Isacks, B. L., Allmendinger, R. W., Brewer, J. A., Ramos, V. A. & Ando, C. J. 1983*b*. Andean tectonics related to geometry of subducted Nazca plate. *Geological Society of America Bulletin*, **94**, 341–361.

Jordan, T. E., Reynolds Iii, J. H. & Enkson, J. P. 1997. Variability in age of initial shortening and uplift in the central Andes, 16–33°30 S. *In*: Ruddiman, W. (ed.) *Tectonic Uplift and Climate Change*. Plenum, New York, 41–61.

Jordan, T. E., Burns, W. M., Veiga, R., Pangaro, F., Copeland, P., Kelley, S. & Mpodozis, C. 2001. Extension and basin formation in the southern Andes caused by increased convergence rate: a Mid-Cenozoic trigger for the Andes. *Tectonics*, **20**, 308–324.

Kato, T. & Godoy, E. 1995. Petrogenesis and tectonic significance of late Paleozoic coarse-crystalline blueschist and amphibolite boulders in the Coastal Range of Chile. *International Geology Review*, **37**, 992–1006.

Kay, S. M. & Abbruzzi, J. M. 1996. Magmatic evidence for Neogene lithospheric evolution of the Central Andean flat-slab between 30 and 32°S. *Tectonophysics*, **259**, 15–28.

Kay, S. M., Ramos, V., Mpodozis, C. & Sruoga, P. 1989. Late Paleozoic to Jurassic silicic magmatism at the Gondwana margin: analogy to the Middle Proterozoic in North America. *Geology*, **17**, 324–328.

Kay, S. M., Mpodozis, C., Ramos, V. A. & Munizaga, F. 1991. Magma source variations for mid to late Tertiary volcanic rocks erupted over a shallowing subduction zone and through a thickening crust in the Main Andean Cordillera (28–33°S). *In*: Harmon, R. S. & Rapela, C. W. (eds) *Andean Magmatism and its Tectonic Setting*. Geological Society of America, Boulder, CO, Special Papers, **265**, 113–137.

Keller, M. 1999. *Argentine Precordillera, sedimentary and plate tectonic history of a Laurentian crustal fragment in South America*. Geological Society of America, Boulder, CO, Special Papers, **341**, 1–131.

Kleiman, L. E. & Japas, M. S. 2009. The Choiyoi volcanic province at 34°S–36°S (San Rafael, Mendoza, Argentina): implications for the Late Palaeozoic evolution of the southwestern margin of Gondwana. *Tectonophysics*, **473**, 283–299.

Klohn, C. 1960. Geología de la Cordillera de los Andes de Chile Central, provincia de Santiago, O'Higgins, Colchagua y Curicó. *Instituto Investigaciones Geológicas Boletín*, **8**, 1–95.

Kokogián, D. A., Fernández-Seveso, F. & Mosquera, A. 1993. Las secuencias sedimentarias triásicas. *In*: *9° Congreso Geológico Argentino*. Mendoza, Relatorio, 65–78.

Kokogián, D. A., Spalletti, L. *et al.* 1999. Depósitos continentales triásicos. *In*: Caminos, R. (ed.) *Geología Argentina*. Servicio Geológico Minero Argentino, Buenos Aires, Argentina, Anales, **29**, 377–397.

Kraemer, P., Escayola, M. & Martino, R. 1995. Hipótesis sobre la evolución tectónica neoproterozoica de las Sierras Pampeanas de Córdoba (30°40′–32°40′S), Argentina. *Revista de la Asociación Geológica Argentina*, **50**, 47–59.

Lanés, L. 2005. Late Triassic to Early Jurassic sedimentation in northern Neuquén Basin, Argentina: tectono sedimentary evolution of the first trangression. *Geológica Acta*, **3**, 81–106.

Larson, R. L. 1991. Geological consequences of superplumes. *Geology*, **19**, 963–966.

Leal, P. R., Hartmann, L. A., Santos, O., Miró, R. & Ramos, V. A. 2004. Volcanismo postorogénico en el extremo norte de las Sierras Pampeanas Orientales: nuevos datos geocronológicos y sus implicancias tectónicas. *Revista de la Asociación Geológica Argentina*, **58**, 593–607.

Legarreta, L., Kokogian, D. A. & Dellape, D. A. 1992. Estructuración terciaria de la cuenca Cuyana: ¿Cuánto de inversión tectónica? *Revista Asociación Geología Argentina*, **47**, 83–86.

Legarreta, L., Gulisano, C. A. & Uliana, M. A. 1993. Las secuencias sedimentarias jurásico-cretácicas. *In*: Ramos, V. A. (ed.) *Relatorio Geología y Recursos Naturales de Mendoza. XII Congreso Geológico Argentino y II Congreso de Exploración de Hidrocarburos*, Buenos Aires, 87–114.

Letelier, M. 1977. *Petrología y ambiente de depositación y estructura de las Formaciones Matahuaico, Las Breas, Tres Cruces sensu lato e intrusivos permotriásicos en el área de Rivadavia-Alcohuás, vallede Elqui, IV Región, Chile*. Thesis, Departamento de Geología, Universidad de Chile.

Levi, B. & Aguirre, L. 1960. El Conglomerado de Algarrobo y su relación con las formaciones de Cretçacico Superior de Chile central. *I Jornadas Geológicas Argentinas*, **2**, 417–431.

Levi, B., Aguirre, L., Nyström, J., Padilla, H. & Vergara, M. 1989. Low-grade regional metamorphism in the Mesozoic–Cenozoic volcanic sequences of the Central Andes. *Journal of Metamorphic Petrology*, **7**, 487–495.

Limarino, C. O. & Spalletti, L. A. 2006. Paleogeography of the upper Paleozoic basins of southern South America: an overview. *Journal of South American Earth Sciences*, **22**, 134–155.

Limarino, C. O., Tripaldi, A., Marenssi, S. & Fauqué, L. 2006. Tectonic, sea-level, and climatic controls on Late Paleozoic sedimentation in the western basins of Argentina. *Journal of South American Earth Sciences*, **22**, 205–226.

Limarino, C. O., Césari, S. N., Spalletti, L. A., Taboada, A. C., Isbell, J. L., Geuna, S. & Gulbranson, E. L. 2013. A paleoclimatic review of southern South America during the late Paleozoic: a record from icehouse to extreme greenhouse conditions. *Gondwana Research*, **25**, 1396–1421.

Lira, R., Millone, H. A., Kirschbaum, A. M. & Moreno, R. S. 1996. Calc-alkaline arc granitoid activity in the Sierra Norte-Ambargasta Ranges, central Argentina. *Journal of South American Earth Sciences*, **10**, 157–177.

Llambías, E. J. 1999. Las rocas ígneas gondwánicas. El magmatismo gondwánico durante el Paleozoico Superior-Triásico. *In*: Caminos, R. (ed.) *Geología Argentina*. Instituto de Geología y Recursos Minerales, Buenos Aires, Argentina, Anales, **29**, 349–363.

Llambías, E. J. & Sato, A. M. 1995. El Batolito de Colangüil: transición entre orogénesis y anorogénesis. *Revista de la Asociación Geológica Argentina*, **50**, 111–131.

Llambías, E. J., Kleiman, L. E. & Salvarredi, J. A. 1993. El magmatismo gondwánico. *In*: Ramos, V. A. (ed.) *Geología y Recursos Naturales de Mendoza. Relatorio XII Congreso Geológico Argentino and II Congreso de exploración de Hidrocarburos*. Mendoza, **I**, 53–64.

Llambías, E. J., Quenardelle, S. & Montenegro, T. 2003. The Choiyoi Group from central Argentina: a subalkaline transitional to alkaline association in the craton adjacent to the active margin of the Gondwana continent. *Journal of South American Earth Sciences*, **16**, 243–257.

Llambías, E. J., Bertotto, G. W., Risso, C. & Hernando, I. 2010. El volcanismo cuaternario en el retroarco de Payenia: una revisión. *Revista de la Asociación Geológica Argentina*. Zurich, **67**, 278–300.

Lo Forte, G. L., Anselmi, G. & Aguirre-Urreta, M. B. 1996. Tithonian Paleogeography of the Aconcagua Basin, West-Central Andes of Argentina. *In*: Riccardi, A. C. (ed.) *Advances in Jurassic Research, Geo-Research Forum*, Transtec Publications, Zurich, **1–2**, 369–376.

López, V. & Gregori, D. A. 2004. Provenance and evolution of the Guarguaraz Complex, Cordillera Frontal, Argentina. *Gondwana Research*, **7**, 1197–1208.

López Gamundi, O. 1994. Facies distribution in an asymmetric half graben: the northern Cuyo Basin (Triassic), western Argentina. *In*: *XIV International Sedimentological Congress*, Recife, Abstract, 6–7.

López Gamundi, O. R., Espejo, I., Conaghan, P. J. & Powell, C. McA. 1994. Southern South America. *In*: Veevers, J. J. & Powell, C. McA. (eds) *Permian Triassic Pangean Basins and Foldbelts Along the Panthalassan Margin of Gondwanaland*. Geological Society of America, Boulder, CO, Memoirs, **184**, 281–329.

MacPhail, D. D. 1966. El gran lahar del Laja. *Estudios Geográficos*. Departamento de Geografía, Universidad de Chile, Santiago, 133–155.

MacPhail, D. D. & Saa, R. 1967. Los Cerrillos de Teno: a laharic landscape of Central Chile. *Annals of the Association of American Geographers*, **59**, 171.

Maksaev, V., Munizaga, F., Mcwilliams, M., Fanning, M., Mathur, R., Ruiz, J. & Zentilli, M. 2004. New chronology for El Teniente, Chilean Andes, from U/Pb, ^{40}Ar/^{39}Ar, Re/Os and fission-track dating: implications for the evolution of a supergiant porphyry Cu-Mo deposit. *In*: Sillitoe, R. H., Perelló, J. & Vidal, C. E. (eds) *Andean Metallogeny: New Discoveries, Concepts, Update*. Society of Economic Geologists, Littleton, CO, Special Publications, **11**, 15–54.

Malbran, F. 1986. *Estudio geológico-estructural del área de río Clarillo, con énfasis en la Formación Coya-Machalí, hoya del río Tinguiririca, Chile*. Thesis, Departamento de Gelogía, Universidad de Chile, Santiago.

Malumián, N. & Ramos, V. A. 1984. Magmatic intervals, transgression–regression cycles and oceanic events in the Cetraceous and Tertiary of souther South America. *Earth and Planetary Science Letters*, **67**, 228–237.

Manceda, R. & Figueroa, D. 1995. Inversion of the Mesozoic Neuquén rift in the Malargüe fold–thrust belt, Mendoza, Argentina. *In*: Tankard, A. J., Suarez, R. & Welsink, H. J. (eds) *Petroleum Basins of South America*. American Association of Petroleum Geologists, Tulsa, OK, Memoirs, **62**, 369–382.

Mángano, M. G. & Buatois, L. A. 1996. Shallow marine event sedimentation in a volcanic arc-related setting: the Ordovician Suri Formation, Famatina Range, northwest Argentina (Famatina System). *Sedimentary Geology*, **105**, 63–90.

Marangunic, C., Moreno, H. & Varela, J. 1979. Observaciones sobre los depósitos de relleno de la Depresión Longitudinal de Chile entre los ríos Tinguiririca y Maule. *In*: *II Congreso Geológico Chileno*, Arica, **3**, J129–J139.

Mardonez, D., Velásquez, R., Merino, R. & Bonilla, R. 2012. Caracterización y condiciones de metamorfismo de una nueva unidad dentro del paleozoico de la Cordillerea de la Costa (Unidad Patagual – El Venado), Región de Biobío, Chile. *In*: *XIII Congreso Geológico Chileno*, Antofagasta, 365–367.

Martin, M., Clavero, J. & Mpodozis, C. 1997. Eocene to Late Miocene magmatic development of the El Indio Belt, ~30°S, north central Chile. *In*: *VIII Congreso Geológico Chileno*, Antofagasta, **1**, 149–153.

Martin, M. W., Clavero, J. & Mpodozis, C. 1999. Late Paleozoic to Early Jurassic tectonic development of the high Andean Principal Cordillera, El Indio region, Chile (29°–30°S). *Journal of South American Earth Sciences*, **12**, 33–49.

Martina, F., Viramonte, J. M., Astini, R. A., Pimentel, M. M. & Dantas, E. 2011. Mississippian volcanism in the southern Central Andes: new U–Pb SHRIMP zircon geochronology and whole-rock geochemistry. *Gondwana Research*, **19**, 524–544.

Martínez, A. N. 2005. *Secuencias volcánicas Permo-Triásicas de los cordones del Portillo y del Plata, Cordillera Frontal, Mendoza: su interpretación tectónica*. PhD thesis, Universidad de Buenos Aires.

Martínez, A. N., Rodríguez Blanco, L. & Ramos, V. A. 2006. Permo-Troassic magmatism of the Choiyoi Group in the Cordillera Frontal of Mendoza, Argentina: geological variations associated with changes in Paleo-Benioff zone. *In*: *Backbone of the Americas*. Asociación Geológica Argentina and Geological Society of America, Mendoza, Argentina, Abstracts with Programs, 77.

Martino, R. D. 2003. Las fajas de deformación dúctil de las Sierras Pampeanas de Córdoba: Una reseña general. *Revista de la Asociación Geológica Argentina*, **58**, 549–571.

Martinod, J., Husson, L., Rosperch, P., Guillaume, B. & Espurt, N. 2010. Horizontal subduction zones, convergence velocity and the building of the Andes. *Earth and Planetary Science Letters*, **299**, 299–309.

Méndez-Bedia, I., Charrier, R., Busquets, P. & Colombo, F. 2009. Barras litorales carbonatadas en el Paleozoico Superior Andino (Formación Huentelauquén, Norte Chico, Chile). *In*: *XII Congreso Geológico Chileno*, Santiago, Actas, 1–4.

Mescua, J. F. 2011. *Evolución estructural de la Cordillera Principal entre Las Choicas y santa Elenea (35° S), Provinciade Mendoza, Argentina*. PhD thesis, Departamento de Ciencias Geológicas, Universidad de Buenos Aires.

Mescua, J. F., Giambiagi, L. B. & Bechis, F. 2008. Evidencias de tectónica extensional en el Jurásico Tardío (Kimeridgiano) del suroeste de la provincia de Mendoza. *Revista de la Asociación Geológica Argentina*, **63**, 512–519.

Milana, J. P. 1998. Anatomía de parasecuencias en un lago de rift y su relación con la generación de hidrocarburos, cuenca triásica de Ischigualasto, San Juan. *Revista de la Asociación Geológica Argentina*, **53**, 365–387.

Milana, J. P. & Alcober, O. 1994. Modelo tectosedimentario de la cuenca triásica de Ischigualasto (San Juan, Argentina). *Revista de la Asociación Geológica Argentina*, **49**, 217–235.

Minato, M. & Tazawa, J. 1977. Fossils of the Huentelauquén Formation at the locality F, Coquimbo Province, Chile. *In*: Ishikawa, T. & Aguirre, L. (eds) *Comparative Studies of the Circum-Pacific Orogenic Belt in Japan and Chile*. First Report. Japan Society for the Promotion of Science, Tokyo, 95–117.

Morata, D. & Aguirre, L. 2003. Extensional Lower Cretaceous volcanism in the Coastal Range (29°20′–30°S), Chile: geochemistry and petrogenesis. *Journal of South American Earth Sciences*, **16**, 459–476.

Morata, D., Féraud, G., Aguirre, L., Arancibia, G., Belmar, M., Morales, S. & Carrillo, J. 2008. Geochronology of the Lower Cretaceous volcanism from the Coastal Range (29°20′–30°S), Chile. *Revista Geológica de Chile*, **35**, 123–145.

Morata, D., Varas, M. J., Higgins, M., Valencia, V. & Verhoort, J. 2010. Episodic emplacement of the Illapel Plutonic Complex (Coastal Cordillera, central Chile): Sr and Nd isotopic, and zircon U–Pb geochronological constraints. *In*: *South American Symposium on Isotope Geology*, *7*, Brasilia, http://refhub.elsevier.com/S0895-9811(1300169-7/sref26)

Morel, R. 1981. *Geología del sector Norte de la hoja Gualleco, entre los 35° 00' y 35° 10' lat. Sur, Provincia de Talca, VII Región, Chile*. Thesis, Departamento de Geología, Universidad de Chile.

Moreno, K. & Benton, M. J. 2005. Occurrence of sauropod dinosaur tracks in the Upper Jurassic of Chile (redescription of *Iguanodonichnus frenki*). *Journal of South American Earth Sciences*, **20**, 253–257.

Moreno, K. & Pino, M. 2002. Huellas de dinosaurios en la Formación Baños del Flaco (Titoniano-Jurásico Superior), VI Región, Chile: paleoetología y paleoambiente. *Revista Geológica de Chile*, **29**, 191–206.

Moscoso, R., Padilla, H. & Rivano, S. 1982. *Hoja Los Andes, Región de Valparaiso*. Servicio Nacional de Geología y Minería, Santiago, Carta Geológica de Chile, **52**.

Mpodozis, C. & Cornejo, P. 1988. *Carta Geológica de Chile, hoja Pisco Elqui, IV Región de Coquimbo a* *escala 1: 250.000*. Servicio Nacional de Geología y Minería, Santiago de Chile, **68**.

Mpodozis, C. & Cornejo, P. 2012. Cenozoic tectonics and porphyry copper systems of the Chilean Andes. *In*: Hedenquist, J. W., Harris, M. & Camus, F. (eds) *Geology and Genesis of Major Copper Deposits and Districts of the World: A tribute to Richard H. Sillitoe*. Society of Economic Geologists, Littleton, CO, Special Publications, **16**, 329–360.

Mpodozis, C. & Kay, S. M. 1990. Provincias magmáticas ácidas y evolución tectónica de Gondwana: Andes chilenos (28–31°S). *Revista Geológica de Chile*, **17**, 153–180.

Mpodozis, C. & Kay, S. M. 1992. Late Paleozoic to Triassic evolution of the Gondwana margin: evidence from Chilean Frontal Cordilleran batholiths (28°S to 31°S). *Geological Society of America Bulletin*, **104**, 999–1014.

Mpodozis, C. & Ramos, V. A. 1989. The Andes of Chile and Argentina. *In*: Ericksen, G. E., Cañas Pinochet, M. T. & Reinemud, J. A. (eds) *Geology of the Andes and its Relation to Hydrocarbon and Mineral Resources*. Circumpacific Council for Energy and Mineral Resources, Houston, Earth Sciences Series, **11**, 59–90.

Mpodozis, C. & Ramos, V. A. 2008. Tectónica jurásica en Argentina y Chile: extensión, subducción oblicua, rifting, deriva y colisiones? *Revista de la Asociación Geológica Argentina*, **63**, 481–497.

Mpodozis, C., Brockway, H., Marquardt, C. & Perelló, J. 2009. Geocronología U/Pb y tectónica de la región Los Pelambres-Cerro Mercedario: implicancias para la evolución cenozoica de los Andes del centro de Chile y Argentina. *In*: *XII Congreso Geológico Chileno*, Santiago, electronic abstract.

Mundaca, P., Padilla, H. & Charrier, R. 1979. Geología del área comprendida entre Quebrada Angostura, Cerro Talinai y Punta Claditas, Provincia de Choapa. *In*: *II Congreso Geológico Chileno*, Arica, Actas, **1**, A121–A161.

Muñoz, J. & Niemeyer, H. 1984. *Hoja Laguna del Maule, Regiones del Maule y del Bio-Bio*. Servicio Nacional de Geología y Minería, Santiago, Carta, **64**.

Muñoz, M., Fuentes, F., Vergara, M., Aguirre, L., Nyström, J. O., Féraud, G. & Demant, A. 2006. Abanico East Formation: petrology and geochemistry of volcanic rocks behind the Cenozoic arc front in the Andean Cordillera, central Chile (33°50′S). *Revista Geológica de Chile*, **33**, 109–140.

Muñoz, M., Aguirre, L., Vergara, M., Demant, A., Fuentes, F. & Fock, A. 2010. Prehnite- pumpellyite facies metamorphism in the eastern belt of the Abanico Formation, Andean Cordillera of central Chile (33° 50′S): chemical and scale controls on mineral assemblages, reaction progress and the equilibrium state. *Andean Geology*, **37**, 54–77.

Muñoz, M., Farías, M., Charrier, R., Fanning, C. M., Polvé, M. & Deckart, K. 2013. Isotopic shifts in the Cenozoic Andean arc of central Chile: records of an evolving basement throughout cordilleran arc mountain building. *Geology*, **41**, 931–934.

Muñoz-Cristi, J. 1942. Rasgos generales de la construcción geológica de la Cordillera de la Costa; especialmente en la Provincia de Coquimbo. *In*: *Congreso Panamericano de Ingeniería de Minas y Geología*. Santiago, Chile, Anales, **1**, 285–318.

Muñoz-Cristi, J. 1946. Estado actual del conocimiento sobre la geología de la provincia de Arauco. *Anales Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile*, **3**, 30–63.

Muñoz-Cristi, J. 1956. Chile. *In*: Yenks, W. F. (ed.) *Handbook of South American Geology*. Geological Society of America, Boulder, CO, Memoirs, **65**, 187–214.

Muñoz-Cristi, J. 1968. Evolución geológica del territorio chileno. *Boletín de la Academia de Ciencias de Chile*, **1**, 18–26.

Muñoz-Cristi, J. 1973. *Geología de Chile: Pre-Paleozoico, Paleozoico y Mesozoico*. Editorial Andrés Bello, Santiago.

Muñoz-Saez, C., Pinto, L., Charrier, R. & Nalpas, T. 2014. Importance of volcanic load and shortcut fault development during inversion of the Abanico basin, Central Chile (33°–35°S). *Andean Geology*, **41**, 1–28.

Mutti, D. I. 1997. La secuencia ofiolítica basal desmembrada de las sierras de Córdoba. *Revista de la Asociación Geológica Argentina*, **52**, 275–285.

Naipauer, M., Vujovich, G. I., Cingolani, C. A. & McClelland, W. C. 2010*a*. Detrital zircon analysis from the Neoproterozoic–Cambrian sedimentary cover (Cuyania terrane), Sierra de Pie de Palo, Argentina: evidences of a rift and passive margin system. *Journal South American Earth Sciences*, **29**, 306–326.

Naipauer, M., Cingolani, C. A., Vujovich, G. I. & Chemale, F. 2010*b*. Geochemistry and Nd isotopic signatures of metasedimentary rocks of the Caucete Group, Sierra de Pie de Palo, Argentina: implications for their provenance. *Journal South American Earth Sciences*, **30**, 84–96.

Nasi, C. & Thiele, R. 1982. Estratigrafía del Jurásico y Cretácico de la Cordillera de la Costa al sur del rio Maipo, entre Melipilla y Laguna de aculeo (Chile Central). *Revista Geológica de Chile*, **16**, 81–99.

Nasi, C., Mpodozis, C., Cornejo, P., Moscoso, R. & Maksaev, V. 1985. El batolito Elqui-Limari (Paleozoico Superior-Triásico): características petrográficas, geoquímicas y significado tectónico. *Revista Geológica de Chile*, **25–26**, 77–111.

Nasi, C., Moscoso, R. & Maksaev, V. 1990. *Hoja Guanta, Regiones de Atacama y Coquimbo*. Servicio Nacional de Geología y Minería, Santiago.

Nielsen, S. 2005. The Triassic Santa Juana Formation at the lower Biobío River, south central Chile. *Journal of South American Earth Sciences*, **19**, 547–562.

Niemeyer, H. & Muñoz, J. 1983. *Geología de la Hoja Laguna de La Laja*. Servicio Nacional de Geología y Minería, Santiago, Serie Carta Geológica de Chile, **58**.

Oliveros, V., Morata, D., Aguirre, L., Féraud, G. & Fornari, G. 2007. Jurassic to Early Cretaceous subduction-related magmatism in the Coastal Cordillera of northern Chile (18°30′–24°S): geochemistry and petrogenesis. *Revista Geológica de Chile*, **34**, 209–232.

Oliveros, V., Labbé, M., Rossel, P., Charrier, R. & Encinas, A. 2012. Late Jurassic paleogeographic evolution of the Andean back-arc basin: new constrains from the Lagunillas Formation, northern Chile (27°30′–28°30′S). *Journal of South American Earth Sciences*, **37**, 25–40.

Orme, H. M. & Atherton, M. P. 1999. New U–Pb and Sr–Nd Data from the Frontal Cordillera Composite Batholith, Mendoza: implications for Magma Source and Evolution. *In*: *IV International Symposium on Andean Geology*, Göttingen, 555–558.

Ota, Y., Miyauchi, T., Paskoff, R. & Koba, M. 1995. Plio–Quaternary terraces and their deformation along the Altos de Talinay, North–Central Chile. *Revista Geológica de Chile*, **22**, 89–102.

Otamendi, J. E., Tibaldi, A. M., Vujovich, G. I. & Viñao, G. A. 2008. Metamorphic evolution of migmatites from the deep Famatinian arc crust exposed in Sierras Valle Fértil e La Huerta, San Juan, Argentina. *Journal of South American Earth Sciences*, **25**, 313–335.

Otamendi, J. E., Vujovich, G. I., de la Rosa, J. D., Tibaldi, A. M., Castro, A. & Martino, R. D. 2009*a*. Geology and petrology of a deep crustal zone from the Famatinian paleo-arc, Sierras Valle Fértil–la Huerta, San Juan, Argentina. *Journal of South American Earth Sciences*, **27**, 258–279.

Otamendi, J. E., Ducea, M. N., Tibaldi, A. M., Bergantz, G., de la Rosa, J. D. & Vujovich, G. I. 2009*b*. Generation of tonalitic and dioritic magmas by coupled partial melting of gabbroic and metasedimentary rocks within the deep crust of the Famatinian magmatic arc, Argentina. *Journal of Petrology*, **50**, 841–873.

Otamendi, J. E., Cristofolini, E., Tibaldi, A. M., Quevedo, F. & Baliani, I. 2010*a*. Petrology of mafic and ultramafic layered rocks from the Jaboncillo Valley, Sierra de Valle Fértil, Argentina: implications for the evolution of magmas in the lower crust of the Famatinian arc. *Journal of South American Earth Sciences*, **29**, 685–704.

Otamendi, J. E., Pinotti, L. P., Basei, M. A. S. & Tibaldi, A. M. 2010*b*. Evaluation of petrogenetic models for intermediate and silicic plutonic rocks from the Sierra de Valle Fértil-La Huerta, Argentina: petrologic constraints on the origin of igneous rocks in the Ordovician Famatinian-Puna paleoarc. *Journal of South American Earth Sciences*, **30**, 29–45.

Padilla, H. & Vergara, M. 1985. Control estructural y alteración de tipo campo geotérmico en los intrusivos subvolcánicos miocénicos del área de la Cuesta de Chacabuco-Baños del Corazón, Chile central. *Revista Geológica de Chile*, **24**, 3–17.

Pankhurst, R. J. & Rapela, C. W. 1998. The proto-Andean margin of Gondwana: an introduction. *In*: Pankhurst, R. J. & Rapela, C. W. (eds) *The Proto-Andean Margin of Gondwana*. Geological Society, London, Special Publications, **142**, 1–9.

Pankhurst, R. J., Millar, I. L. & Hervé, F. 1996. A Permo-Carboniferous U–Pb age for part of the Guanta Unit of the Elqui–Limari Batholith at Rio del Transito, Northern Chile. *Revista Geologica de Chile*, **23**, 35–42.

Parada, M. A., Rivano, S. & Sepúlveda, P. 1988. Mesozoic and Cainozoic plutonic development in the Andes of central Chile. *Journal of South American Earth Sciences*, **1**, 249–260.

Parada, M. A., Levi, B. & Nyström, J. 1991. Geochemistry of the Triassic to Jurassic plutonism of central Chile (30 to 33°S): petrogenetic implications and a tectonic discussion. *In*: Harmon, R. S. & Rapela, C. W. (eds) *Andean Magmatism and its Tectonic Setting*. Geological Society of America, Boulder, CO, Special Papers, **265**, 99–112.

Parada, M. A., Nystrom, J. O. & Levi, B. 1999. Multiple sources for the Coastal Batholith of central Chile (31–34°S): geochemical and Sr–Nd isotopic evidence and tectonic implications. *Lithos*, **46**, 505–521.

Parada, M. A., Féraud, G., Fuentes, F., Aguirre, L., Morata, D. & Larrondo, P. 2005. Ages and cooling history of the Early Cretaceous Caleu pluton: testimony of a switch from a rifted to a compressional continental margin in central Chile. *Journal of the Geological Society of London*, **162**, 273–287.

Parada, M. A., López-Escobar, L. *et al.* 2007. Andean magmatism. *In*: Moreno, T. & Gibbons, W. (eds) *The Geology of Chile*. Geological Society, London, 115–146.

Pardo, M., Comte, D. & Monfret, T. 2002. Seismotectonic and stress distribution in the central Chile subduction zone. *Journal of South American Earth Sciences*, **15**, 11–22.

Pardo-Casas, F. & Molnar, P. 1987. Relative motion of the Nazca (Farallon) and South American plates since Late Cretaceous time. *Tectonics*, **6**, 233–248.

Paskoff, R. 1970. *Recherches Géomorphologiques Dans le Chili Semi-Aride*. Biscaye Frères, Bordeaux.

Paskoff, R. 1977. The Quaternary of Chile: the state of research. *Quaternary Research*, **8**, 2–31.

Pazos, P. J. 2002. The Late Carboniferous glacial to postglacial transition: facies and sequence stratigraphy, Western Paganzo Basin, Argentina. *Gondwana Research*, **5**, 467–487.

Petford, N. & Gregori, D. A. 1994. Geological and geochemical comparison between the coastal batholith (Perú) and the Frontal Cordillera composite batholith (Argentina). *In*: *VII Congreso Geológico Chileno*, Concepción, Actas, **2**, 1428–1432.

Pineda, V. 1983*a*. *Evolución paleogeográfica de la península de Arauco durante el Cretácico Superior-Terciario*. Thesis, Departamento de Geología, Universidad de Chile, Santiago.

Pineda, V. 1983*b*. Evolución Paleogeográfica de la Cuenca Sedimentaria Cretácico-Terciaria de Arauco. *Geología y Recursos Minerales de Chile, Universidad Concepción*, **1**, 375–390.

Pineda, G. & Calderón, M. 2008. *Geología del área Monte Patria-El Maqui, Región de Coquimbo*. Servicio Nacional de Geología y Minería, Santiago.

Pineda, G. & Emparan, C. 2006. *Geología del área Vicuña-Pichasca, Región de Coquimbo*. Servicio Nacional de Geología y Minería, Santiago.

Piñán-Llamas, A. & Simpson, C. 2006. Deformation of Gondwana margin turbidites during the Pampean orogeny, north-central Argentina. *Bulletin Geological Society of America*, **118**, 1270–1279.

Pirацés, R. 1976. Estratigrafía de la Cordillera de la Costa entre la cuesta El Melón y Limache, Provincia de Valparaíso, Chile. *In*: *I Congreso Geológico Chileno*, Santiago, Actas, **1**(A), 65–82.

Piracés, R. 1977. *Geología de la Cordillera de la Costa entre Catapilco y Limache, región de Aconcagua*. Thesis, Departamento de Geología, Universidad de Chile.

Polanski, J. 1964. Descripción geológica de la Hoja 25a Volcán San José, provincia de Mendoza. *Dirección Nacional de Geología y Minería, Boletín*, **98**, 1–94.

Polanski, J. 1972. Descripción geológica de la Hoja 24a-b Cerro Tupungato, provincia de Mendoza. *Dirección Nacional de Geología y Minería, Boletín*, **128**, 1–110.

Poma, S. & Ramos, V. A. 1994. Las secuencias básicas iniciales del Grupo Choiyoi. Cordón del Portillo, Mendoza: sus implicancias tectónicas. *In*: *VII Congreso Geológico Chileno*, Concepción, Actas, **2**, 1162–1166.

Quenardelle, S. & Ramos, V. A. 1999. The Ordovician western Sierras Pampeanas magmatic belt: record of Precordillera accretion in Argentina. *In*: Ramos, V. A. & Keppie, D. (eds) *Laurentia Gondwana Connections before Pangea*. Geological Society of America, Boulder, CO, Special Papers, **336**, 63–86.

Quiroga, R. 2013. *Análisis estructural de los depósitos cenozoicos de la Cordillera Principal entre el cerro Provincia y el cordón El Quempo, Región Metropolitana, Chile (33°18′ a 33°25′S)*. Thesis, Departamento de Geología, Universidad de Chile.

Radic, J. P., Rojas, L., Carpinelli, A. & Zurita, E. 2002. Evolución tectónica de la Cuenca de Cura-Mallín, región cordillerana chileno argentina (36°30′–39°00′S). *In*: *XV Congreso Geológico Argentino, El Calafate*, **3**, 233–237.

Ramos, V. A. 1981. *Descripción geológica de la hoja 33 c. Los Chihuidos Norte, provincia de Neuquén*. Servicio Geológico Nacional, Buenos Aires, **182**.

Ramos, V. A. 1988*a*. Tectonics of the Late Proterozoic–Early Paleozoic: a collisional history of southern South America. *Episodes*, **11**, 168–174.

Ramos, V. A. 1988*b*. The tectonics of the Central Andes; 30° to 33° S latitude. *In*: Clark, S. & Burchfiel, D. (eds) *Processes in Continental Lithospheric Deformation*. Geological Society of America, Boulder, CO, Special Paper, **218**, 31–54.

Ramos, V. A. 1994. Terranes of southern Gondwanaland and their control in the Andean structure (30–33°s lat.). *In*: Reutter, K. J., Scheuber, E. & Wigger, P. J. (eds) *Tectonics of the Southern Central Andes, Structure and Evolution of an Active Continental Margin*. Springer, Berlin, 249–261.

Ramos, V. A. 1999. Rasgos estructurales del territorio argentino. 1. Evolución tectónica de la Argentina. *In*: Caminos, R. (ed.) *Geología Argentina*. Instituto de Geología y Recursos Naturales, Buenos Aires, Argentina, Anales, **29**, 715–784.

Ramos, V. A. 2004. Cuyania, an exotic block to Gondwana: review of a historical success and the present problems. *Gondwana Research*, **7**, 1009–1026.

Ramos, V. A. 2010. The tectonic regime along the Andes: present settings as a key for the Mesozoic regimes. *Geological Journal*, **45**, 2–25.

Ramos, V. A. & Dalla Salda, L. 2011. Occidentalia: Un terreno acrecionado sobre el margen gondwánico? *In*: *XVIII Congreso Geológico Argentino*, Neuquén, Actas, 222–223.

Ramos, V. A. & Folguera, A. 2005. Tectonic evolution of the Andes of Neuquén: constraints derived from the magmatic arc and foreland deformation. *In*: Veiga, G. D., Spalletti, L. A., Howell, J. A. & Schwarz, E. (eds) *The Neuquén Basin, Argentina: A Case Study in Sequence Stratigraphy and Basin Dynamics*. Geological Society, London, Special Publications, **252**, 15–35.

Ramos, V. A. & Folguera, A. 2009. Andean flat slab subduction through time. *In*: Murphy, B. (ed.) *Ancient Orogens and Modern Analogues*. Geological Society, London, Special Publications, **327**, 31–54.

Ramos, V. A. & Folguera, A. 2011. Payenia volcanic province in Southern Andes: an appraisal of an exceptional Quaternary tectonic setting. *Journal of Volcanology and Geothermal Research*, **201**, 53–64.

Ramos, V. A. & Kay, S. M. 1991. Triassic rifting and associated basalts in the Cuyo basin, central Argentina. *In*: Harmon, R. S. & Rapela, C. W. (eds) *Andean Magmatism and its Tectonic Setting*. Geological Society of America, Boulder, CO, Special Papers, **265**, 79–91.

Ramos, V. A. & Vujovich, G. I. 1993. The Pampia Craton within Western Gondwanaland. *In*: Ortega-Gutiérrez, F., Coney, P., Centeno-García, E. & Gómez-Caballero, A. (eds) *Proceedings of The First Circum-Pacific and Circum-Atlantic Terrane Conference*, México, 113–116.

Ramos, V. A., Jordan, T. E., Allmendinger, R. W., Kay, S. M., Cortés, J. M. & Palma, M. A. 1984. Chilenia: un terreno alóctono en la evolución paleozoica de los Andes Centrales. *In*: *IX Congreso Geológico Argentino*, Bariloche, Actas, **2**, 84–106.

Ramos, V. A., Jordan, T. E., Allmendinger, R. W., Mpodozis, C., Kay, S., Cortés, J. M. & Palma, M. A. 1986. Paleozoic terranes of the Central Argentine Chilean Andes. *Tectonics*, **5**, 855–880.

Ramos, V. A., Rivano, S., Aguirre-Urreta, M. B., Godoy, E. & Lo Forte, G. L. 1990. El Mesozoico del cordón del Límite entre Portezuelo Navarro y Monos de Agua (Chile-Argentina). *In*: *XI Congreso Geológico Argentino*, San Juan, Actas, **2**, 43–46.

Ramos, V. A., Munizaga, F. & Kay, S. M. 1991. El magmatismo cenozoico a los 33°S de latitud: geocronología y relaciones tectónicas. *In*: *VI Congreso Geológico Chileno*, Viña del Mar, Actas, **1**, 892–896.

Ramos, V. A., Aguirre-Urreta, M. B. & Álvarez, P. P. 1996*a*. *Geología de la Región del Aconcagua*. Dirección Nacional del Servicio Geológico, Buenos Aires, Subsecretaría de Minería de la Nación Anales, **24**.

Ramos, V. A., Cegarra, M. & Cristallini, E. 1996*b*. Cenozoic tectonics of the High Andes of west-central Argentina, (30°–36°S latitude). *Tectonophysics*, **259**, 185–200.

Ramos, V. A., Escayola, M., Mutti, D. & Vujovich, G. I. 2000. Proterozoic–early Paleozoic ophiolites in the Andean basement of southern South America. *In*: Dilek, Y., Moores, E. M., Elthon, D. & Nicolas, A. (eds) *Ophiolites and Oceanic Crust: New Insights from Field Studies and Ocean Drilling Program*. Geological Society of America, Boulder, CO, Special Papers, **349**, 331–349.

RAMOS, V. A., CRISTALLINI, E. O. & PÉREZ, D. J. 2002. The Pampean flat-slab of the Central Andes. *Journal of South America Earth Sciences*, **15**, 59–78.

RAMOS, V. A., VUJOVICH, G., MARTINO, R. & OTAMENDI, J. 2010. Pampia: a large cratonic block missing in the Rodinia supercontinent. *Journal of Geodynamics*, **50**, 243–255.

RAMOS, V. A., LITVAK, V., FOLGUERA, A. & SPAGNUOLO, M. 2014. An Andean tectonic cycle: from crustal thickening to extension in a thin crust (34°–37°SL). *Geoscience Frontiers*, **5**, 351–367. http://dx.doi.org/10.1016/j.gsf.2013.12.009

RAPALINI, A. E. 2012. Paleomagnetic evidence for the origin of the Argentine Precordillera, fifteen years later: what is new, what has changed, what is still valid? *Latinmag Letters*, **2**, 1–20.

RAPALINI, A. E. & ASTINI, R. A. 1998. Paleomagnetic confirmation of the Laurentian origin of the Argentine Precordillera. *Earth and Planetary Science Letters*, **155**, 1–14.

RAPELA, C. & KAY, S. 1988. Late Paleozoic to Recent magmatic evolution of northern Patagonia. *Episodes*, **11**, 175–182.

RAPELA, C. W., PANKHURST, R. J., CASQUET, C., BALDO, E., SAAVERDRA, J., GALINDO, C. & FANNING, C. M. 1998. The Pampean Orogeny of the southern Proto-Andean: Cambrian continental collision in the Sierras de Córdoba. *In*: PANKHURST, R. J. & RAPELA, C. W. (eds) *The Proto-Andean Margin of Gondwana*. Geological Society, London, Special Publications, **142**, 181–217.

RAPELA, C. W., PANKHURST, R. J. *ET AL.* 2007. The Río de la Plata craton and the assembly of SW Gondwana. *Earth-Science Reviews*, **83**, 49–82.

RAPELA, C. W., PANKHURST, R. J., CASQUET, C., BALDO, E., GALINDO, C., FANNING, C. M. & DAHLQUIST, J. A. 2010. The Western Sierras Pampeanas: protracted Grenville-age history (1330–1030 Ma) of intra-oceanic arcs, subduction–accretion at continental-edge and AMCG intraplate magmatism. *Journal of South American Earth Sciences*, **29**, 105–127.

RAULD, R. A. 2002. *Análisis morfoestructural del frente cordillerano: Santiago oriente entre el río Mapocho y Quebrada de Macul*. Thesis, Departamento de Geología, Universidad de Chile, Santiago.

REBOLLEDO, S. & CHARRIER, R. 1994. Evolución del basamento paleozoico en el área de Punta Claditas, Región de Coquimbo, Chile (31–32°S). *Revista Geológica de Chile*, **21**, 55–69.

REGARD, V., SAILLARD, M. *ET AL.* 2010. Renewed uplift of the Central Andes Forearc revealed by coastal evolution during the Quaternary. *Earth and Planetary Science Letters*, **297**, 199–210.

REUTTER, K. J. 2001. Le Ande centrali: elemento di un'orogenesi di margine continentale attivo. *Acta Naturalia de l'Ateneo Parmense*, **37**, 5–37.

RICCARDI, A. C. & IGLESIA LLANOS, M. P. 1999. Primer hallazgo de amonites en el Triásico de Argentina. *Revista de la Asociación Geológica Argentina*, **54**, 298–300.

RICHTER, P., RING, U., WILLNER, A. P. & LEISS, B. 2007. Structural contacts in subduction complexes and their tectonic significance: the Late Palaeozoic coastal accretionary wedge of central Chile. *Journal of the Geological Society, London*, **164**, 203–214.

RIVANO, S. 1996. *Geología de las Hojas Quillota y Portillo*. Servicio Nacional de Geología y Minería. Santiago.

RIVANO, S. & SEPÚLVEDA, P. 1983. Hallazgo de foraminíferos del Carbonífero Superior en la Formación Huentelauquén. *Revista Geológica de Chile*, **19–20**, 25–35.

RIVANO, S. & SEPÚLVEDA, P. 1985. Las calizas de la Formación Huentelauquén: depósitos de aguas templadas a frías en el Carbonífero Superior–Pérmico Inferior. *Revista Geológica de Chile*, **25–26**, 29–38.

RIVANO, S. & SEPÚLVEDA, P. 1991. *Hoja Illapel, Región de Coquimbo. Carta Geológica de Chile*. Servicio Nacional de Geología y Minería, Santiago.

RIVANO, S., SEPÚLVEDA, P., BORIC, R. & ESPIÑEIRA, D. 1993. *Hojas Quillota y Portillo*. Servicio Nacional de Geología y Minería, Santiago, Carta Geológica de Chile, **73**.

ROBINSON, D., BEVINS, R. E. & RUBINSTEIN, N. 2005. Subgreenschist facies metamorphism of metabasites from the Precordillera terrane of western Argentina: constraints on the latter stages of accretion to Gondwana. *European Journal of Mineralogy*, **17**, 441–452.

ROCHA CAMPOS, A. C., BASEI, M. A. *ET AL.* 2011. 30 million years of Permian volcanism recorded in the Choiyoi igneous province (W Argentina) and their source for younger ash fall deposits in the Paraná Basin: SHRIMP U–Pb zircon geochronology evidence. *Gondwana Research*, **19**, 509–523.

RODRÍGUEZ, M. P. 2013. Cenozoic uplift and exhumation above the southern part of the flat slab subduction segment of Chile (28.5–32°S). Thesis, Departamento de Geología, Universidad de Chile, Santiago.

RODRÍGUEZ, M. P., PINTO, L. & ENCINAS, A. 2012. Cenozoic erosion in the Andean forearc in Central Chile (33°–34°S): Sediment provenance inferred by heavy mineral studies. *In*: RASBURY, E. T., HEMMING, S. R. & RIGGS, N. (eds) *Mineralogical and Geochemical Approaches to Provenance*. Geological Society of America, Boulder, CO, Special Papers, **487**, 141–162.

RODRÍGUEZ, M. P., CARRETIER, S. *ET AL.* 2013. Geochronology of pediments and marine terraces in north-central Chile and their implications for Quaternary uplift in the Western Andes. *Geomorphology*, **180–181**, 33–46.

RODRÍGUEZ, M. P., AGUILAR, G., URRESTY, C. & CHARRIER, R. 2014. Neogene landscape evolution in the Andes of north-central Chile between 28 and 32°S: interplay between tectonic and erosional processes. *In*: SEPÚLVEDA, S. A., GIAMBIAGI, L. B., MOREIRAS, S. M., PINTO, L., TUNIK, M., HOKE, G. D. & FARÍAS, M. (eds) *Geodynamic Processes in the Andes of Central Chile and Argentina*. Geological Society, London, Special Publications, **399**. First published online April 2, 2014, http://dx.doi.org/10.1144/SP399.15

ROSSEL, P., OLIVEROS, V., DUCEA, M. N., CHARRIER, R., SCAILLET, S., RETAMAL, L. & FIGUEROA, O. 2013. The Early Andean subduction system as an analogue to island arcs: evidence from across-arc geochemical variations in northern Chile. *Lithos*, **179**, 211–230, http://dx.doi.org/10.1016/j.lithos.2013.08.014

ROSSEL, P., OLIVEROS, V. *ET AL.* 2014. La Formación Rio Damas-Tordillo (33°–35,5°S): antecedentes sobre petrogénesis, proveniencia e implicancias tectónicas. Andean Geology, http://ww.scielo.cl/andgeol.htm

RUTLAND, R. W. R. 1971. Andean Orogeny and ocean floor spreading. *Nature*, **233**, 252–255.

SAILLARD, M., HALL, S. R. *ET AL.* 2009. Non-steady long-term uplift rates and Pleistocene marine terrace development along the Andean margin of Chile (31°S) inferred from 10Be dating. *Earth and Planetary Science Letters*, **277**, 50–63.

SAILLARD, M., RIOTTE, J., REGARD, V., VIOLETTE, A., HÉRAIL, G., AUDIN, L. & RIQUELME, R. 2012. Beach ridges U–Th dating in Tongoy bay and tectonic implications for a peninsula–bay system, Chile. *Journal of South American Earth Sciences*, **40**, 77–84.

SALAZAR, C., STINNESBECK, W. & QUINZIO-SINN, L. A. 2010. Ammonites from the Maastrichtian (Upper Cretaceous) Quiriquina Formation in central Chile. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **257**, 181–236.

SALAZAR, E., ARRIAGADA, C., MPODOZIS, C., MARTÍNEZ, F., PEÑA, M. & ÁLVAREZ, J. 2009. Análisis Estructural del Oroclino de Vallenar: Primeros Resultados. *In*: *XII Congreso Geológico Chileno*, Santiago, electronic actas.

SATO, A. M. & LLAMBÍAS, E. J. 1993. El Grupo Choiyoi, provincia de San Juan: equivalente efusivo del Batolito de Colangüil. *In*: *XII Congreso Geológico Argentino y II Congreso Exploración de Hidrocarburos*. Mendoza, Argentina, Actas, **4**, 156–165.

SATO, A. M., LLAMBÍAS, E. J., SHAW, S. E. & CASTRO, C. E. 1990. El Batolito de Colangüil: modelo del magamtismo neopaleozoico de la provincia de San Juan. *In*: BORDONARO, O. (ed.) *Geología y Recursos Naturales de la provincia de San Juan, Relatorio XI Congreso Geológico Argentino*, San Juan, 100–122.

SATO, A. M., LLAMBÍAS, E. J., BASEI, M. A. S. & CASTRO, C. E. 2014. El magmatismo Choiyoi de la Cordillera Frontal de San Juan. *In*: *XIX Congreso Geológico Argentino*, Córdoba, Session 21: Pre-Andean tectonics, Presentation no. 52, Digital.

SCHWARTZ, J. J., GROMET, L. P. & MIRÓ, R. 2008. Timing and duration of the calc-alkaline arc of the Pampean orogeny: implications for the late Neoproterozoic to Cambrian evolution of western Gondwana. *Journal of Geology*, **116**, 39–61.

SCHILLER, W. 1912. La Alta Cordillera de San Juan y Mendoza y parte de la provincia de San Juan. *Anales del Ministerio de Agricultura, Sección Geología, Mineralogía y Minería*, **7**, 1–68.

SCHMIDT, S., HETZEL, R., MINGORANCE, F. & RAMOS, V. A. 2011. Coseismic displacements and Holocene slip rates for two active thrust faults at the mountain front of the Andean Precordillera (~33°S). *Tectonics*, **30**, TC5011, http://dx.doi.org/10.1029/2011TC002932

SELLÉS, D. & GANA, P. 2001. *Geología del área Talagante-San Francisco de Mostazal, Regiones metropolitana y del Libertador Bernardo O'Higgins*. Servicio Nacional de Geología y Minería, Santiago, Carta Geológica, Serie Geología Básica, **74**.

SERRANO, L., VARGAS, R. & STAMBUK, V. 1996. The Late Miocene Río Blanco–Los Bronces copper deposit central Chilean Andes. *In*: CAMUS, F., SILLITOE, R. H. & PETERSEN, R. (eds) *Andean Copper Deposits: New Discoveries, Mineralization Styles and Metallogeny*. Society of Economic Geologists, Littleton, CO, Special Publications, **5**, 119–130.

SILVESTRO, J. & ATENCIO, M. 2009. La cuenca cenozoica del Río Grande y Palauco: edad, evolución y control estructural. Faja plegada de Malargüe (36°S). *Revista de la Asociación Geológica Argentina*, **65**, 154–169.

SIMPSON, C., LAW, R. D., GROMET, L. P., MIRO, R. & NORTHRUP, C. J. 2003. Paleozoic deformation in the Sierras de Córdoba and Sierra de La Minas, eastern Sierras Pampeanas, Argentina. *Journal of South American Earth Sciences*, **15**, 749–764.

SERNAGEOMIN. 2002. *Mapa Geológico de Chile, escala 1: 1.000.000*. Servicio Nacional de Geología y Minería, Santiago, **75**.

SKEWES, M. A., ARÉVALO, A., FLOODY, R., ZÚÑIGA, P. & STERN, C. R. 2002. The giant El Teniente, breccia deposit: hypogene copper distribution and emplacement. *In*: GOLDFARB, R. J. & NIELSEN, R. L. (eds) *Integrated Methods for Discovery: Global Exploration in the Twenty-first Century*. Society of Economic Geologists, Littleton, CO, Special Publications, **9**, 299–332.

SØAGER, N., HOLM, P. M. & LLAMBÍAS, E. J. 2013. Payenia volcanic province, southern Mendoza, Argentina: OIB mantle upwelling in a backarc environment. *Chemical Geology*, **349–350**, 36–53.

SPAGNUOLO, C., RAPALINI, A. E. & ASTINI, R. A. 2012*a*. Assembly of Pampia to the SW Gondwana margin: a case of strike-slip docking? *Gondwana Research*, **21**, 406–421.

SPAGNUOLO, M. G., LITVAK, V. D., FOLGUERA, A., BOTTESI, G. & RAMOS, V. A. 2012*b*. Neogene magmatic expansion and mountain building processes in the southern Central Andes, 36–37°S, Argentina. *Journal of Geodynamics*, **53**, 81–94.

SPALLETTI, L. 1999. Cuencas triásicas del oeste argentino: origen y evolución. *Acta Geológica Hispánica*, **32**, 29–50.

SPALLETTI, L., ARTABE, A., MOREL, E. & BREA, M. 1999. Paleofloristic biozonation and chronostratigraphy of the Argentine Triassic. *Ameghiniana*, **36**, 419–451.

SPALLETTI, L., MOREL, E., ARTABE, A., ZAVATTIERI, A. & GANUZA, D. 2005. Estratigrafía, facies y paleoflora de la sucesión triásica de Potrerillos, Mendoza, República Argentina. *Revista Geológica de Chile*, **32**, 249–272.

SPALLETTI, L. A., FANNING, C. M. & RAPELA, C. W. 2008. Dating the Triassic continental rift in the southern Andes: the Potrerillos Formation, Cuyo Basin, Argentina. *Geologica Acta*, **6**, 267–283.

SPALLETTI, L. A., LIMARINO, C. O. & COLOMBO PIÑOL, F. 2012. Petrology and geochemistry of Carboniferous siliciclastics from the Argentine Frontal Cordillera: a test of methods for interpreting provenance and tectonic setting. *Journal of South American Earth Sciences*, **36**, 32–54.

STEINMANN, G. 1929. *Geologie von Perú*. Karl Winter, Heidelberg.

STEINMANN, G., DEEKE, W. & MÖRICKE, W. 1895. Das Alter und die Fauna der Quiriquina Schichten in Chile. *Neues Jahrbuch Mineralogie und Palaeontologie*, **10**, 1–118.

Stern, C. R., Amini, H., Charrier, R., Godoy, E., Hervé, F. & Varela, J. 1984. Petrochemistry and age of rhyolitic pyroclastics flows which occur along the drainage valleys of the Río Maipo and Río Cachapoal (Chile) and the Río Chaucha and Río Papagayos (Argentina). *Revista Geológica de Chile*, **23**, 39–52.

Stern, C. R., Moreno, H. *et al.* 2007. Chilean volcanoes. *In*: Moreno, T. & Gibbons, W. (eds) *The Geology of Chile*. Geological Society, London, 147–178.

Stinnesbeck, W. 1986. Zu den faunistischen und palökologischen Verhältnissen in der Quriquina Formation (Maastrichtium) Zentral-Chiles. *Palaeontographica*, **194**, 99–237.

Suárez, M. & Bell, M. 1992. Triassic rift-related sedimentary basins in northern Chile (24°–29°S). *Journal of South American Earth Sciences*, **6**, 109–121.

Suárez, M. & Emparan, C. 1997. *Hoja Curacautín, Regiones de Araucanía y Bío-Bío*. Carta geológica de Chile, Santiago, Servicio Nacional de Geología y Minería, **71**.

Tavera, J. 1942. Contribución al estudio de la estratigrafía y paleontología del Terciario de Arauco. *In*: *I Congreso Panamericano de Ingeniería de Minas y Geología*. Santiago, Chile, **2**, 580–632.

Tavera, J. 1979. Estratigrafía y paleontología de la Formación Navidad, Provincia de Colchagua, Chile (30°50′–34°S). *Boletín del Museo Nacional de Historia Natural, Santiago*, **36**.

Tavera, J. 1980. *El Cretáceo y Terciario de Alagarrobo*. Imprentas Gráficas, Santiago.

Thiele, R. 1965. *El Triásico-Jurásico del Departamento de Curepto en la Provincia de Talca*. Departamento de Geología, Universidad de Chile, Santiago, Chile, **28**.

Thiele, R. 1980. Hoja Santiago. Región Metropolitana. Carta Geológica de Chile. *Instituto de Investigaciones Geológicas*, **39**, 1–51.

Thiele, R. & Hervé, F. 1984. Sedimentación y Tectónica de antearco en los terrenos pre-andinos del Norte Chico. *Revista Geológica de Chile*, **22**, 61–75.

Thomas, H. 1958. Geología de la Cordillera de la Costa entre el valle de La Ligua y la cuesta de Barriga. *Instituto de Investigaciones Geológicas Boletín*, **2**, 1–80.

Thomas, H. 1967. *Geología de la Hoja Ovalle, Provincia de Coquimbo*. Instituto de Investigaciones Geológicas, Santiago, Boletín, **23**.

Thomas, W. A. & Astini, R. A. 1996. The Argentine Precordillera: a traveller from the Ouachita embayment of North American Laurentia. *Science*, **273**, 752–757.

Thomas, W. A. & Astini, R. A. 2003. Ordovician accretion of the Argentine Precordillera terrane to Gondwana: a review. *Journal of South American Earth Sciences*, **16**, 67–79.

Thomas, W. A. & Astini, R. A. 2007. Vestiges of an Ordovician west-vergent thin-skinned Ocloyic thrust belt in the Argentine Precordillera, southern Central Andes. *Journal of Structural Geology*, **29**, 1369–1385.

Thompson, S. N. & Hervé, F. 2002. New time constraints for the age of metamorphism at the ancestral Pacific Gondwana margin of southern Chile. *Revista Geológica de Chile*, **29**, 255–271.

Tibaldi, A. M., Otamendi, J. E., Gromet, L. P. & Demichelis, A. H. 2008. Suya Taco and Sol de Mayo mafic complexes from eastern Sierras Pampeanas, Argentina: evidence for the emplacement of primitive OIB-like magmas into deep crustal levels at a late stage of the Pampean orogeny. *Journal of South American Earth Sciences*, **26**, 172–187.

Tickyj, H. 2011. Granitoides calcoalcalinos tardío-famatinianos en el Cordón del Carrizalito, Cordillera Frontal, Mendoza. *In*: *XVIII Congreso Geológico Argentino*, Neuquén, 1531–1532.

Tickyj, H., Rodríguez Raising, M., Cingolani, C. A., Alfaro, M. & Uriz, N. 2009*a*. Graptolitos ordovícicos en el Sur de la Cordillera frontal de Mendoza. *Revista de la Asociación Geológica Argentina*, **64**, 295–302.

Tickyj, H., Fernández, M. A., Chemale, J. F. & Cingolani, C. A. 2009*b*. *Granodiorita Pampa de los Avestruces, Cordillera Frontal, Mendoza: Un intrusivo sintectónico de edad devónica inferior*. 14° Reunión de Tectónica y 3° Taller de Campo de Tectónica, p. 27, Córdoba.

Tunik, M. A. 2003. Interpretación paleoambiental de los depósitos de la Formación Saldeño (Cretácico Superior), en la alta cordillera de Mendoza. *Revista de la Asociación Geológica Argentina*, **58**, 417–433.

Tunik, M., Folguera, A., Naipauer, M., Pimentel, M. & Ramos, V. A. 2010. Early uplift and orogenic deformation in the Neuquén basin: constraints on the Andean uplift from U–Pb and Hf isotopic data of detrital zircons. *Tectonophysics*, **489**, 258–273.

Uliana, M. A. & Biddle, K. T. 1988. Mesozoic–Cenozoic paleogeographic and geodynamic evolution of southern South America. *Revista Brasileira de Geociências*, **18**, 172–190.

Urbina, N. P. & Sruoga, P. 2009. La faja metalogenética de San Luis, Sierras Pampeanas: mineralización y geocronología en el contexto metalogenético regional. *Revista de la Asociación Geológica Argentina*, **64**, 635–645.

Van Staal, C. R., Vujovich, G. I. & Naipauer, M. 2011. An Alpine-style Ordovician collision complex in the Sierra de Pie de Palo, Argentina: record of subduction of Cuyania beneath the Famatina arc. *Journal of Structural Geology*, **33**, 343–361.

Vargas, G. & Rebolledo, S. 2012. Paleosismología de la Falla San Ramón e implicancias para el peligros sísmico de Santiago. *In*: *XIII Congreso Geológico Chileno*, Antofagasta, electronic abstract.

Vásquez, P. & Franz, G. 2008. The Triassic Cobquecura Pluton (Central Chile): an example of a fayalite-bearing A-type intrusive massif at a continental margin. *Tectonophysics*, **459**, 66–84.

Verdecchia, S. O., Baldo, E. G., Benedetto, J. L. & Borghi, P. A. 2007. The first shelly faunas from metamorphic rocks of the Sierras Pampeanas (La Cébila Formation, Sierra de Ambato, Argentina): age and paleogeographic implications. *Ameghiniana*, **44**, 493–498.

Vergara, M. 1969. *Rocas volcánicas y sedimentario-volcánicas Mesozoicas y Cenozoicas en la latitud 34° 30′S, Chile*. Departamento de Geología, Universidad de Chile, Santiago, Chile, **32**.

Vergara, M. & Drake, R. 1978. *Edades K–Ar y su implicancia en la Geología Regional de Chile central*. Universidad de Chile, Departamento de Geología y Geofísica, Santiago, Comunicaciones, **23**.

Vergara, M., Charrier, R., Munizaga, F., Rivano, S., Sepúlveda, P., Thiele, R. & Drake, R. 1988. Miocene volcanism in the central Chilean Andes (31°30′S–34°35′S). *Journal of South American Earth Sciences*, **1**, 199–209.

Vergara, M., Levi, B., Nystrom, J. & Cancino, A. 1995. Jurassic and Early Cretaceous island arc volcanism extension and subsidence in the Coastal Range of central Chile. *Geological Society of America Bulletin*, **107**, 1427–1440.

Vergara, M., Lopez Escobar, L. & Hickey-Vargas, R. 1997. Geoquímica de las rocas volcanicas miocenas de la cuenca intermontana de Parraly Ñuble. *In*: *VIII Congreso Geológico Chileno*. Antofagasta, Actas, **2**, 1570–1573.

Vergara, M., López-Escobar, L., Palma, J. L., Hickey-Vargas, R. & Roeschmann, C. 2004. Late Tertiary episodes in the area of the city of Santiago de Chile: new geochronological and geochemical data. *Journal of South American Earth Sciences*, **17**, 227–238.

Vicente, J. C. 1974. Geological cross section of the Andes between Santiago and Mendoza (33° Lat. S.) Guide Book, Excursion D-5, International Association of Volcanology and Chemistry of Earth's Interior. *In*: *Symposium Andean and Antarctic Problems*. Santiago, Chile, 1–10.

Vicente, J. C. 2005. Dynamic paleogeography of the Jurassic Andean Basin: pattern of transgression and localization of main straits through the magmatic arc. *Revista de la Asociación Geológica Argentina*, **60**, 221–250.

Vicente, J. C., Charrier, R., Davidson, J., Mpodozis, C. & Rivano, S. 1973. La orogénesis subhercínica: fase mayor de la evolución paleogeográfica y estructural de los Andes argentino-chilenos centrales. *In*: *V Congreso Geológico Argentino*. Carlos Paz, Argentina, Actas, **5**, 81–98.

Vivallo, W., Zanettini, J. C. M., Gardeweg, M., Márquez, M. J., Tassara, A. & González, R. A. 1999. *Mapa de recursos minerales del área fronteriza argentino-chilena entre los 34° y 56°S*. Servicio Nacional de Geología y Minería, Chile, Publicación Multinacional, **1**.

Voldman, G. G., Albanesi, G. L. & Ramos, V. A. 2009. Ordovician metamorphic event in the carbonate platform of the Argentine Precordillera: implications for the geotectonic evolution of the proto-Andean margin of Gondwana. *Geology*, **37**, 311–314.

Voldman, G. G., Albanesi, G. L. & Ramos, V. A. 2010. Conodont geothermometry of the lower Paleozoic from the Precordillera (Cuyania terrane), northwestern Argentina. *Journal of South American Earth Sciences*, **29**, 278–288.

Volkheimer, W. 1978. Descripción geológica de la Hoja 27b, Cerro Sosneado, Provincia de Mendoza. *Secretaría de Estado de Minería, Boletín*, **151**, 1–83, Buenos Aires.

Von Gosen, W. 1992. Structural evolution of the Argentine Precordillera: the Río San Juan Section. *Journal of Structural Geology*, **14**, 643–667.

Von Gosen, W., Loske, W. & Prozzi, C. 2002. New isotopic dating of intrusive rocks in the Sierra de San Luis (Argentina): implications for the geodynamic history of the Eastern Sierras Pampeanas. *Journal of South American Earth Sciences*, **15**, 237–250.

Vujovich, G. & Kay, S. M. 1998. A Laurentian? Grenville-age oceanic arc/back-arc terrane in the Sierra de Pie de Palo, Western Sierras Pampeanas, Argentina. *In*: Pankhurst, R. & Rapela, C. W. (eds) *Protomargin of Gondwana*. Geological Society, London, Special Publications, **142**, 159–180.

Vujovich, G. & Ramos, V. A. 1994. La Faja de Angaco y su relación con las Sierras Pampeanas Occidentales, Argentina. *In*: *VII Congreso Geológico Chileno*, Concepción, Actas, **1**, 215–219.

Wall, R., Gana, P. & Gutiérrez, A. 1996. *Mapa Geológico del área de San Antonio-Melipilla*. Regiones de Valparaiso, Metropolitana y del Libertador General Bernardo O'Higgins, Servicio Nacional de Geología y Minería, Mapa, Santiago, Chile, **2**.

Wall, R., Selles, D. & Gana, P. 1999. *Mapa área Tiltil–Santiago, región Metropolitana*. Servicio Nacional de Geología y Minería, Chile.

Wenzel, O., Wathelet, J., Chávez, L. & Bonilla, R. 1975. La sedimentación cíclica Meso-Cenozoica en la región Carbonífera de Arauco–Concepción, Chile. *In*: *II Congreso Americano de Geología Económica*, Buenos Aires, 215–237.

Wetzel, W. 1930. Die Quiriquina Schichten als Sediment und paläontologisches Archiv. *Palaeontographica*, **73**, 49–101.

Willner, A. P. 2005. Pressure–temperature evolution of a Late Palaeozoic paired metamorphic belt in north-central Chile (34–35° 30′ S). *Journal of Petrology*, **46**, 1805–1833.

Willner, A. P., Glodny, J., Gerya, T. V., Godoy, E. & Massonne, H. 2004. A counterclockwise *PTt* path of high-pressure/low-temperature rocks from the Coastal Cordillera accretionary complex of south-central Chile: constraints for the earliest stage of subduction mass flow. *Lithos*, **75**, 283–310.

Willner, A. P., Thomson, S. N., Kröner, A., Wartho, J.-A., Wijbrans, J. R. & Hervé, F. 2005. Time markers for the evolution and exhumation history of a Late Palaeozoic paired metamorphic belt in North-Central Chile (34°–35°30′S). *Journal of Petrology*, **46**, 1835–1858.

Willner, A. P., Gerdes, A. & Massonne, H. J. 2008. History of crustal growth and recycling at the Pacific convergent margin of South America at latitudes 29–36°S revealed by a U–Pb and Lu–Hf isotope study of detrital zircon from late Paleozoic accretionary systems. *Chemical Geology*, **253**, 114–129.

Willner, A. P., Gerdes, A., Massonne, H.-J., Schmidt, A., Sudo, M., Thomson, S. N. & Vujovich, G. 2011. The geodynamics of collision of a microplate (Chilenia) in Devonian times deduced by the pressure–temperature–time evolution within part of a collisional belt (Guarguaraz Complex, W-Argentina). *Contributions to Mineralogy and Petrology*, **162**, 303–327.

Willner, A. P., Massonne, H.-J., Ring, U., Sudo, M. & Thomson, S. N. 2012. P-T evolution and timing of a late Palaeozoic fore-arc system and its heterogeneous Mesozoic overprint in north-central Chile (latitudes 31–32°S). *Geological Magazine*, **149**, 177–207.

Winocur, D. A., Litvak, V. D. & Ramos, V. A. 2014. Magmatic and tectonic evolution of the Oligocene Valle del Cura basin, main Andes of Argentina and Chile: evidence for generalized extension. *In*: Sepúlveda, S. A., Giambiagi, L. B., Moreiras, S. M., Pinto, L., Tunik, M., Hoke, G. D. & Farías, M. (eds) *Geodynamic Processes in the Andes of Central Chile and Argentina*. Geological Society, London, Special Publications, **399**. First published online February 17, 2014, http://dx.doi.org/10.1144/SP399.2

Yáñez, G., Cembrano, S., Pardo, M., Ranero, C. & Sellés, D. 2001. The Challenger–Juan Fernández–Maipo major tectonic transition of the Nazca–Andean subduction system at 33°–34°S: geodynamic evidence and implications. *Journal of South American Earth Sciences*, **15**, 23–38.

Yury-Yáñez, R. E., Otero, R. A., Soto-Acuña, S., Suárez, M. E., Rubilar-Rogers, D. & Sallaberry, M. 2012. First bird remains from the Eocene of Algarrobo, central Chile. *Andean Geology*, **39**, 548–557.