PERGAMON

Journal of South American Earth Sciences 16 (2003) 81–90

Journal of
South American
Earth Sciences

www.elsevier.com/locate/jsames

Tectonic and paleoenvironmental evolution of Mesozoic sedimentary basins along the Andean foothills of Argentina (32°–54°S)

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Abstract

Chronoenvironmental and tectonic charts are presented for Mesozoic basins located along the Andean foothills of the South American plate. On the basis of the main tectonic events, pre-Andean basins, break-up-related basins, extensional back-arc basins, and Andean foreland basins are recognized. The pre-Andean basins were formed by continental extension and strike-slip movement before the development of the Mesozoic–Cenozoic Andean magmatic arc. Upper Permian to Middle Triassic extension along Palaeozoic terrane sutures resulted in rifting, bimodal magmatism (Choiyoi group), and continental deposition (Cuyo basin). From the Late Triassic to the Early Jurassic, continental extension related to the collapse of the Gondwana orogen initiated a series of long, narrow half-grabens that filled with continental volcaniclastic deposits. These depocenters were later integrated into the Neuquén basin. Coeval development of the shallow marine Pampa de Agnia basin (42–44°S) is related to short-lived extension, probably driven by dextral displacement along major strike-slip faults (e.g. the Gastre fault system).

Widespread extension related to the Gondwana breakup (180–165 Ma) and the opening of the Weddell Sea reached the western margin of the South American plate. As a result, wide areas of Patagonia were affected by intraplate volcanism (Chon Aike province), and early rifting occurred in the Magallanes basin.

The Andean magmatic arc was almost fully developed by Late Jurassic times. A transgressive stage with starvation and anoxia characterized the Neuquén basin. In western Patagonia, back-arc and intra-arc extension produced the opening of several grabens associated with explosive volcanism and lava flows (e.g. Río Mayo, El Quemado). To the south, a deep marginal basin floored by oceanic crust (Rocas Verdes) developed along the back-arc axis. In mid-to late Cretaceous times, Andean compressional tectonics related to South Atlantic spreading caused the inversion of previous extensional structures and the beginning of a retro-arc foreland phase in the Neuquén and Austral basins.

Keywords: Argentina; Gondwana; Mesozoic; Paleogeography; Sedimentary basins; South America

1. Introduction

The Mesozoic paleogeographic and paleoenvironmental evolution of southern South American basins occurred under the influence of two main tectonic processes: (1) subduction of the proto-Pacific plate below the western margin of Gondwana and progressive development of the western Gondwana magmatic arc and (2) asthenospheric plumes that resulted in regional extension, intraplate magmatism, continental breakup, and the opening of the South Atlantic.

The area located east of the southern Andes is the most suitable region to study the interaction between these two major tectonic processes because plate convergence and continental extension are closely related and accurate information on the regional distribution and timing of these tectonic episodes is available (Storey, 1995; Ramos, 1996, 1999. Whereas the structure and sedimentary infill of the Mesozoic basins developed along the eastern Andes foothills between 32–56°S is well known, an integrated model of their common evolution has not been developed. In this paper, we analyze the relative influence of the growth of the Andean magmatic arc and the South Atlantic breakup on basin development, including regional distribution and evolution of the resulting depositional systems. We subdivide the Mesozoic history of the southern South

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0895-9811/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0895-9811(03)00020-8

American basins into four main tectonic stages. In addition, we use several paleogeographic maps of southern South America and two chronoenvironmental charts to illustrate regional and temporal changes in basin configuration and the distribution of depositional systems.

2. Methodology

This work was carried out as part of a major project developed as a research collaboration among institutes in the United Kingdom (Cambridge Arctic Shelf Programme and University of Aberdeen), Argentina (Centro de Investigaciones Geológicas), and the United States (Institute for Geophysics, University of Texas at Austin). The project presents new continental reconstructions, paleofacies, and tectonic models for southern Gondwana (Macdonald et al., 2003).

The paleogeographic reconstructions presented here were carried out using the UTIG PLATES program and plate model (Lawver et al., 1999; Macdonald et al., 2003) based on gravity data, marine magnetic anomalies, seafloor radiometric ages, and significant geological lineaments as piercing points. Fig. 1 shows a portion of a world plate tectonic reconstruction for 240 Ma, illustrating the deformation of South America necessary to achieve a tight fit (Lawver et al. 1999; Macdonald et al., 2003). The studied region is subdivided into three rigid continental plates: (1) a north central (Paraná) plate, bounded to the south by the Colorado-Huincul line; (2) a south central (Río Negro) plate, bounded to the south by the Gastre fault system; and (3) a southern (Patagonia) plate.

On the basis of previous paleofacies maps (Spalletti and Franzese, 1996; Spalletti et al., 1999), 12 new maps at 15 Ma intervals were developed (Figs. 2–5). They show the main sedimentary basins, the areas undergoing active subduction, and the extent of the magmatic arc, as well as the most notable episodes of intraplate magmatism from 240 (Anisian-Ladinian) to 75 Ma (Campanian-Maastrichtian). Source references are cited when appropriate.

Chronoenvironmental charts were constructed along two N–S transects, located at 70°30′W and 69°W, respectively, (Figs. 1 and 6). The vertical axis of each of these charts is a time line subdivided into 15 Ma intervals. The charts show the evolution of basin configuration, the space/time distribution of depositional systems, and the location of arc and intraplate magmatism.

3. Tectonic stages and evolution of depositional systems

The processes of proto-Pacific subduction and continental extension that culminated in the opening of the Atlantic Ocean created a complex tectonic scenario for southernmost South America. During the Jurassic, the magmatic arc evolved diachronously and reached its complete development along the continental margin at approximately 150 Ma (Spalletti and Franzese, 1996; Macdonald et al., 2003). The tectonic regime associated with the Andean magmatic arc shows significant regional and temporal variations. Several intra- and back-arc basins were created and evolved during Mesozoic extension (Dalziel et al., 1974; Ramos, 1999), some of which were subsequently inverted and evolved as foreland basins when Andean fold-and-thrust belts formed under compressional regimes (Ramos, 1999).

Continental extension dominated in intraplate regions. During the Jurassic, vast volumes of acidic volcanic material were produced in the south (Patagonia) in response to intraplate extension (Gust et al., 1985; Pankhurst et al., 1998; Riley and Leat, 1999). Coevally, a significant paleogeographic reconfiguration occurred in Patagonia along major intracontinental strike-slip fault systems. The regional structures, such as the Gastre fault system (Rapela et al., 1991; Rapela and Pankhurst, 1992), appear in our maps as boundaries between neighboring continental plates. The Cretaceous extension resulted in the opening of the south Atlantic Ocean and the formation of associated taphrogenic basins and deep rift troughs (Urien et al., 1995; Ramos, 1996, 1999; Rossello and Mozetic, 1999).

On the basis of the linked influence of these major tectonic controls, the following evolutionary stages can be defined for the southern South American basins: (1) pre-Andean, (2) break-up, (3) extensional back-arc with complete development of the magmatic arc, and (4) inversion and foreland.

3.1. Pre-Andean stage (240–195 Ma)

This first stage covers the interval between the Early Triassic and the Early Jurassic (Fig. 2). The most remarkable feature is the contrasting tectonic behavior of the Gondwana margin north and south of 40°S, which suggests significant pre-Andean tectonic segmentation (Franzese and Spalletti, 2001). To the north, the Gondwana (during the Carboniferous-Permian) orogenic belt controlled basin evolution. At the beginning of the pre-Andean stage, this area showed no evidence of a subducted slab beneath Gondwana. The tectonic scenario was dominated by a strike-slip regime subparallel to the western continental margin, and the continental interior was characterized by intraplate extension (Franzese and Spalletti, 2001).

To the south, the batholith of central Patagonia, which is orientated obliquely to the current continental margin (Fig. 2), shows clear evidence of arc magmatism (Rapela and Pankhurst, 1992). To the east, calc-alkaline volcanic rocks of the Los Menucos depocenter could be interpreted as evidence of coeval retro-arc magmatism (Spalletti et al., 1999).

The older pre-Andean basins formed as a result of continental extension and strike-slip movements. Between the Late Permian and Middle Triassic, extension along Paleozoic terrane sutures resulted in rifting, continental

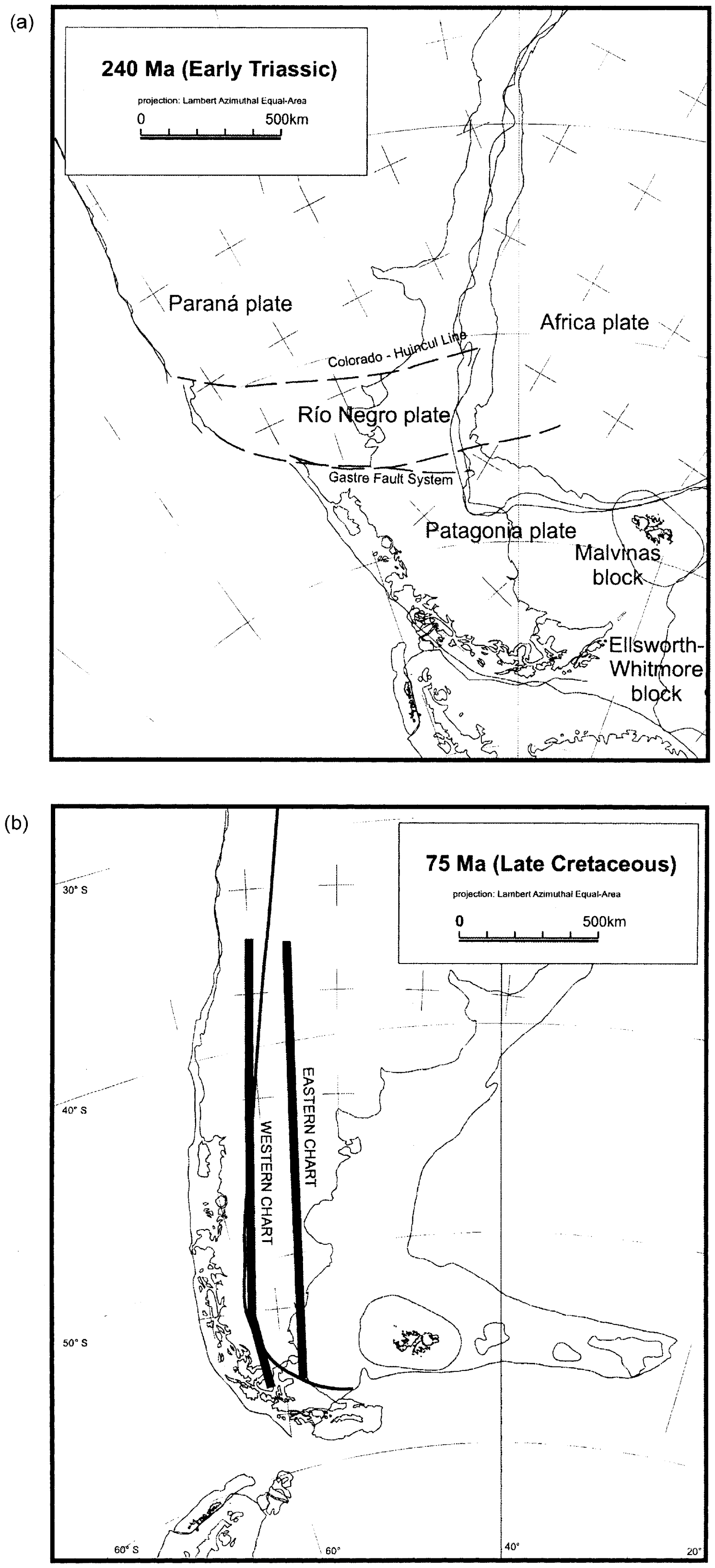

Fig. 1. Reconstructions of SW Gondwana (Lawver et al., 1999; Macdonald et al., 2003). (a) 240 Ma based on a three-plate southern South America comprising a north central (Paraná) plate, bounded to the south by the Colorado-Huincul line; a south central (Río Negro) plate, bounded to the south by the Gastre fault system; and a southern (Patagonian) plate. (b) 75 Ma, showing the location of the chronoenvironmental charts.

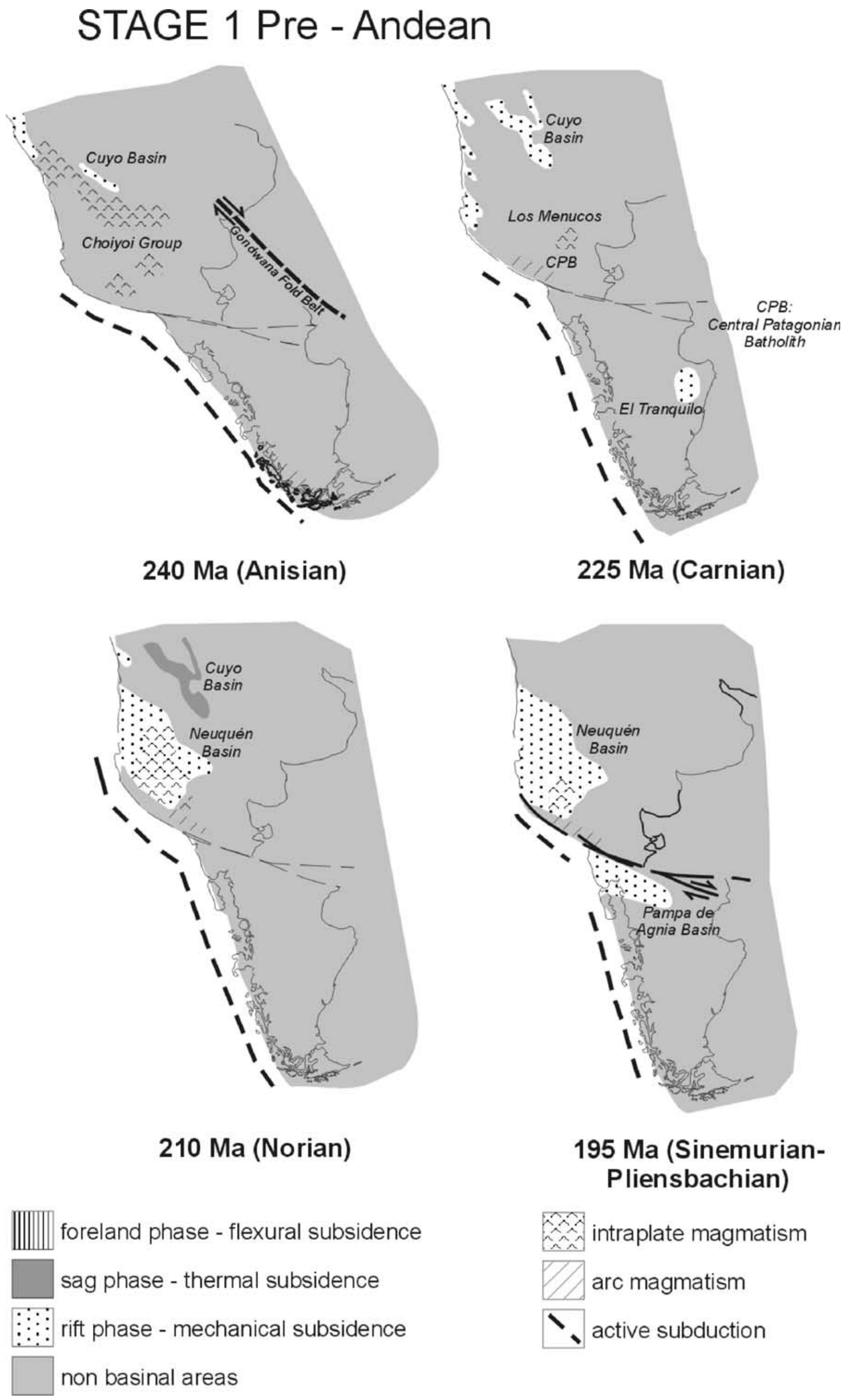

Fig. 2. Paleogeographic reconstructions of southern South America, showing the main tectonic elements and stages of evolution of sedimentary basins during the pre-Andean stage.

deposition, and the bimodal magmatism of the Choiyoi group (Ramos and Kay, 1991). The proto-Pacific margin was characterized by a series of NW–SE-oriented depocenters generated by strike-slip tectonics and filled with continental, shallow marine deposits (Charrier, 1979). The evolution of the sedimentary infill during these early events is shown by the chronoenvironmental charts (Fig. 6). The oldest synrift record of the Cuyo and related basins mainly consists of alluvial and fluvial deposits (Kokogian et al., 2001; Spalletti, 2001). Subsequently, the expansion of half-grabens favored the development of fluvio-lacustrine systems.

The last event of this tectonic stage was the Upper Triassic-Lower Jurassic extension related to the collapse of

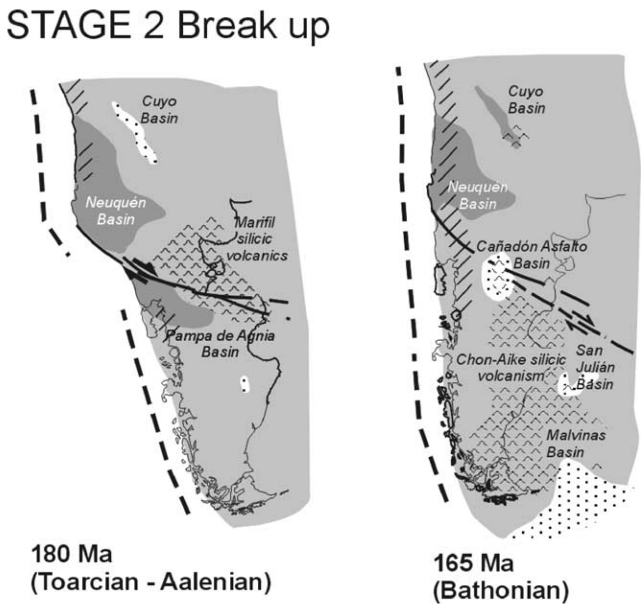

Fig. 3. Paleogeographic reconstructions of the break-up stage of basin evolution. Legend is as for Fig. 2.

the Gondwana orogen (Franzese and Spalletti, 2001). A new series of long, narrow half-grabens was formed, which were dominated by continental volcaniclastic rocks and local shallow marine deposits (Fig. 2). During the Early Jurassic, these depocenters were integrated into the Neuquén basin, where widespread lacustrine and shallow marine facies developed (Figs. 2 and 3).

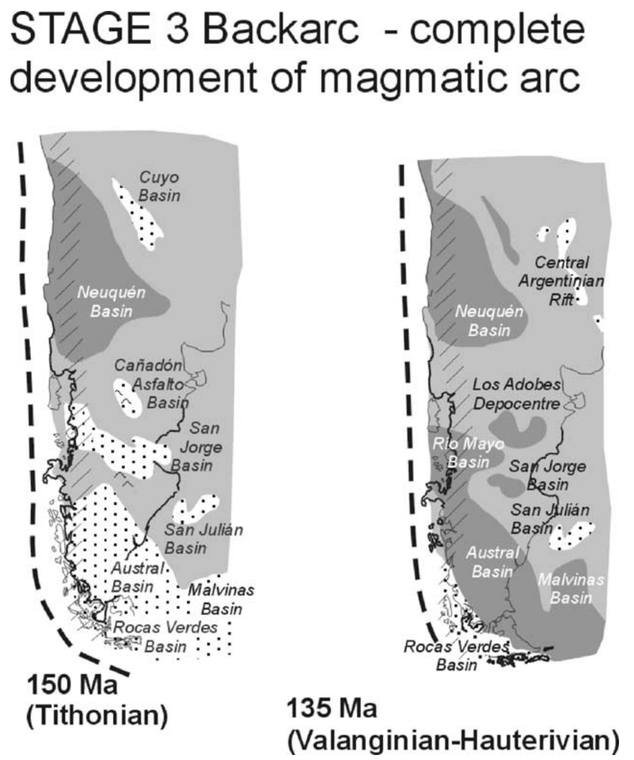

Fig. 4. Paleogeographic reconstructions of the evolutionary stage of extensional back-arc and complete development of the magmatic arc. Legend is as for Fig. 2.

At the end of the pre-Andean stage, the Cuyo basin and neighboring depocenters reached their maximum expansion as a result of thermal cooling. This sag phase was characterized by high sinuosity fluvial and lacustrine systems and followed by contraction of the depositional areas, which culminated in inversion and closure during the Early Jurassic (Fig. 6) (Spalletti, 2001).

The coeval development of the Pampa de Agnia basin (42–44°S) was related to a short-lived extension that probably was driven by dextral movement of the Gastre fault system. As shown in Fig. 6, this basin is represented by shallow marine deposits surrounded by fluvial and deltaic systems.

3.2. Break-up stage (180–165 Ma)

The second evolutionary stage began in the latest Early Jurassic (Toarcian–Aalenian) and ended in the Middle Jurassic (Bathonian–Callovian) (Fig. 3). It was characterized by widespread continental extension, the Gondwana breakup, and the opening of the Weddell Sea (Storey, 1995; Storey et al., 1996). As a result, wide areas of Patagonia were covered by extensional intraplate volcanic rocks of the Chon Aike province (Féraud et al., 1999; Pankhurst et al., 2000).

A key tectonic element of this stage is the paleogeographic reconfiguration of Patagonia along major dextral strike-slip faults (Rapela et al., 1991). This process could have been mechanically driven by the thermal effect of the Karoo plume (Macdonald et al., 2003).

Development of the Andean magmatic arc began in Patagonia in the Early–Middle Jurassic (Ramos, 1976; Haller and Lapido, 1982; Gordon and Ort, 1993; Lizuaín, 1999). Initially, the Neuquén and Pampa de Agnia basins underwent a thermal subsidence stage and the consequent expansion of the marine environment. Subsequently, tectonic inversion and growth of the magmatic arc caused the closure of the Pampa de Agnia basin and the opening of the continental depocenter of Cañadón Asfalto, along with the development of widespread lacustrine systems and marginal fluvial systems (Figs. 3 and 4). The Neuquén basin underwent a significant paleogeographic reorganization toward continental (fluvial-dominated) deposition (Fig. 6). North of the studied region, the Cuyo basin was reactivated as a new rift characterized by continental deposits and basic lava flows (Legarreta et al., 1993).

3.3. Extensional back-arc and complete development of the Andean magmatic arc (150–135 Ma)

The Andean magmatic arc was almost fully developed by the Late Jurassic (Fig. 4), whereas the paleogeographic reconfiguration of Patagonia ended when intracontinental transcurrent fault activity ceased. Regional extension associated with the opening of the Atlantic Ocean controlled the development of basins located in the continental interior and near the Andean magmatic arc.

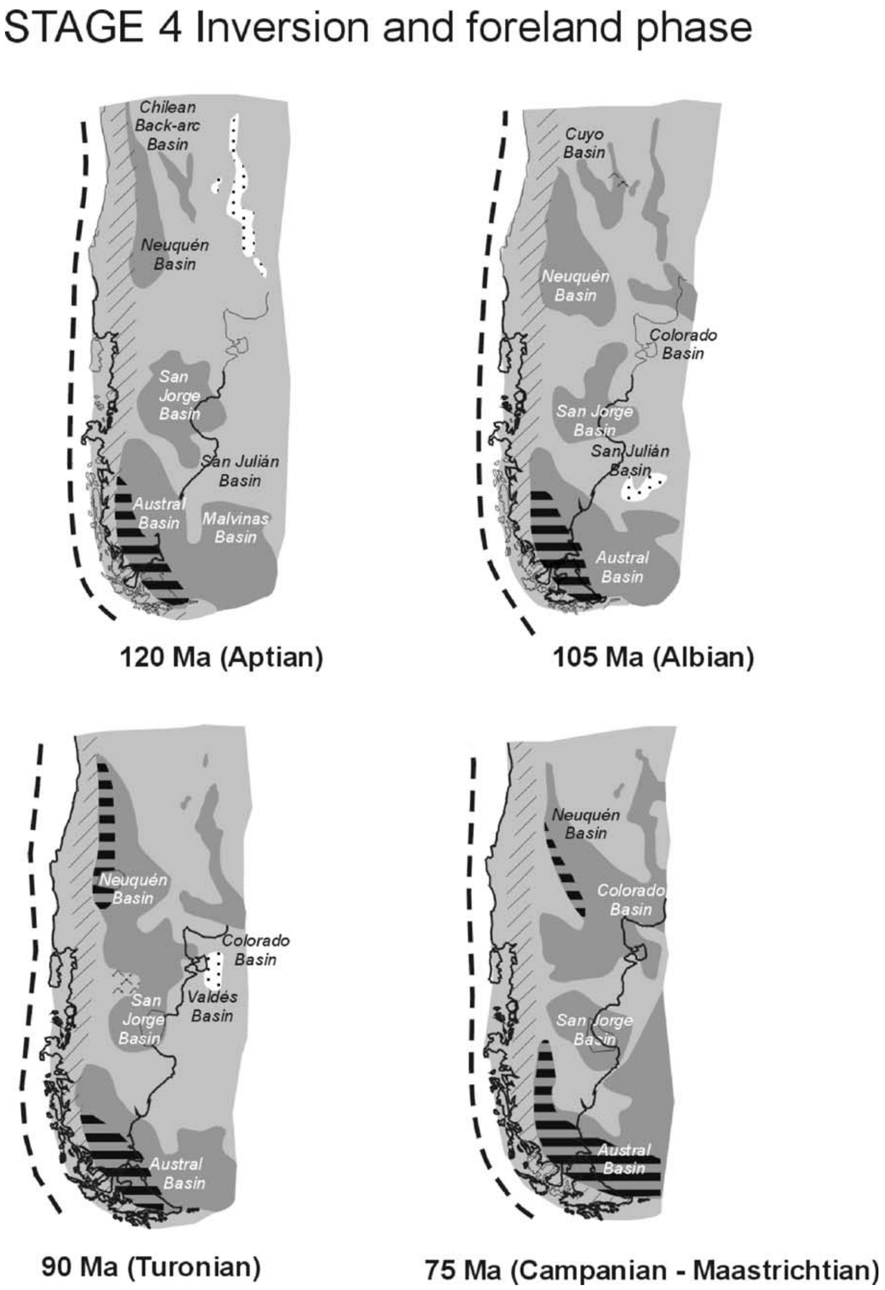

Fig. 5. Paleogeographic reconstructions of the inversion and foreland stages of basin evolution. Legend is as for Fig. 2.

In southernmost South America, the mutual influence of the Andean magmatic arc and intraplate extension resulted in the opening of the Austral (or Magallanes) basin (Figs. 4 and 6).

At the beginning of this stage, back-arc and intra-arc extension permitted several depocenters to open along western Patagonia, such as the Río Mayo basin, as well as rifting related to the Ibáñez group (Suárez and de la Cruz, 2000) and El Quemado complex (Franzese and Poiré, 2001). These depocenters were associated with explosive volcanism and lava flows, which represent the final expression of Chon Aike volcanism (Pankhurst et al., 2000). To the south, a deep marginal basin with an oceanic crust floor (Rocas Verdes; Dalziel et al., 1974) developed along the back-arc axis (Figs. 4 and 6).

In the continental interior, Upper Jurassic intraplate extension reactivated preexisting depocenters and originated new ones, such as the San Jorge basin (Fitzgerald et al., 1990). Intracontinental basins (e.g. Cañadón Asfalto, San Julián, San Jorge, Cuyo) are characterized by mechanical subsidence, continental (fluvial and lacustrine) deposition, and strong volcaniclastic influx (Figs. 4 and 6). The initial rifts of the eastern Austral basin also were formed as a result of this extensional process; shallow

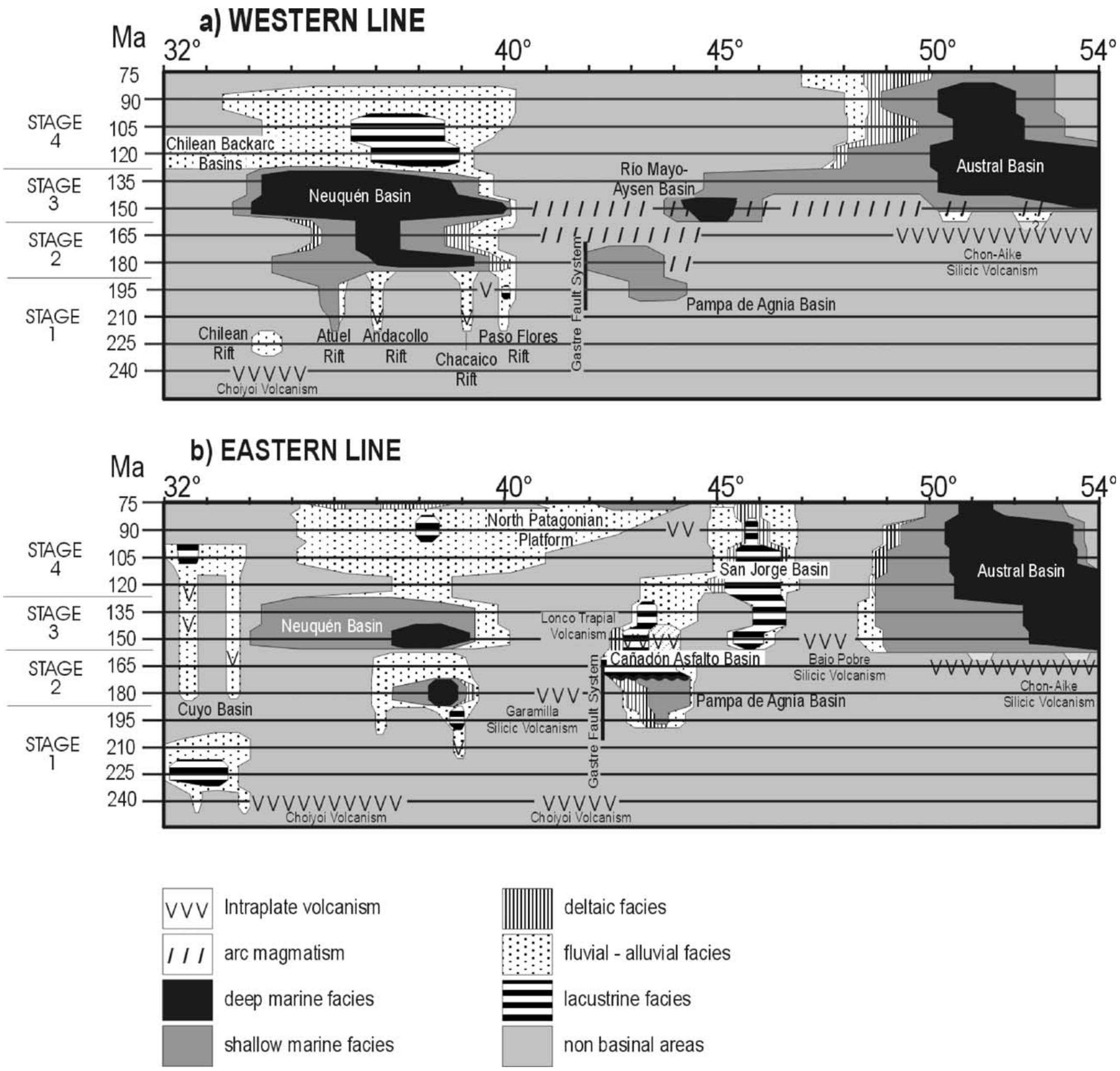

Fig. 6. Chronoenvironmental charts illustrating the spatial and temporal distribution of depositional systems and the main magmatic events. (a) Western chronoenvironmental chart along 70°30′W. (b) Eastern chronoenvironmental chart along 69°W.

marine clastic deposits demonstrate a close paleogeographic relationship with the Weddell Sea (Spalletti and Franzese, 1996).

During the Early Cretaceous, thermal subsidence enabled generalized marine sedimentation in almost all the Patagonian back-arc basins (Fig. 6). The Neuquén basin reached its maximum sag phase with transgressive facies, starvation, and anoxia (Spalletti et al., 2000). Active extension continued in southernmost Patagonia, where the Rocas Verdes basin (Dalziel et al., 1974) was dominated by deep marine conditions and turbidite systems.

From 135 Ma, narrow, deep rift furrows composed of a thick record of continental red beds developed in central Argentina (Central Argentinian Rift; Urien et al., 1995; Ramos, 1996, 1999; Fig. 4). These were connected to taphrogenic basins (e.g. Colorado, Salado) related to the opening of the south Atlantic Ocean.

3.4. Foreland stage (120–75 Ma)

In mid- to late Cretaceous times, as the south Atlantic spread, Andean compressional tectonics caused the inversion of previous extensional structures (Mpodozis and Ramos, 1989). A retro-arc foreland phase started in the Neuquén basin and the western part of the Austral basin (Figs. 5 and 6). This process resulted in the closure of the connection between them and the proto-Pacific Ocean. Some arc-related depocenters became definitively closed (e.g. Río Mayo; Spalletti et al., 1999; Folguera et al., 2000). The intracontinental San Jorge basin also underwent partial inversion, followed by a second synrift-postrift stage (Fitzgerald et al., 1990) (Fig. 6).

The Austral basin was characterized by a flexural foredeep that progressively migrated east as Andean deformation proceeded (Biddle et al., 1986). This process was associated with continental deposition along the foothills of the magmatic arc and strong progradation of fluvial and deltaic facies toward the axis of the basin, where offshore environments still prevailed. The Neuquén basin was characterized by depocentral evaporitic facies associated with marginal fluvial and aeolian deposits (Legarreta and Uliana, 1991). In the Neuquén basin, inversion began in the Late Cretaceous and was accompanied by the deposition of thick, widespread fluvial red beds of the Neuquén group (Vergani et al., 1995) (Figs. 5 and 6).

By the end of the Cretaceous, continental sedimentation was widespread in central Argentina and northern Patagonia, and the Neuquén and San Jorge basins were integrated into a single giant depocenter (Figs. 5, 6). The basins related to the Atlantic opening were characterized by a sag phase that involved accumulation of shallow marine facies over fluvial and deltaic deposits. Around 75 Ma, a generalized transgression occurred, and shallow marine deposits covered wide areas of central and north Patagonia, as well as the Neuquén basin (Fig. 5). The central Argentinian rift and the Cuyo basin also experienced a sag phase and dominantly fluvial sedimentation (Spalletti and Franzese, 1996; Spalletti et al., 1999).

4. Discussion

Most of the Mesozoic basins of southwestern South America originated as a result of continental intraplate extension and Andean magmatic arc-related extension. The first stage of development of their sedimentary infill (240–195 Ma) was dominated by alluvial, fluvial, deltaic, and lacustrine facies. Shallow marine facies were restricted to basins near the proto-Pacific margin. A complex process of thermal subsidence followed this stage (180–135 Ma), especially in the larger basins, and was accompanied by a marked change in the sedimentary record. Depositional systems were dominantly marine, and the resulting sequences show common stacking of transgressive–regressive cycles of different temporal and regional magnitude. Although several authors have interpreted these sequences as the result of the interaction of different eustatic cycles (Mitchum and Uliana, 1985; Legarreta and Gulisano, 1989; Arbe, 1989; Legarreta and Uliana, 1991; Legarreta et al., 1993, 1999), regional tectonism could have exerted a significant influence on their development (Hallam, 1991; Tankard et al., 1995; Vergani et al., 1995; Galeazzi, 1996; Robbiano et al., 1996).

The sag phase of subsidence was frequently disturbed by tectonic reactivation that was related to changes in the stress field and in the growth of the magmatic arc. In some of these basins, tectonic reactivation produced new superimposed rifts and a remarkable change in the regional distribution of depositional systems.

The foreland stage (120–75 Ma) was associated with Cretaceous inversion due to a compressional regime on the Andean margin. This stage led to significant variation in the size and shape of the Andean basins, as well as eastward migration of the depocenters, and therefore in the distribution of depositional systems. South Atlantic expansion occurred coevally with this process. Toward the end of this stage, the first Atlantic transgression was recorded over large areas of Patagonia and west central Argentina.

The chronoenvironmental charts show the changes in basin geometry and the distribution of depositional systems associated with each of the tectonic stages defined herein. The passage between the pre-Andean stage and the break-up stage in the Early Jurassic is marked by the change from mechanical subsidence to thermal subsidence in the pre-Andean basins. This change favored the integration of several isolated troughs into huge depocenters and produced the first evidence of widespread marine sedimentation (Fig. 6). The transition between the break-up stage and the back-arc stage (and the complete development of the Andean magmatic arc) in the Late Jurassic was characterized by basin enlargement and the maximum expansion of marine systems (Fig. 6). Between the back-arc stage and the foreland stage, the basins located on the eastern side of the Andes became isolated from the Pacific Ocean, and smaller depocenters were totally inverted. Initial Andean uplift also favored progradation of large fluvial and deltaic systems over the depocentral facies located to the east (Fig. 6).

5. Conclusions

Four tectonic stages are defined for the Mesozoic basins of southwestern Gondwana, along the east side of the southern Andes, between 32–56°S. They are the result of the mutual influence of two major tectonic processes: subduction along the western margin of Gondwana and intracontinental extension and the opening of the southern Atlantic Ocean. These four tectonic stages conditioned the regional extent and temporal evolution of the sedimentary record in each basin. Chronoenvironmental charts thus demonstrate a common response of the main depositional systems to regional tectonism.

Acknowledgements

Manuel Suárez and Bryan Storey are specially thanked for their thorough and useful reviews of this manuscript.

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