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Editorial

# Andean Cenozoic foreland basins: a review

Interaction between the South American craton and the oceanic Nazca Plate throughout the Cenozoic gave rise to the Andean orogen and a related assemblage of retroarc foreland basins. This review partly summarizes abundant existing data on the sedimentary and tectonic evolution of Andean Cenozoic foreland basins and intends to serve as a geographic and geologic framework for the detailed papers in this special issue. Several of these papers were presented orally at a special Andean session held during the 14th Congreso Geológico Argentino, Salta, Argentina, on September 1999.

## 1. Morphology and structural style

The Central Andes form an arcuate bundle of subparallel morphostructural domains showing pronounced along-strike variations in stratigraphic and structural organization. Between 17–27°S, the Andean belt can be divided into three morphostructural domains from west to east: the Altiplano–Puna plateau, with an average elevation of 3500 m and a width of 700 km in the region of maximum curvature of the Andean orocline, the Cordillera Oriental, mostly underlain by upthrusted Paleozoic and older rocks (Isacks, 1988), attaining heights of 5000 m a.s.l., and the Sierras Subandinas, with elevations commonly not exceeding 3000 m a.s.l., and an eastward-vergent, thin-skinned structural style (Mingramm et al., 1979). East and northeast of the Sierras Subandinas the undeformed foreland underlies the Chaco plains. Southward along-strike, between approximately 24–25°S, the Sierras Subandinas give way to the Santa Barbara Ranges, which show a dominantly westward structural vergence (Kley and Monaldi, 1999).

Between 29–34°S the Andes narrow to about 250 km and consist of, from west to east, the Cordillera Principal and Cordillera Frontal, largely made of upthrusted upper Paleozoic igneous and sedimentary rocks covered by Mesozoic marine deposits, and the Precordillera, where Paleozoic and Cenozoic sedimentary rocks are dominant. The Neogene Bermejo Basin separates the Precordillera from the Sierras Pampeanas, upfaulted crystalline basement blocks bounded by high-angle westward-vergent faults.

Major fault zones oriented oblique to the main Andean structural grain (e.g. the Toro, Tucumán, and Bermejo–Desaguadero lineaments) contribute to the segmentation. Introcaso and Ruiz (this issue) argue for Quaternary transcurrent displacement along the Bermejo–Desaguadero fault, based on gravity and magnetic data.

Fig. 1 shows Central Andean morphostructural units superimposed on the depth of the subducted Nazca Plate (cf. Isacks, 1988). The plate shows a normally dipping central segment bounded by shallow dipping segments to the northwest and south. The differential plate flexure possibly developed in the Miocene (Isacks, 1988). The change in dip of the Nazca Plate controlled the along-strike segmentation noted earlier (Jordan et al., 1983), in conjunction with inherited pre-Andean controls (Mon, 1993). Giraudo and Limachi (this issue) demonstrate the control exerted by pre-Silurian relief on the structural style of the Bolivian Sierras Subandinas.

## 2. Stratigraphy and diachronism

Central Andean Cenozoic foreland basin fills attain thicknesses in excess of 7 km and are composed of continental deposits except for the local presence of a marine wedge representing the Miocene Paranense transgression. Typically, the sedimentary successions show coarsening-upward intervals ranging from shale at the base to coarse conglomerate at the top (cf. Re and Barredo, 1993; Hernández et al., 1999).

Stratigraphic subdivision of the foreland basin deposits has followed lithostratigraphic, allostratigraphic, and chronostratigraphic procedures (González-Bonorino, 2002). The lithologically monotonous Cenozoic successions in northwestern Argentina, for instance, initially were subdivided on the basis of intercalated tuff beds, a chronostratigraphic approach, in combination with conglomeratic packages to establish the boundaries. This gave rise to the informal but still employed nomenclature Terciario Subandino Inferior, Terciario Subandino Medio, and Terciario Subandino Superior. Modern mapping in this region generally has adopted allostratigraphic conventions (Starck and Vergani, 1993; Hernández et al., 1999). In central western Argentina, on the other hand, lithostratigraphic subdivisions prevailed, with each formation typically comprising one coarsening-upward succession (cf. Re and Barredo, 1993). Magnetostratigraphy has greatly aided


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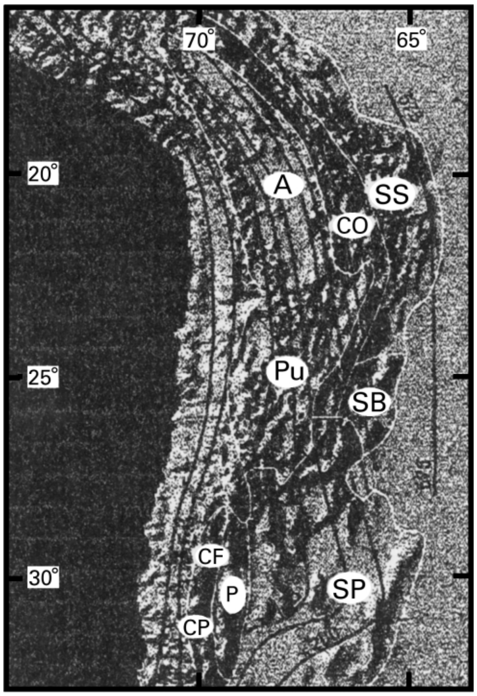


Fig. 1. Attitude of the Nazca Plate Benioff plane (from Isacks, 1988; values are depths in km) superimposed on GTOPO30 DEM of the Andes. Major Morphostructural divisions are Altiplano (A), Cordillera Oriental (CO), Sierras Subandinas (SS), Puna (P), Santa Barbara System (SB), Cordillera Frontal (CF), Cordillera Principal (CP), Precordillera (P), and Sierras Pampean (SP).

in revealing the stratigraphic architecture of these thick continental deposits virtually devoid of fossils (Reynolds et al., 1990; Re and Barredo, 1993). An important conclusion of magnetostratigraphic work has been that marked diachronism of sedimentary facies, and consequently of lithostratigraphic units, is common (Re and Barredo, 1993; Fig. 2) and that older nomenclature assuming layer-cake geology is inadequate (Reynolds et al., this issue).

## 3. Foreland basin development

A starting point for development of the Central Andes may be set in the Cretaceous. At that time topographic relief was low along the Pacific seaboard of central South America, mainly due to volcanic edifices of the ensialic magmatic arc presently located in Chile. During the Cenozoic the arc migrated farther into the South American craton in western Argentina and Bolivia. Thermally-induced forces and subduction shear at the base of the continental plate gave rise to the Andean orogen and related foreland fold-and-thrust belt (Isacks, 1988).

Areally restricted basins developed on the Altiplano–Puna crust are related to local thrusting (cf. Kraemer et al., 1999) and are not considered foreland basins. Initial development of Central Andean foreland basins related to thrusting and crustal thickening in the hinterland took place diachronously: Paleocene–early Eocene in the Altiplano–Cordillera Oriental region of central Bolivia (Sempere et al., 1997); early Tertiary (ca. 30 Ma) in the Cordillera Oriental of southwestern Bolivia and northwestern Argentina (Hernández et al., 1999) and late Oligocene (ca. 20 Ma) in the Cordillera Principal of central western Argentina (Jordan et al., 1997). Pérez (this issue) reconstructs the structural evolution of a Neogene foreland basin in the Cordillera Frontal, based on radiometric ages and the analysis of unroofing sequences.

Later development of the foreland basins appears to have taken place episodically, related to times of major structural shortening in the hinterland. A widespread and intense tectonic phase took place at ca. 10 Ma (Quechua phase in northwestern Argentina), giving rise to the Sierras Subandinas in Bolivia and northwestern Argentina, and the Precordillera in central western Argentina.

A second intense tectonic phase took place in the Pliocene (ca. 5–3 Ma; the Diaguita phase of northwestern Argentina) and was responsible for development of the

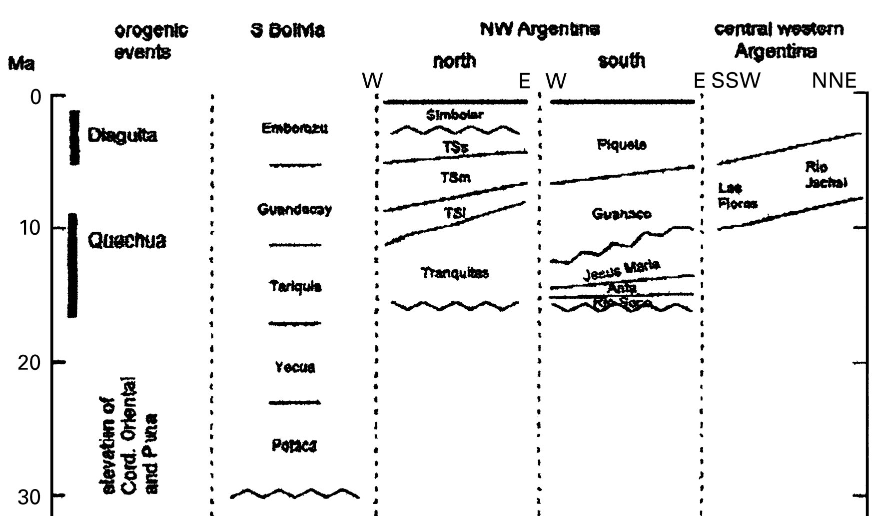


Fig. 2. Selected stratigraphic columns on the Central Andean foreland, with indications of diachronism and relation to orogenic events in the hinterland.

broken foreland areas in the Santa Barbara (Kley and Monaldi, 1999) and Pampeanas ranges (Coughlin et al., 1998). Foreland basins were structurally segmented, and intramontane basins developed. Growth strata have been recognized from outcrop (Jordan et al., 1983; Monaldi et al., 1996; Giambiagi, 1999) and seismic records (Hernández et al., 1999). Examples of growth strata as spectacular as those exposed in the Spanish Pyrenees (Riba, 1973) have yet to be reported from the Andean foreland.

The provenance of foreland basin detritus was dominantly from the hinterland (Reynolds et al., 1990; Re and Barredo, 1993; Monaldi et al., 1996), with minor contributions from broken foreland areas in the Santa Barbara Ranges in northwestern Argentina, and the Sierras Pampeanas in central western Argentina (Malizzia et al., 1995).

Central Andean foreland basin depocenters migrated from west to east (Jordan and Alonso, 1987; Starck and Vergani, 1993; Hernández et al., 1999), locally constricted by the broken foreland areas of Santa Barbara Ranges and Sierras Pampeanas, and also by sticking points interior to the fold-and-thrust belt (Giambiagi et al., this issue). In northwestern Argentina, proposed reconstructions suggest an increasing influence of the Sierras Pampeanas basement from north to south. At about 27°S, in an area transitional between the Santa Barbara and Sierras Pampeanas geologic provinces, crystalline rocks are shallow and the Tertiary cover is relatively thin. For this area Bossi et al. (1999) postulated a structurally stable situation from about 11–3 Ma and a foreland occupied by two basins incompletely separated by the crystalline uplift of the Sierras Calchaquies. Bossi et al. (this issue) suggest that the structural and sedimentary evolution of this region differed markedly from that in neighboring foreland basins, in spite of their similar stratigraphies.

Rates of erosion/sedimentation (Vergés et al., this issue), patterns of fluvial drainage (Jordan et al., 1993), styles of fluvial sedimentation (Limarino et al., this issue), and environments of deposition (Starck and Vergani, 1993; Hernández et al., 1999) in Central Andean foreland basins changed in accordance with topographic reorganization. Important climate changes may have resulted from this topographic reorganization (Starck and Anzótegui, this issue). Mechanical modeling of Central Andean foreland basins is in progress (Flemings and Jordan, 1989; Jordan et al., this issue).

## 4. Future work

Much has been learned about the geology of the Central Andean foreland basins. The stratigraphic arrangement of the basin fills has been moderately well established, and the general pattern of their tectonic and sedimentary evolution is known. A second stage of research will likely pursue a better understanding between distribution of sedimentary facies, tectonics, paleoclimate, and paleogeomorphology, and a more detailed analysis of basin partitioning both across- and along-strike. Hopefully, in time, interregional mechanical models of Central Andean foreland basin evolution will be constructed.

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## References

Bossi, G.E., Muruaga, C.M., Gavriloff, I.J.C., 1999. Sierras Pampeanas. In: González Bonorino, G., Omarini, R., Viramonte, J. (Eds.), Geología del Noroeste Argentino. Relatorio XIV Congreso Geológico Argentino, Salta, pp. 329–360.

Coughlin, T.J., O'Sullivan, P.B., Kohn, B.P., Holcombe, R.J., 1998. Apatite fission-track thermochronology of the Sierras Pampeanas, central western Argentina: implications for the mechanism of plateau uplift in the Andes. Geology 26, 999–1002.

Flemings, P.B., Jordan, T.E., 1989. A synthetic stratigraphic model of foreland basin development. Journal of Geophysical Research 94, 3851–3866.

Giambiagi, L.B.,1999. Las discordancias erosivas en los depósitos sinorogénicos neógenos de la cuenca de antepaís del Alto Tunuyán. Mendoza. XIV Congreso Geológico Argentino, Actas I, pp. 490∇493.

González Bonorino, G., 2002. Hoja Geológica Tartagal 1:250,000. Servicio Geológico Minero Argentino (en prensa).

Hernández, R.M., Galli, C.I., Reynolds, J., 1999. Estratigrafía del Terciario en el noroeste argentino. In: González Bonorino, G., Omarini, R., Viramonte, J. (Eds.), Geología del Noroeste Argentino. Relatorio XIV Congreso Geológico Argentino, Salta, pp. 316–328.

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

Jordan, T.E., Alonso, R.N., 1987. Cenozoic stratigraphy and basin tectonics of the Andes mountains, 20–28° south latitude. American Association of Petroleum Geologists, Bulletin 71, 49–64.

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

Jordan, T.E., Allmendinger, R.W., Damanti, J.F., Drake, R.E., 1993. Chronology of motion in a complete thrust belt: the Precordillera 30–31°S, Andes Mountains. Journal of Geology 101, 135–156.

Jordan, T.E., Reynolds, J.H., Erikson, J.P., 1997. Variability in age of initial shortening and uplift in the Central Andes, 16–33°30′S. In: Ruddiman, W.F. (Ed.). Uplift and Climate Change. Plenum Press, New York, pp. 41–61.

Kley, J., Monaldi, C.R., 1999. Estructura de las Sierras Subandinas y del Sistema de Santa Bárbara. In: González Bonorino, G., Omarini, R., Viramonte, J. (Eds.), Geología del Noroeste Argentino. Relatorio XIV Congreso Geológico Argentino, Salta, pp. 415–425.

Kraemer, B., Adelmann, D., Alten, M., Schnurr, W., Erpenstein, K., Kiefer, E., van den Bogaard, P., Görler, K., 1999. Incorporation of the Paleogene foreland into the Neogene Puna plateau: the Salar de Antofalla area, NW Argentina. Journal of South American Earth Sciences 12, 157–182.

Malizzia, D.C., Reynolds, J.H., Tabbutt, K.D., 1995. Chronology of Neogene sedimentation, stratigraphy, and tectonism in the Campo de Talampaya region, La Rioja Province, Argentina. Sedimentary Geology 96, 231–255.

Mingramm, A., Russo, A., Pozzo, A., Cazau, L., 1979. Sierras Subandinas. In: Segundo Simposio de Geología Regional Argentina. Academia Nacional de Ciencias, Córdoba I, pp. 95–137.

Mon, R., 1993. Influencia de la orogénesis Oclóyica (Ordovícico–Silúrico) en la segmentación andina en el noroeste argentino. XII Congreso Geológico Argentino, Actas III, pp. 65–71.

Monaldi, C.R., González, R.E., Salfity, J.A., 1996. Thrust fronts in the Lerma Valley (Salta, Argentina) during the Piquete Formation deposition (Pliocene–Pleistocene). Third ISAG, St. Malo, pp. 447–450.

Re, G.H., Barredo, S.P., 1993. Esquema de correlación de las formaciones terciarias aflorantes en el entorno de las Sierras Pampeanas y la Precordillera argentina. XII Congreso Geológico Argentino y II Congreso de Exploración de Hidrocarburos, Actas II, pp. 172–179.

Reynolds, J.H., Jordan, T.E., Johnson, N.M., Damanti, J.F., Tabbutt, K.D., 1990. Neogene deformation of the flat-subduction segment of the Argentine–Chilean Andes: magnetostratigraphic constraints from Las Juntas, La Rioja province, Argentina. Geological Society of America Bulletin 102, 1607–1622.

Riba, O., 1973. Las discordancias sintectónicas del Alto Cardener (Prepirineo catalán), ensayo de interpretación evolutiva. Acta Geológica Hispánica 8, 90–99.

Sempere, T., Butler, R.F., Richards, D.R., Marshall, L.G., Sharp, W., Swisher III, C.C., 1997. Stratigraphy and chronology of Upper Cretaceous–lower Paleogene strata in Bolivia and northwest Argentina. Geological Society of America, Bulletin 109, 709–727.

Starck, D., Vergani, G., 1993. Desarrollo tecto–sedimentario del Cenozoico en el sur de la provincia de Salta—Argentina. XII Congreso Geológico Argentino, Actas I, pp. 433–452.

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