Sedimentary record of plate coupling and decoupling during growth of the Andes

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ABSTRACT

Geochronologic, provenance, and sediment accumulation records from the long-lived (>100 m.y.) retroarc basin at the transition from the central to southern Andes provide improved resolution to examine the duration and controls on mixed-mode deformation and an enigmatic foreland depositional hiatus. Detrital zircon U-Pb ages for the Malargüe and Neuquén basin systems of western Argentina reveal shifts in exhumation and accumulation compatible with magmatic-arc and thrust-belt sources during unsteady Cretaceous–Neogene deformation. Fully developed foreland basin conditions were only achieved during separate periods of Late Cretaceous and Neogene shortening contemporaneous with possible episodes of enhanced coupling between a westward-advancing South American plate and the subducting Nazca slab. Separating these two contractional episodes is a 20–40 m.y. phase of reduced sedimentation and unconformity development, potentially signifying a neutral to extensional mode across the retroarc hinterland to forearc region during diminished plate coupling. We propose that the Andean orogen and its foreland and forearc basins have always been sensitive to variations in subduction dynamics, such that regional shifts in slab buoyancy and subduction geometry (particularly slab dip) superimposed on plate-scale shifts in convergence have governed mechanical coupling along the plate boundary and resulting fluctuations among contractional, extensional, and neutral tectonic regimes.

INTRODUCTION

Transient shifts in geodynamic coupling along subduction boundaries (Dewey, 1980; Royden, 1993; Wells et al., 2012) may regulate the evolution of convergent-margin sedimentary basins. With sufficient age control, these basins can provide valuable constraints on the inception and duration of possible alternating modes of upper plate shortening, extension, and neutral conditions that govern orogenic growth (e.g., Ramos, 2010; Mpodozis and Cornejo, 2012). For South America (Fig. 1), it is generally accepted that mid-Cretaceous separation from Africa marked a fundamental shift to a chiefly compressive Andean orogenic regime (Dalziel et al., 1974; Mpodozis and Ramos, 1990; Coney and Evenchick, 1994). However, evidence for periodic lulls, punctuated extension, and pulsed shortening suggests a complex interplay among contrasting modes of deformation (Jordan et al., 2001; Folguera et al., 2015), potentially driven by phases of variable subduction and plate coupling.

Uncertainties on the onset and pace of Andean deformation are compounded by limited constraints on depositional timing and potentially significant unconformities, as well as incomplete documentation of responsible structures. Although long-term construction of the Andes is routinely attributed to a single switch to regional shortening (e.g., Wilson, 1991; DeCelles and Horton, 2003; Balgord and Carrapa, 2016), the central to southern Andean history of Argentina and Chile has involved proposals for mixed-mode deformation throughout Mesozoic–Cenozoic time (Maloney et al., 2013). In the retroarc Neuquén Basin and Malargüe fold-thrust belt (Fig. 2), a critical sedimentary package and regional unconformity of uncertain duration define a lengthy late Mesozoic to mid-Cenozoic transitional period of questionable tectonic conditions. We present geochronologic, stratigraphic, and sediment accumulation results in support of two distinct and broadly separated phases of Late Cretaceous and Neogene shortening, crustal thickening, and flexural foreland basin development in west-central Argentina. This seemingly anomalous record of fluctuating tectonic regimes can be reconciled with patterns of plate coupling and decoupling, highlighting an underappreciated sensitivity of retroarc basins to multiple shifts in deformation along Andean-type convergent margins.

GEOLOGIC SETTING

The transition between the central and southern Andes is situated above a 30° east-dipping segment of the subducting Nazca slab (Fig. 1). At 33°–41°S, the retroarc zone encompasses the northern Neuquén Basin and Malargüe fold-thrust belt (Fig. 2), which contain thin-skinned thrust systems and basement-involved block uplifts superimposed on Mesozoic extensional structures, with a modest 10–40 km of total east-west shortening (Manceda and Figueroa, 1995; Giambiagi et al., 2012). A 5–10-km-thick succession recorded Late Triassic to Early Cretaceous extension and postextensional thermal subsidence followed by irregular Late Cretaceous–Neogene deformation and foreland basin genesis (Vergani et al., 1995). Andean clastic sedimentation (Fig. 3) is expressed in two thick coarse-grained packages.

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Figure 1. Map of western South America showing plate boundaries (including the ~7000 km active margin), Nazca subduction zone (Peru-Chile trench, large teeth), oceanic aseismic ridges (dark gray), zones of flat-slab subduction (light gray), Andean deformation front (small teeth), and magmatic arc (triangles) of the northern, central, and southern Andes (after Ramos and Folguera, 2009).
the Cenomanian–Campanian Neuquén Group (>1000 m) and the Neogene foreland succession (>2000 m; Agua de la Piedra, Loma Fiera, and Tristeza Formations), separated by the thin, fine-grained Campanian–Paleogene Malargüe Group (<500 m; Loncoche, Roca, Picara, and Coihueco Formations). A regional disconformity of uncertain age marks the base of the Neogene succession, as defined by distinctive, heavily weathered, highly polished pebble-cobble clasts (<20-m-thick Rodados Lustrosos unit) of the basal Agua de la Piedra Formation (Fig. 3).

Provenance signatures for these deposits reflect contributions from basement blocks, fold-thrust systems, and the long-lived Andean magmatic arc (Fig. 2; Tunik et al., 2010; Combina and Nullo, 2011; Sagripanti et al., 2011). Moreover, contemporaneous igneous activity offers the potential to accurately constrain the age and duration of accumulation and the apparent hiatus between fine-grained Paleogene and coarse-grained Neogene basin fill.

U-Pb GEOCHRONOLOGY

Zircon U-Pb ages for seven sandstone and three tuffaceous sandstone samples provide provenance and chronostratigraphic constraints for the Upper Cretaceous–Neogene succession (Fig. 4; Table DR1 in the GSA Data Repository1). Laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) results were generated following methods outlined for the University of Arizona LaserChron Center (Tucson, Arizona, USA) (Gehrels et al., 2008). Compiled U-Pb age spectra for the Cenomanian–Campanian Neuquén Group (Tunik et al., 2010) show a prevailing Cretaceous population with subordinate Jurassic, Permian, and older Paleozoic ages (Fig. 4). The overlying Campanian–Paleogene Malargüe Group records replacement of these diverse populations by a narrow distribution of ages in which five samples from the Picara and Coihueco Formations display unimodal latest Cretaceous to middle Eocene populations. These samples exhibit a systematic upsection decrease in the youngest age populations, from 57.3 ± 0.5 Ma to 41.1 ± 1.1 Ma (Fig. 4). U-Pb age distributions for five samples from overlying Neogene basin fill show the introduction of a diverse assemblage spanning the range of age populations expressed in underlying samples, but with an increase in late Paleozoic basement populations (330–250 Ma). Above the disconformity, the basal conglomerate of the Neogene Agua de la Piedra Formation (Rodados Lustrosos unit; Fig. 3) contains a youngest age population of 18.9 ± 0.6 Ma, and overlying units (Loma Fiera and Tristeza Formations) yield youngest ages of 10–8 Ma (Fig. 4).

1GSA Data Repository item 2016210, U-Pb geochronological results, is available online at www.geosociety.org/pubs/ft2016.htm, or on request from editing@geosociety.org.
PROVENANCE AND CHRONOSTRATIGRAPHY

U-Pb results provide provenance signatures of the activation and variable contribution of magmatic-arc and shortening-related source regions, as well as absolute ages for Cenozoic stratigraphic units above and below the foreland disconformity.

(1) The Upper Cretaceous Neuquén Group (Figs. 3 and 4) was sourced mainly from the Late Cretaceous magmatic arc in the west, recycled Jurassic extensional basin fill, and late Paleozoic basement in the east, matching evidence for shortening-related exhumation (Tunik et al., 2010; Mescua et al., 2013).

(2) The overlying Malargüe Group (Figs. 3 and 4) shows derivation from magmatic-arc sources of latest Cretaceous–Eocene age, with restricted input from fold-thrust belt or basement sources. The youngest populations are considered to represent the age of deposition, consistent with a nearly exclusive magmatic-arc source (e.g., Horton et al., 2015). These ages demonstrate a late Paleocene through middle Eocene signal, indicating prolonged ca. 57–41 Ma deposition (Fig. 4).

(3) Above the disconformity, Neogene basin fill (Figs. 3 and 4) contains diverse ages compatible with derivation principally from the fold-thrust belt and inverted basement blocks (Giambiagi et al., 2012). The youngest ages for the Agua de la Piedra Formation yield a ca. 19 Ma basal age, requiring a ca. 41–19 Ma hiatus (Fig. 4). Overlying units show youngest ages of 10–8 Ma, in accordance with rapid Miocene synorogenic genetic accumulation in a proximal foreland basin.

SEDIMENT ACCUMULATION HISTORY

The provenance variations and stratigraphic hiatus quantified here correspond to an unsteady multiphase accumulation history. Industry age-thickness data from five wells and two surface localities in the northern Neuquén Basin (Fig. 5) reveal (1) Late Triassic–Early Cretaceous accumulation consistent with extensional and postextensional subsidence (Manceda and Figueroa, 1995); (2) a Late Cretaceous onset of rapid accumulation during early Andean shortening; (3) Paleocene to earliest Miocene slow accumulation, then disconformity development; and (4) Miocene–Quaternary rapid accumulation during late Andean shortening.

The unsteady post–100 Ma history of rapid, then slow, then rapid accumulation (Fig. 5) is potentially indicative of long-term passage of a flexural forebulge (e.g., Horton et al., 2001; DeCelles and Horton, 2003; Fuentes et al., 2011), particularly in light of the long-duration (>20 m.y.) foreland disconformity. However, the corresponding lack of evidence for significant Paleogene shortening, exhumation, thrust-belt provenance, and rapid flexural accommodation requires an alternative explanation. Given the synchrony with late middle Eocene to earliest Miocene extension farther west (Burns et al., 2006; Charrrier et al., 2007; Rojas Vera et al., 2014), we interpret the hiatus to reflect a period of no thrust loading, no flexural accommodation, and sediment bypass in the foreland, possibly amplified by minor isostatic rebound due to erosional unloading (e.g., Legarreta and Ulíana, 1991). The preceding Late Cretaceous and subsequent Neogene phases of high retroarc accommodation suggest a complex history of fluctuating deformation configurations contrary to most models of Andean orogenesis.

SUMMARY AND IMPLICATIONS

Provenance and accumulation records for the Andean retroarc basin (34°–37°S) reveal Late Cretaceous and Neogene phases of shortening-induced flexural subsidence separated by a protracted period of little to no foreland accommodation. After Late Cretaceous flexure, a ca. 60–40 Ma phase of reduced accumulation was succeeded by the ca. 40–20 Ma hiatus identified here, and then renewed Neogene flexural subsidence (Figs. 3–5). The hiatus coincided with a distinctive record of late middle Eocene to earliest Miocene extensional basin development in the adjacent Andean hinterland, magmatic arc, and forearc (Loncopué, Abanico, and Cura–Mallín basins; Fig. 2). We attribute the long-term variable pattern to (1) crustal shortening and flexural loading during enhanced plate coupling (Late Cretaceous and Neogene; Fig. 6A) alternating with protracted intervals of limited shortening and foreland accommodation during (2) neutral (ca. 60–40 Ma; Fig. 6B) to (3) extensional regimes (ca. 40–20 Ma; Fig. 6C) driven by diminished plate coupling.

Alternating phases of shortening-induced flexure and tectonic quiescence may seem broadly applicable across the Andes, but such discrete phases need not be synchronous or margin wide. In fact, late middle Eocene to earliest Miocene extension appears to have been confined to the Chile-Argentina segment at 30°–40°S. Therefore, although changes in plate coupling could represent continent-scale (>5000–7000 km along margin) variations in plate convergence, upper plate advance, and age or thickness of the subsiding slab (Sobolev and Babeyko, 2005; Schellart, 2008; Capitanio et al., 2011; Maloney et al., 2013), we contend that transient variations in slab dip, as commonly dictated by buoyancy and thickened oceanic crust at aseismic ridges or plateaus (Fig. 1) (Goucher, 2002; Ramos and Folguera, 2009), provide the most viable mode of regulating the degree of coupling at smaller length scales (<1000–2000 km) along Andean-type margins.

This interpretation reconciles proposals for seemingly disparate and contradictory modes of Cretaceous and Cenozoic deformation; i.e., late middle Eocene to earliest Miocene shortening in the central Andes at 15°–25°S (Horton et al., 2001, 2015; DeCelles and Horton, 2003; Oncken et al., 2006) versus coeval neutral to extensional conditions at 30°–40°S (e.g., Jordan et al., 2001; Folguera et al., 2015). In addition to explaining such spatiotemporal complexities, potential Pliocene–Quaternary (post–5 Ma) extension and mafic alkaline magmatism during slab steepening at 30°–40°S (Kay et al., 2006; Ramos et al., 2014; Folguera et al., 2015) raise the possibility of cyclical behavior in which phases of variable slab geometry regulate tectonic regimes and basin genesis. This proposed conceptual framework involving independent cycles of shallowing and steepening subduction operating over discrete periods along different segments of the Andes (Figs. 1 and 6) offers a potential low-shortening analog for the orogenetic cyclicity observed in high-shortening retroarc systems such as the central Andes and North American Cordillera (e.g., DeCelles et al., 2009).
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