ABSTRACT

The shortening history of the Andes is important for understanding retroarc deformation along convergent margins and forcing mechanisms of Cenozoic climate. However, the timing of uplift in the northern Andes is poorly constrained, with estimates ranging from Cretaceous to Pliocene. Detrital zircon U-Pb ages from the Middle Magdalena Valley Basin in Colombia reveal two provenance shifts during Cenozoic time. The first shift occurs between early and late Paleocene strata, where U-Pb results show a switch from Proterozoic-dominated to Phanerozoic-dominated age spectra. We attribute this change to uplift-related exhumation of the Central Cordillera. The second shift occurs between middle-late Eocene and late Oligocene strata, where increased Grenville ages and diminished Mesozoic ages can be linked to uplift of the Eastern Cordillera. Our results show that significant pre-Neogene deformation affected the northern Andes, underscoring the potential importance of Andean uplift on the dynamics of Paleogene climate.

INTRODUCTION

Despite decades of research, the forcing mechanisms for Cenozoic cooling remain elusive (Zachos et al., 2001). Intensified chemical weathering associated with tectonic uplift (Raymo and Ruddiman, 1992) has been suggested as the most plausible cause for the cooling trend in Cenozoic climate. Previous efforts have focused on the role of plateau uplift in Asia (Raymo and Ruddiman, 1992; Garzione, 2008). However, South America has the highest non-collisional plateau and longest latitudinal range of Earth’s mountain belts; if proven to have initiated during the Paleogene, the Andes could be an important force for Cenozoic climate cooling. Although pre-Neogene shortening and uplift has been proposed for the central Andes based on integrated stratigraphic and structural considerations (Horton et al., 2001; DeCelles and Horton, 2003; Horton, 2005; McQuarrie et al., 2005), the uplift history of the northern Andes remains poorly understood. For the Eastern Cordillera of Colombia, initial uplift ages of latest Cretaceous, middle Eocene, late Eocene–early Oligocene, and middle Miocene–Pliocene (Dengo and Covey, 1993; Hoorn et al., 1995; Gregory-Wodzicki, 2000; Gómez et al., 2003; Bayona et al., 2008; Parra et al., 2009; Horton et al., 2010) have all been proposed using stratigraphic and thermochronological data. Estimates for initial uplift of the Central Cordillera, based primarily on sedimentological evidence, range from mid-Cretaceous to early Cenozoic (Cooper et al., 1995; Villamil, 1999; Gómez et al., 2005; Jaimes and de Freitas, 2006). For the Western Cordillera, available studies suggest initial uplift during Late Cretaceous–early Cenozoic accretion (McCourt et al., 1984; Dengo and Covey, 1993). Detrital zircon U-Pb age analyses have proven useful in defining the provenance history of sedimentary basins and tracking exhumation of sediment source regions. In this study we evaluate erosional exhumation of the Central Cordillera and Eastern Cordillera using detrital zircon U-Pb geochronology from Cenozoic strata in the intermontane Middle Magdalena Valley Basin of the Colombian Andes (Fig. 1). Potential source regions (Horton et al., 2010; see the GSA Data Repository1), including the Western Cordillera, Central Cordillera, Eastern Cordillera, and Amazonian craton, have diagnostic basement ages, allowing us to recognize provenance shifts recorded by sediments of the Middle Magdalena Valley Basin (Fig. 2).

GEOLOGIC SETTING

Three ranges in the Colombian Andes (Western Cordillera, Central Cordillera, Eastern Cordillera) are separated by the Magdalena and Cauca valleys (Fig. 1). The Western Cordillera is composed of Late Cretaceous–Cenozoic igneous rocks of oceanic affinity (McCourt et al., 1984; Aspden and McCourt, 1986). The Central Cordillera has mixed continental and oceanic basement that is intruded and overlapped by numerous Jurassic–Cretaceous igneous rocks (Aspden and McCourt, 1986; Aspden et al., 1987; Gómez et al., 2005). The Eastern Cordillera has continental-affinity basement of Proterozoic–Paleozoic age that is mostly covered by Paleozoic–Mesozoic strata (Dengo and Covey, 1993; Gómez et al., 2005; Chew et al., 2007). To the east of these ranges and the Llanos foreland basin is the Amazonian craton, consisting of several terranes accreted to an Archean nucleus.

Cenozoic strata in the Middle Magdalena Valley Basin consist of the Lisama, La Paz, Esmeraldas, Mugrosa, Colorado, Real, and Mesa Formations. Ages of Paleocene–middle Miocene units are based on palynology and invertebrate fossils (Hopping, 1967; Nuttall, 1990; Gómez et al., 2005). Ages for late Miocene–pliocene units are based on intercalated tuffs (Gómez et al., 2005).

The Paleocene Lisama Formation transitionally overlies the Maastrichtian shallow-marine Umir Formation and records regressive sedimentation in deltaic and alluvial plains (Gómez et al., 2005). The middle to late Eocene La Paz Formation consists of amalgamated channel sandstones and minor mudstones that unconformably overlie the Lisama Formation. Eocene strata were deposited in a fluvial setting and indicate transformation of the Middle Magdalena Valley Basin into a nonmarine basin (Gómez et al., 2005). The early Oligocene Esmeraldas Formation is also composed of broadly lenticular fluvial sandstones, but with a much higher proportion of fine-grained overbank deposits. In the late Oligocene Mugrosa Formation, abundant well-developed pedogenic features have overprinted channel sandstones and floodplain mudstones. Available paleocurrent data indicate dominantly eastward flow in the La Paz and Esmeraldas Formations (Gómez et al., 2005); the Mugrosa Formation mainly shows a strike-perpendicular, westward or eastward direction. The contact with the early-middle Miocene Colorado Formation is transitional, with continued evidence for extensive pedogenesis and upward coarsening to alluvial-fan boulder conglomerates at the top. The late Miocene Real Formation is distinguished from the Colorado Formation by a greater proportion of volcanic and igneous detritus, along with northward-directed paleocurrents (Gómez et al., 2005).
METHODS

Medium- and coarse-grained sandstones were collected from the eastern limb of the Nuevo Mundo syncline, a type locality for Cenozoic fill of the Middle Magdalena Valley Basin (Gómez et al., 2005) (Fig. 1C). We obtained eight samples from five exposed formations (Fig. 1C). Detrital zircon grains were separated by standard heavy liquid techniques, selected randomly, and analyzed by laser-ablation–inductively coupled plasma–mass spectrometry in the Department of Geological Sciences at the University of Texas at Austin. Analyses and associated age calculations followed methods outlined in the Data Repository, utilizing results for zircon standards Plesovice (337.13 ± 0.37 Ma; Slama et al., 2008) and in-house standard S97–19.

We report 730 U-Pb ages (Table DR1) for the 8 samples, including only those analyses between 40% and −20% discordant for ages older than 500 Ma and between 65% and −20% discordant for ages younger than 500 Ma. A 50% uncertainty filter (2σ) was applied to all samples. Discordance was calculated based on 206Pb/238U and 207Pb/235U ages. Results are plotted on a relative age probability diagram and age histogram for each sample (Fig. 2). Following previous studies, age peaks on age probability diagrams are considered significant only if defined by three or more analyses (e.g., Dickinson and Gehrels, 2008). This approach minimizes the likelihood of erroneously identifying source terranes based on ages affected by Pb loss in young grains or discordance in older grains.

RESULTS

The lower Lisama sample (RS0114091, early Paleocene) has no significant zircon age populations younger than 500 Ma; instead, most ages are concentrated at 2000–1500 Ma and 1000–500 Ma. In contrast, the overlying upper Lisama (U821, late Paleocene), lower La Paz (U08022, middle Eocene), and upper La Paz (CU612P, middle-late Eocene) samples show abundant Phanerozoic ages, with 2 of the 3 samples exhibiting 150–100 Ma ages. Few significant populations (defined by 3 or more grains, as observed on histograms) are detected in the 2000–500 Ma range in these samples.

In comparison to the Paleocene–Eocene samples, two changes are detected in the late Oligocene–late Miocene record. For the upper Mugrosa (U08025, late Oligocene), lower Colorado (M09, early Miocene), upper Colorado (U08027, middle Miocene), and lower Real (U08028; late Miocene) samples, (1) Grenville ages (1200–900 Ma) become more abundant and (2) Late Jurassic–Early Cretaceous ages (150–100 Ma) are eliminated.

DISCUSSION AND CONCLUSIONS

Detrital zircon U-Pb ages from the Middle Magdalena Valley Basin reveal two age population shifts during the Cenozoic. The first occurs between early and late Paleocene strata, where U-Pb results indicate a change from Proterozoic-dominated to Phanerozoic-dominated age spectra. The second shift occurs between middle-late Eocene to late Oligocene strata, where Grenville ages increase markedly and Late Jurassic–Early Cretaceous ages are eliminated. Based on a review of potential sediment sources (see the Data Repository), we attribute the first shift in age spectra to a provenance change from the craton to the Central Cordillera and the second age shift to a provenance change from the Central Cordillera to the Eastern Cordillera.
We argue that separate episodes of shortening-related uplift of the Central Cordillera and Eastern Cordillera are the most plausible causes for the two provenance shifts recorded in the Middle Magdalena Valley Basin.

Age spectra of the lower Lisama sample are characterized by a lack of ages younger than 500 Ma and abundant ages older than 1500 Ma. Lower Lisama zircons can only originate from the Amazonian craton because limited ages younger than 500 Ma suggest little or no contribution from the Central Cordillera and the Eastern Cordillera (Aspden et al., 1987; Dörr et al., 1995; Cordani et al., 2005; Mejía et al., 2006). It is conceivable that craton-derived sediments were originally deposited across the Central Cordillera and subsequently uplifted and recycled into the Middle Magdalena Valley Basin. However, if this were the case, we would expect to see a mixed age signal of both the craton (older than 1500 Ma) and the arc rocks of the Central Cordillera (150–100 Ma). Because such mixed ages are not observed, we attribute the provenance of lower Lisama strata to the craton. The dominance of Late Jurassic–Early Cretaceous ages in the overlying upper Lisama sample (U821) suggests that shortening-induced uplift of the Central Cordillera was under way by middle Paleocene time. Although this shift from a craton source to Central Cordillera source could also be expressed in other stratigraphic measures, the distal facies of the Lisama Formation reveal no clear changes in lithofacies, paleoecolocations, or composition (Cooper et al., 1995; Villamil, 1999; Gómez et al., 2005).

Oligocene–Miocene samples from the Mugrosa, Colorado, and Real Formations record increased Grenville ages (1200–900 Ma) and the elimination of 150–100 Ma ages. The lack of Late Jurassic–Early Cretaceous zircons suggests limited input from the Central Cordillera, whereas the increased amount of Grenville-aged zircons is consistent with an Eastern Cordillera source. A probable source of Grenville aged zircons is the Cretaceous section of the Eastern Cordillera (Horton et al., 2010), consistent with initial recycling of the sedimentary cover of the Eastern Cordillera. Ages of ca. 600–400 Ma and 300–200 Ma are also representative of the Eastern Cordillera and Santander massifs (Horton et al., 2010). Therefore, we attribute the shift in age spectra between the La Paz and Mugrosa Formations to initial shortening-related uplift of the Eastern Cordillera between middle-late Eocene and late Oligocene time. The timing and polarity of this provenance shift matches evidence from growth strata for initial thrusting along the western flank of the Eastern Cordillera (Gómez et al., 2003).

This study, together with previous studies from the central Andes (Horton et al., 2001; DeCelles and Horton, 2003; Horton, 2005; McQuarrie et al., 2005), suggests that nearly the entire latitudinal extent of the Andes likely underwent shortening-related uplift and exhumation in the Paleogene. Potential early Andean uplift is important because Paleogene climate underwent significant changes, but the forcing mechanisms remain unclear. In theory, early Andean uplift could significantly affect climate (1) by changing the location of the Intertropical Convergence Zone (Rodwell and Hoskins, 2001; Takahashi and Battisti, 2007), which affects global climate by altering monsoons (Yancheva et al., 2007) responsible for a large amount of moisture redistribution between tropical and polar oceans (Emile-Geay et al., 2003; Nie et al., 2008); (2) by changing the atmospheric CO2 concentration via intensified chemical weathering (Raymo and Ruddiman, 2001; Takahashi and Battisti, 2007), which controls greenhouse gas concentrations; and (3) by changing the distribution of surface-water salinity between the Pacific and Atlantic Oceans and thus changing the pattern of thermohaline circulation. The existence of both the northern and central Andes, spanning the southern tropics and equatorial zones (from ~25°S to 10°N), is critical in this aspect because the belt intercepts a large amount of precipitation on the eastern Andean slope (Horton, 1999; Mora et al., 2008). This process further affects the tropical ocean-water salinity distribution, which is an important factor controlling poleward transport of warm tropical water (Knauss, 1996), thus regulating the amount of polar sea ice and the ability of sinking polar water to sustain thermohaline circulation. In summary, our results suggest that initial uplift of the Central Cordillera was under way by middle Paleocene time, and initial uplift of the Eastern Cordillera occurred between the middle-late Eocene and the late Oligocene, underscoring the potential importance of early Andean uplift on the dynamics of Paleogene climate.
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