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U-Pb ages of detrital and volcanic zircons of the Toro Negro Formation, northwestern Argentina: Age, provenance and sedimentation rates

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A B S T R A C T

The Toro Negro Formation is a foreland sequence in western La Rioja province, Argentina, which records the late-stage tectonic evolution of the Vinchina Basin. Together with the underlying Vinchina Formation, these two units represent one of the thickest and longest continually exposed foreland sections in northwest Argentina. The Vinchina basin is uniquely situated between the Toro Negro and Umango blocks of the Western Sierra Pampeanas to the north and south, the Precordillera to the west, and the Sierra de Famatina to the east. New U-Pb dating of volcanic tephra provides improved age constraints on the pace of sedimentation, and U-Pb ages of detrital zircons serve to strengthen existing provenance interpretations. We show that deposition of the Toro Negro Formation spans roughly 6.9 to 2.3 Ma: Late Miocene to Early Pleistocene. A high-relief, erosional unconformity with the underlying Vinchina Formation developed sometime between 9.3 and 6.9 Ma, although stratigraphic considerations suggest it spanned only the later part of this time interval (perhaps 7.5–6.9 Ma). Above this unconformity, undecompacted sedimentation rates are remarkably high at ~1.2 mm/yr, slowing to ~0.3 mm/yr after ~6 Ma. An unconformity in the upper part of the section is constrained to occur sometime between 5.0 and 3.0 Ma, probably beginning not long after 5.0 Ma. The timing of both unconformities broadly Matches the timing of inferred tectonic events in the Sierra Famatina ~50 km to the east, the Fiambalá basin to the north, and the Bermejo basin to the south, suggesting they May record regional tectonism at these times. Provenance interpretations of detrital zircon spectra are consistent with previous interpretations based on sediment petrography. They show that provenance did not change significantly during the course of Toro Negro deposition, precluding major tectonically-induced drainage reorganization events. Sediments were derived primarily from the north (Toro Negro Block) and west (Precordillera). The data are consistent with a subtle increase in sediment supply from the Precordillera beginning around 6.5 Ma.

1. Introduction

Foreland basin sediments are important recorders of the tectonic and climatic evolution of mountain ranges. Such stratigraphic successions have proven especially useful in unraveling the tectonic evolution of the eastern Andes, where the structural style changes rapidly and precise age control is commonly available from tephrochronology. For example, foreland sequences in northern Argentina have been critical to distinguishing regions of in-sequence thrust progradation, such as the Subandean belt, from regions of out-of-sequence thrusting that are more characteristic of the Sierras Pampeanas and Santa Barbara System (Strecker et al., 2007). Foreland sediments are also valuable records of terrestrial climate and vegetation, presenting an additional impetus for understanding their age, provenance, and depositional setting (e.g. Mulch et al., 2010).

The Bermejo basin of NW Argentina is a world-class example of

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a foreland basin that has evolved by a mixture of thin- and thick-skinned deformation (Beer and Jordan, 1989; Collo et al., 2011; Jordan et al., 1993, 2001; Milana et al., 2003). The classic model of Jordan et al. (2001) involves a transition from an initially "simple foreland" that is subsequently divided into sub-basins by the rise of mountain ranges along deep-seated basement thrusts to create a "broken foreland". In this model, the simple foreland stage from (~20-8 Ma) is primarily a flexural response to shortening in the Frontal Cordillera and Precordillera to the west. By ~6.5 Ma, uplift of the Sierras Pampeanas fragments the Bermejo foreland into more localized depocenters (Jordan et al., 2001). As additional studies have focused on these localized depocenters, it has become clear that some of the basement uplifts, particularly those in the north, such as the Vinchina Basin, are older and record a complex interplay of thin- and thick-skinned deformation throughout the Miocene (e.g. Dávila and Astini, 2007; Ciccioli et al., 2011, 2013a; Marenssi et al., 2015). Thus, many questions remain about the precise spatio-temporal pattern with which the broken foreland evolved, and how it was controlled by pre-existing structures and changes in the Pacific-South America plate dynamics.

This study seeks to better understand the history of the Toro Negro Formation, a clastic foreland sequence deposited in the Vinchina depocenter (the modern Bolson de Jagüé basin) at the northern end of the Bermejo Basin near 28.5 °S (Fig. 1). The Vinchina basin is a classic example of a localized depocenter, because it is bounded to the north, south, and east by basement-cored uplifts (Fig. 2). The Toro Negro block to the north and the Umango-Espinal arch to the south are both part of the Western Sierras Pampeanas, whereas the Sierra de Famatina to the east and Sierra de Narváez to the northeast are part of the Famatina System. To the west, the Vinchina depocenter is bound by the Frontal Cordillera and the northernmost extent of the Precordillera (Figs. 1 and 2). The Frontal Cordillera is composed of metamorphic basement, Late Paleozoic to Triassic granitoids, and young Cenozoic volcanics (Caminos, 1972; Caminos et al., 1979; Caminos and Fauqué, 2001). Farther east, the Precordillera is a thin-skinned fold-and-thrust belt, creating a series of north-south oriented mountain ranges immediately west of the Jagüé basin. The Vinchina depocenter also sits ~50 km north of a major basement structural lineament known as the Valle Fértil lineament, which is interpreted to be an important basement structure whose Miocene reactivation exerted a strong control on partitioning of the Bermejo Basin (Ciccioli et al., 2011, 2013a). The Toro Negro Formation is thus well situated to record both uplift of basement blocks in the Western Sierras Pampeanas, as well as thrust activity in the northern Precordillera (Ciccioli, 2008; Ciccioli et al., 2014a).

The sedimentology of the Vinchina depocenter has been well studied over the past 10 years (e.g. Tripaldi et al., 2001; Limarino et al., 2001; Ciccioli, 2008; Ciccioli and Marenssi, 2012; Ciccioli et al., 2011, 2013b, 2014a; Marenssi et al., 2015). In particular, the modal composition of sandstones and conglomerates has proven an effective means to establish source areas and to explore the relation between shifts in compositional framework and changes in watershed configuration (Ciccioli, 2008; Ciccioli et al., 2014a). Sandstone composition does not, however, depend exclusively on the source rocks: it may be affected by the physiography and chemical weathering in the source area, by reworking and abrasion of the sediments during transportation and sedimentation, by recycling of older sediments, and by diagenetic effects (Amorosi and Zuffa, 2011; Dickinson and Suczek, 1979; Espejo and López-Gamundí, 1994). Additionally, uncertainty regarding the age of the Toro Negro Formation has prevented sedimentological observations from being interpreted in a well-dated regional framework. Age estimates for the Toro Negro Formation have ranged from Plio-Pleistocene (Reynolds, 1987; Tabbutt et al., 1989; Ré and Barredo, 1993) to late Miocene-early Pliocene (Ciccioli et al., 2005; Collo et al., 2011). In the absence of better time control, significant uncertainty persists concerning the timing and pace of Toro Negro deposition.

This study presents eight, new U/Pb zircon ages on volcanic tephra from the La Troya section. These new dates refine the age of the Toro Negro Formation to approximately 6.87 to 2.37 Ma (Late Miocene-earliest Pleistocene). We also combine existing petrographic and clast-count data with U-Pb dating of detrital zircons from eight sites to better constrain provenance changes. These results demonstrate that the Toro Negro Formation is somewhat younger than previously thought, they define four-fold changes in sediment-accumulation rates, and they support the conclusions of Ciccioli et al. (2014a) that these sediments are derived primarily from the north and west with only minor changes in provenance over time.

2. Geologic setting

The bedrock geology in the study area is a mosaic of accreted terranes intruded by igneous rocks that record nearly every stage of Andean margin evolution. The geologic evolution is briefly reviewed here to provide a context for interpretation of detrital U-Pb ages. During Grenville time (~1300–1050 Ma), the margin of the Rio de la Plata craton was sutured with Laurentia as part of the supercontinent Rodinia (Ramos and Folguera, 2009). Numerous granitoids were intruded and sedimentary rocks accreted, which are now preserved as high-grade schists and gneisses exposed in basement blocks throughout the Western Sierras Pampeanas, e.g., the Maz, Espinal, and Umango ranges(Casquet et al., 2008; Colombo et al., 2009; Martina et al., 2005; Ramos and Folguera, 2009; Rapela et al., 2010). Spatially significant meta-sedimentary units include the dominantly quartz schists and gneisses of the El Espinal and Tambillito Formations (Turner, 1964), and the dominantly pellitic schists and gneisses of the Sierra de Maz, El Zaino, and El Taco Groups (Kilmurray, 1971).

By the early Cambrian (~535 Ma), a subduction margin was established, followed shortly by accretion of the Pampia Terrane during the middle Cambrian. Granitoids and meta-sedimentary rocks of this age are widely exposed in the Eastern Sierras Pampeanas, but are less common near the study area (Pankhurst et al., 1998). Subduction was reestablished by the early Ordovician accompanied by voluminous plutonism and intrusion of the Famatina granitoid belt from ~465 to 490 Ma and by compression during the ensuing Ocloyic orogeny (Pankhurst et al., 1998; Rapela et al., 1998; Rubiolo et al., 2002). Famatinian granites are widely exposed in the Sierra de Famatina and Sierra de Narváez (Famatina System), and sparsely exposed in the Sierra de Umango (Western Sierras Pampeanas), with ages from~ 464-481 Ma (Pankhurst et al., 2000; Rapela et al., 1999; Rubiolo et al., 2002; Varela et al., 2000, 2011). Ordovician Famatinian arc volcanism was accompanied by deposition of siliciclastic and volcaniclastic sedimentary rocks in a back-arc basin (Bahlburg and Herve, 1997; Sims et al., 1998). A thick (~3200 m) succession of Ordovician sediments exposed in the Famatina System includes siliciclastic, rocks such as the Negro Peinado, Suri, Las Planchadas, Río Bonete, Achival, La Escondida, Aguadita, and Bordo Atravesado Formations (Aceñolaza and Toselli, 1981; Aceñolaza et al., 1996; Astini et al., 2003; Mangano and Droser, 2003; Turner, 1967; among others).

During the latest Ordovician and Silurian, the Precordillera (Cuyania) Terrane docked and sutured a crustal fragment with an overlying shelf sedimentary sequence during the Ocloyic orogeny (Ramos et al., 1986; Rapela et al., 1998). The strictly defined Cambro-Ordovician Precordillera terrane is exposed to the south of the Vinchina region, including the Las Vacas, Trapiche, Yerba Loca,