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Plio–Pleistocene pumice floods in the ancestral Rio Grande, southern Rio Grande rift, USA

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Abstract

At least four times during the late Pliocene and early Pleistocene pyroclastic eruptions in the Jemez volcanic field, northern Rio Grande rift, flooded the ancestral Rio Grande with gravel-sized pumice. Following as much as 400 km of fluvial transport, the pumice was deposited in beds 0.2 to 2.0 m thick in the Camp Rice Formation of the southern Rio Grande rift. A combination of reversal magnetostratigraphy and single-crystal sanidine $^{40}Ar/^{39}Ar$ dating constrains the ages of pumice-clast conglomerates at 3.1, ~ 2.0, 1.6, and 1.3 Ma. The coarsest pumice beds (cobbles, boulders) were deposited as antidune-like bedforms in a fluvial channel and as a crevasse-splay sheet. Granule and pebble-sized pumice was deposited as dune bedforms in fluvial channels and as ripple bedforms on the floodplain. The abundance of pumice clasts in the gravel fraction (60–100%) suggests very rapid transport downriver, probably in a few days or weeks. The two older pumice-clast conglomerates correlate with the Puye Formation in the Jemez volcanic field, whereas the younger two are coeval to the Lower Bandelier Tuff and Cerro Toledo Rhyolite.

1. Introduction

The Jemez volcanic field of northern New Mexico has been the site of chemically diverse volcanism since the Miocene and represents one of the most active volcanic centers in the Rio Grande rift (Fig. 1; Gardner et al., 1986; Self et al., 1986; Goff et al., 1989). One of the youngest features in the volcanic field, the Valles Caldera, rises about 1400 m above the present level of the Rio Grande located 20 km to the east. At least four times during the late Pliocene and early Pleistocene history of the volcanic field, pyroclastic eruptions flooded the ancestral Rio Grande with gravel-sized pumice, which was then transported southward over 400 km, where it was deposited as thin (< 2 m) pumice-clast conglomerates within fluvial strata. The purpose of this paper is: (1) to describe the location and stratigraphic position of pumice-clast conglomerates in the southern Rio Grande rift; (2) to determine the age of the pumice-clast conglomerates, based on reversal magnetostratigraphy and single-crystal, laser-fusion $^{40}Ar/^{39}Ar$ dating; (3) to interpret the method of transportation and deposition of the pumice-clast

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conglomerates; and (4) to correlate pumice-clast conglomerates in the southern Rio Grande rift with potential eruptive events in the Jemez volcanic field.

2. Stratigraphy and age of pumice-clast conglomerates

Pumice-clast conglomerates have been identified at seven locations in the southern Rio Grande rift (Figs. 1 and 2). The pumice beds are in the fluvial lithofacies of the Camp Rice Formation, which has been dated between approximately 4.2 and 0.78 Ma (Repenning and May, 1986; Mack et al., 1993). Each of six stratigraphic sections contains a single pumice bed, whereas three pumice beds are present at the La Union section (Fig. 2). The pumice-clast conglomerates exist in both channel and floodplain lithofacies and range in thickness from 0.2 to 2.0 m. In all cases, pumice is the dominant gravel-sized clast (60–100% of gravel component).

The age of the pumice-clast beds has been determined by reversal magnetostratigraphy and laser-fusion $^{40}Ar/^{39}Ar$ dating of single crystals of sanidine. Reversal magnetostratigraphy is available for the Hatch Siphon and Rincon Arroyo sections (Fig. 2). The details of the paleomagnetic data are given in Mack et al. (1993). In addition, magnetostratigraphic analysis by Vanderhill (1986) suggests that all but the basal and upper few meters of Camp Rice strata near the La Union pumice-clast site corresponds to the Matuyama Chron. Polarity data from Vanderhill (1986) are not shown in Fig. 2, however, because it is not clear in detail how the section of Vanderhill correlates with the La Union pumice-clast site.

Each of the nine pumice beds was sampled for $^{40}Ar/^{39}Ar$ single-crystal, laser-fusion dating. Pumice clasts were hand picked from each sample, ultrasonically cleaned, then crushed. Sanidine phenocrysts were separated using magnetic and heavy-liquid techniques, then were ultrasonically cleaned in dilute HF. Following irradiation, using Fish Canyon Tuff sanidine (27.84 Ma) as the neutron flux monitor, individual crystals were dated using the CO_2 laser extraction system at New Mexico Geochronology Research Laboratory, following procedures detailed in McIntosh and Quade (1995). Sanidines from each sample produced relatively well-defined clusters of ages (Table 1) interpreted as the predominant eruptive age of the pumice bed. Some of the samples also contained populations of older sanidines, interpreted as representing older pumices incorporated by eruptive or fluvial processes. The quoted precision of the mean eruptive ages (Table 1) for the nine analyzed pumice beds varies widely depending on grain size and number of analyzed sanidines. Pumice from Hatch Siphon and Rincon Arroyo contain abundant large (>0.8 mm) sanidine phenocrysts, which yielded precise ages; sanidine phenocrysts from the other localities are sparse and small (<0.3 mm) and provide less precise age data. Fluvial transport processes may have removed denser, crystal-bearing pumices from the pumice population.

A combination of stratigraphic position, reversal magnetostratigraphy, and $^{40}Ar/^{39}Ar$ dating indicates the occurrence of at least four and perhaps six distinct pumice-clast depositing events in the Camp Rice Formation in the southern Rio Grande rift (Fig. 2). The oldest bed is at the Hatch Siphon section, whose pumice has been dated at 3.12 ± 0.03 Ma (Fig. 2). Reversal magnetostratigraphy is also available for the Hatch Siphon section, and the pumice-clast bed is positioned within the Kaena subchron (Fig. 2). Recent data place the boundaries of the Kaena between 3.02 and 3.11 Ma, consistent with the radiometric age of the Hatch Siphon pumice bed (Hilgen, 1991a, b; Walter, 1994; Berggren et al., 1995). That two independent techniques resulted in nearly identical ages for the Hatch Siphon pumice bed is noteworthy. In addition to 3.1 Ma pumice clasts, the Hatch Siphon bed also contains rare outsized clasts dated at 8.4 Ma. These older clasts are considered contaminants derived from one of the older volcanic units in the Jemez volcanic field or picked up during river transport south of the Jemez volcanic field.

The most frequently encountered pumice-clast conglomerate, present at Rincon Arroyo, La Union (lower), Las Cruces, and Jornada Experimental Station, yields $^{40}Ar/^{39}Ar$ dates near 1.6 Ma (Fig. 2; Table 1). The accuracy of this date is supported by reversal magnetostratigraphy at the Rincon Arroyo section, where the pumice-clast bed occupies a position between the Olduvai and Jaramillo subchrons (Fig. 2). The date of 1.6 Ma falls between the

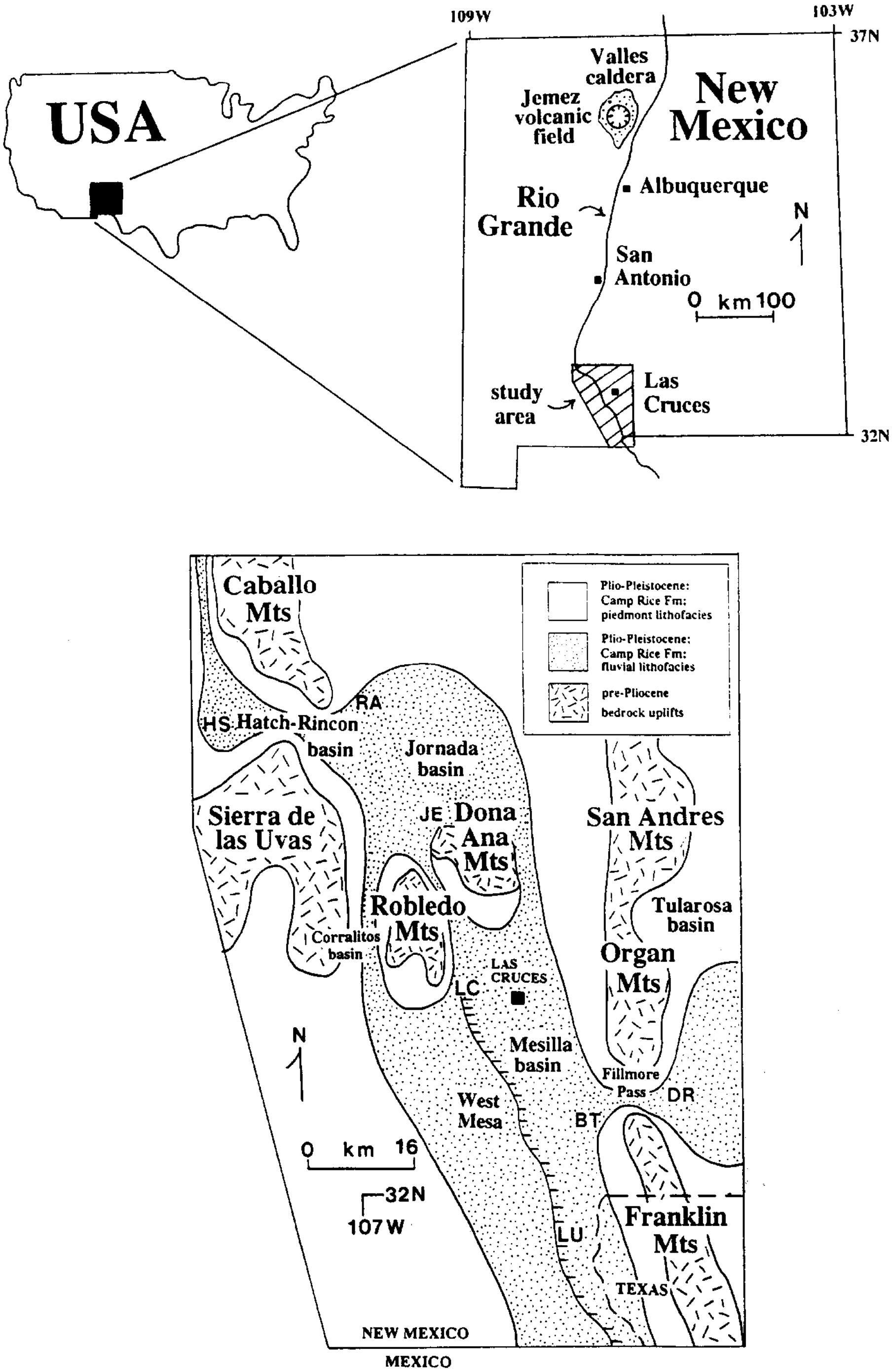

Fig. 1. Index map showing the location of the Jemez volcanic field and Valles Caldera and the location of pumice-clast conglomerates in the southern Rio Grande rift. *HS* = Hatch Siphon; *RA* = Rincon Arroyo; *LC* = Las Cruces; *BT* = Berino Tank; *DR* = Dona Ana Range Camp; *LU* = La Union; *JE* = Jornada Experimental Station.

Table 1
Single-crystal laser-fusion sanidine $^{40}Ar/^{39}Ar$ results from ancestral Rio Grande pumice deposits

Unit	n	Age $\pm 1\sigma$
Hatch Siphon	10	3.12 ± 0.03
Rincon Arroyo	7	1.59 ± 0.02
La Union, upper	5	1.32 ± 0.12
La Union, middle	3	1.31 ± 0.03
La Union, lower	3	1.59 ± 0.05
Berino Tank	5	1.84 ± 0.26
Dona Ana Range Camp	4	2.22 ± 0.27
Las Cruces	3	1.47 ± 0.07
Jornada Exp. Station	2	1.61 ± 0.10

subchrons using recent calibrations of the subchron boundaries (top of Olduvai = 1.77 to 1.84; base of Jaramillo = 1.1 or 1.07 Ma; Shackleton et al., 1990; Hilgen, 1991a; Tauxe et al., 1992; Izett and Obradovich, 1994; Berggren et al., 1995).

The La Union section contains three pumice-clast conglomerates, dated at 1.59 ± 0.05, 1.31 ± 0.03, and 1.32 ± 0.12 Ma (Fig. 2; Table 1). The La Union dates are credible, because they correspond to stratigraphic order (within the 1σ error), as well as to the determination by Vanderhill (1986) that an adjacent section is primarily Matuyama in age (2.58–0.78 Ma; Berggren et al., 1995). Despite nearly identical dates, the middle and upper pumice beds probably represent closely spaced but separate eruptive events, because they are 9 m apart stratigraphically. Alternatively, the upper bed could represent reworking of previously deposited pumice stored in the fluvial system, although this seems unlikely given the high

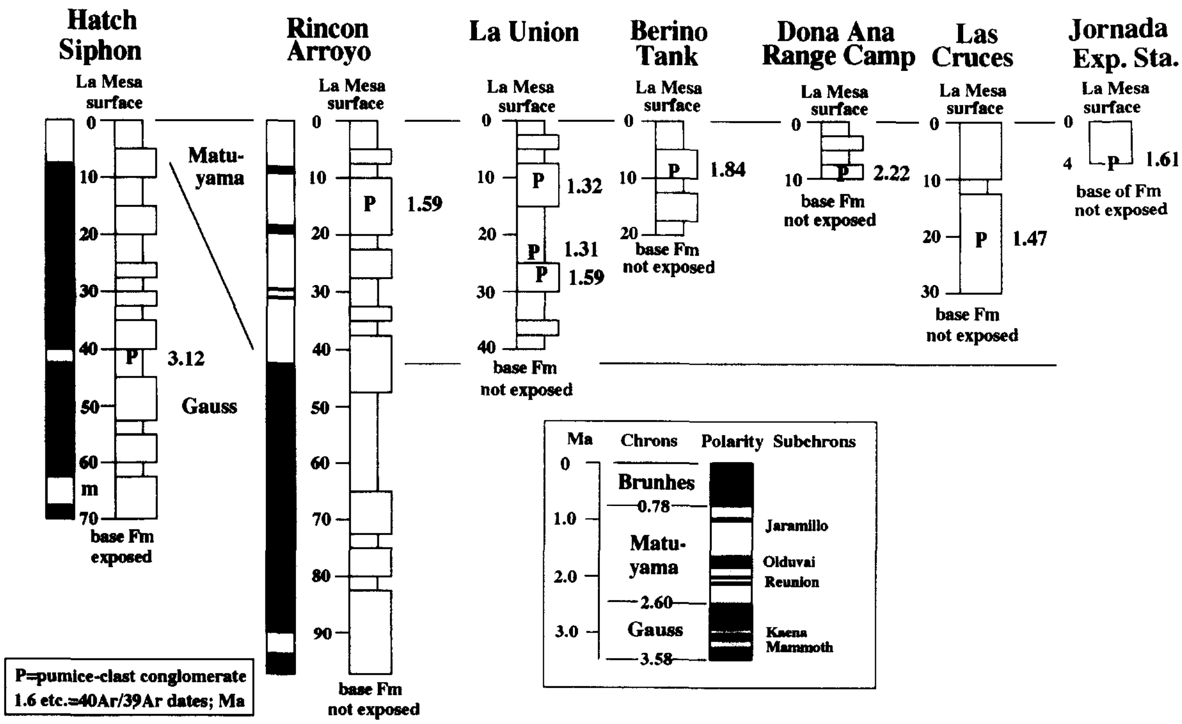

Fig. 2. Stratigraphic sections of the Camp Rice Formation showing the location of pumice-clast conglomerates (P). Numbers associated with pumice-clast conglomerates are single-crystal sanidine $^{40}Ar/^{39}Ar$ dates in millions of years. On the stratigraphic columns the ledges represent fluvial channels and the recessed areas floodplain strata. Chron boundary values for the Geomagnetic Polarity Time Scale are from Shackleton et al. (1990), Baksi et al. (1991a, b, 1992), Hilgen (1991a, b), Tauxe et al. (1992), Cande and Kent (1992), Izett and Obradovich (1994), and Berggren et al. (1995).

concentration of pumice (60%) in the gravel-sized fraction.

In addition, two pumice beds (Berino Tank, Dona Ana Range Camp) yield dates around 2.0 Ma, but these dates are not as reliable as the others, because: (1) small sanidine size limited analytical precision; (2) magnetostratigraphic data are not available for either section; and (3) the sections each contain only one pumice bed. Thus, the data suggest a distinct pumice-depositing event between 3.1 and 1.6 Ma, but existing data are not precise enough to determine whether there were separate events at 2.22 and 1.84 Ma or whether the pumice at Berino Tank and Dona Ana Range Camp represent the same event.

3. Deposition and transportation of pumice

3.1. Depositional processes

The processes by which the pumice-clast conglomerates were deposited can be interpreted from bed morphology, sedimentary structures and general considerations of physical flow mechanisms appropriate to concentrated dispersions. The coarsest pumice-clast conglomerates, at Hatch Siphon and Rincon Arroyo, are organized into symmetrical or nearly symmetrical bedforms that range in amplitude from 20 cm in the troughs to 30–50 cm at the crests and have wavelengths of 4 to 5 m (Figs. 3A, 3B).

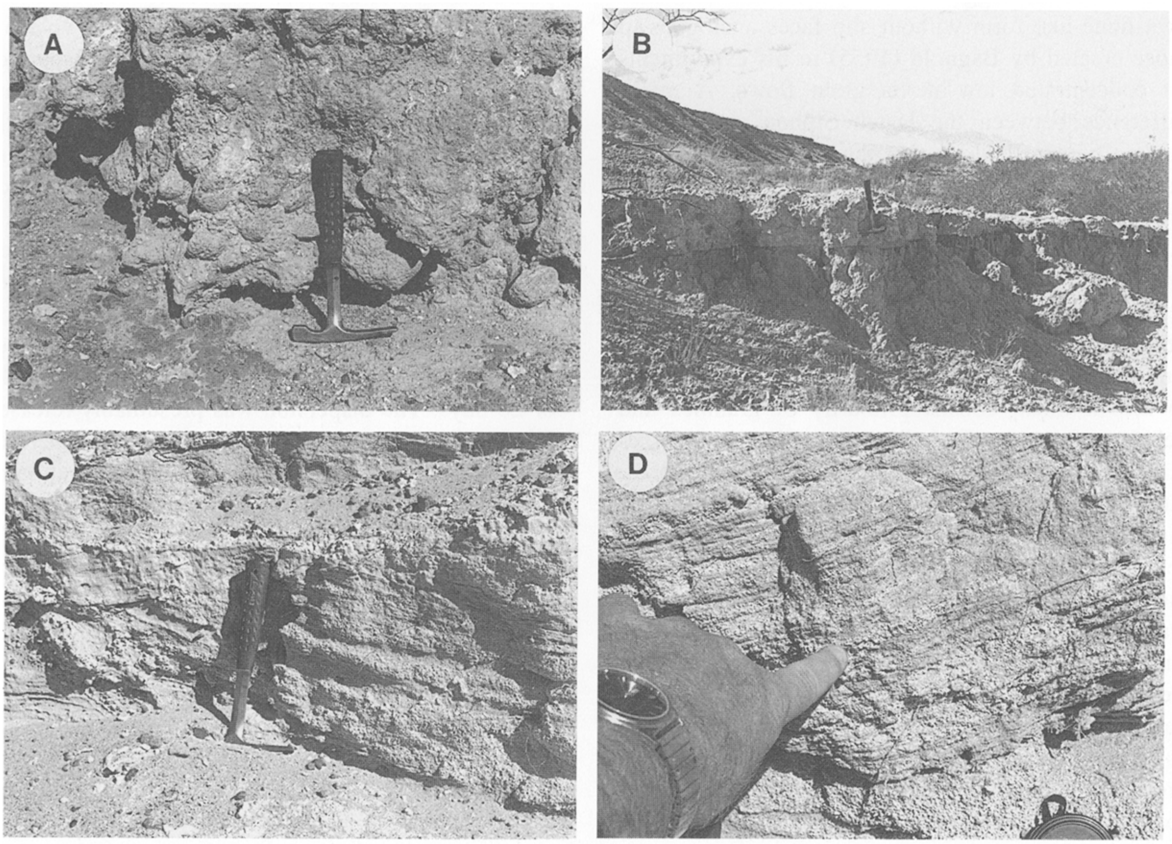

Fig. 3. Photographs of pumice-clast conglomerates in the southern Rio Grande rift. (A) Pumice cobbles at the Rincon Arroyo site; hammer is 25 cm long. (B) Antidune bedform at the Hatch Siphon site; hammer is 25 cm long. (C) Two sets of trough cross-beds at the lower La Union site; hammer is 25 cm long. (D) Foresets of trough cross-bed defined by granule-sized pumice clasts, lower La Union site.

The bedforms have erosional bases and a few rip-up clasts of mudstone and pedogenic carbonate. Both upstream-dipping and downstream-dipping, low-angle ($< 15°$) laminae are present, and in some cases the long axis of clasts are oriented parallel to the dip of the laminae. In other parts of the beds, however, the clasts show no preferred orientation or are oriented vertically. Both deposits are grain supported, moderately well to poorly sorted, and contain 80% to 100% pumice in the gravel-sized fraction. The Rincon Arroyo pumice bed is coarser, composed primarily of cobbles and small boulders, with the largest clast having an A-axis length of 50 cm (Fig. 3A). The Hatch Siphon bed consists primarily of large pebbles, but also has small cobbles up to 11 cm long and a few outsized clasts as much as 30 cm long. The symmetrical morphology, upstream-dipping laminae and lack of steeply downstream-dipping foresets in the bedforms suggest that they are either antidunes or a dune-like form without slip faces analogous to those created by Bagnold (1955) in his experiments on concentrated low-inertia grain flows. A major difference between the Hatch Siphon and Rincon Arroyo pumice beds is that the Rincon Arroyo bed occupies the basal part of a thick (6 m) fluvial channel, whereas the Hatch Siphon bed is intercalated with floodplain mudstone and very fine sand and probably represents a crevasse splay.

The most common mode of deposition of pumice-clast conglomerates was as dune bedforms in fluvial channels. These beds, which range from 0.5 to 2.0 m thick, consist primarily of granules and pebbles of pumice and display medium and large-scale trough cross-beds (Fig. 3C). In most cases, pumice is restricted to one set of cross-beds, although locally pumiceous cosets with two or three sets can be found. Pumice constitutes 60% to 90% of the gravel fraction of the cross-beds and pumice clasts commonly define individual foresets (Fig. 3D). Cross-bedded pumice beds are present at Las Cruces, Berino Tank, Dona Ana Range Camp, Jornada Experimental Station, and in the upper and lower beds at La Union (Fig. 2). Cross-bedded pumice is also present at Rincon Arroyo, overlying and locally truncating the coarser, antidune-like deposit.

The middle pumice bed at La Union represents a third mode of deposition of pumice-clast conglomerates. This bed is tabular in morphology, 30 cm thick, and is interbedded with floodplain mudstones. It consists of about 70% granules and small pebbles of pumice and has an irregular erosional base with mudstone rip-up clasts. The only sedimentary structure within the pumice bed is ripple cross-laminae. This pumice bed is interpreted to have been deposited as a crevasse-splay sheet by low-velocity currents.

3.2. Transportation

The mode of transport of pumice clasts from the Jemez volcanic field to southern New Mexico cannot be unequivocally determined. It seems clear, however, that transportation was rapid, because the pumice beds contain such a small non-pumice component. A long residence time in the ancestral Rio Grande would have allowed substantial mixing of pumice and other detritus, which is not observed. We envision a pyroclastic eruption in the Jemez volcanic field choking the ancestral Rio Grande with pumice that was immediately sent downriver by a catastrophic flow or created a dam that was subsequently breached causing a flood of pumice to move downriver. It is likely that a dense suspension of pumice clasts at or about neutral buoyancy will travel as a concentrated dispersion analogous to that contrived by Bagnold (1955) using experimental wax spheres in water flows. Released as a flood wave for velocities of 1, 3, or 5 m s^{-1} we can estimate travel times for the first wave of the pumice dispersion of 4, 12 or 20 days. The dispersion was presumably released into the floodplains of the southern rift as a supercritical but decelerating surge, causing the formation of the antidune-like forms. Alternatively these might represent analogues to the dune-like forms briefly noted by Bagnold (1955) in his experiments on dispersions of neutrally buoyant particles. Cather (1988) has interpreted a pumice-clast bed near San Antonio, New Mexico, which correlates with the lower part of the Rincon Arroyo deposit, to be a debris flow. It is possible that this could be a very concentrated development of the neutrally-buoyant pumice flood wave. There is no evidence for such a mode of deposition in southern New Mexico, but a flow could have begun as a debris flow and changed downriver into a current-driven flow. The finer fractions of pumice observed in 'normal' cross-stratified

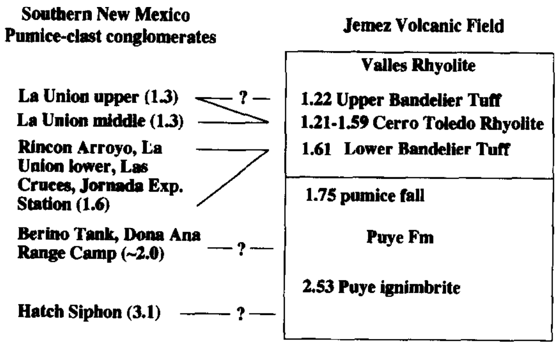

Fig. 4. Potential correlation of pumice-clast conglomerates with pyroclastic eruptive events in the Jemez volcanic field. Numbers are radiometric age dates in millions of years.

units we interpret to have been transported more slowly as bedload in dune bedforms comprising 60–90% pumice. These deposits are likely to have taken considerably longer to reach the southern rift, perhaps several weeks or months and it is remarkable that the available Rio Grande bedload sediment was able to remain so concentrated in pumice during this time.

4. Correlation of pumice-clast conglomerates with eruptive events in the Jemez volcanic field

$^{40}Ar/^{39}Ar$ and magnetostratigraphic age dates of pumice-clast conglomerates in the southern Rio Grande rift allow them to be correlated with probable eruptive events in the Jemez volcanic field of the northern Rio Grande rift (Fig. 4). The two oldest pumice-clast conglomerates, Hatch Siphon (3.1 Ma) and Berino Tank/Dona Ana Range Camp (~ 2.0 Ma), correlate with the Puye Formation in the Jemez volcanic field (Fig. 4). The Puye Formation constitutes a volcanogenic alluvial fan shed eastward from the Tschicoma volcanic center (Waresback and Turbeville, 1990). Composed primarily of andesitic and dacitic volcaniclastic sedimentary rocks, the Puye Formation also contains as many as 18 pumice-fall beds and ignimbrites, some of which can be traced to the vicinity of the modern Rio Grande (Waresback and Turbeville, 1990). Two of the pumiceous beds of the Puye Formation have been radiometrically dated: (1) the 'Puye ignimbrite', located near the middle of the formation, has been dated at 2.53 ± 0.1 Ma by the K/Ar method (Turbeville and Self, 1988); and (2) a pumice-fall bed at the top of the formation, which is correlative with the San Diego Canyon Ignimbrites, has been dated by the $^{40}Ar/^{39}Ar$ method at 1.75 ± 0.08 Ma (Spell et al., 1990). Although the dated volcanic rocks in the Puye Formation may not correlate directly with the Hatch Siphon and Berino Tank/Dona Ana Range Camp pumice beds, they suggest that Puye pyroclastic events are in the same age range as the pumice-clast conglomerates. A Puye source for the Hatch Siphon bed is further strengthened by the fact it is dacitic in composition (63.75% SiO_2; G. Mack, unpubl. data), as are many Puye rocks.

The youngest three pumice-clast conglomerates in the southern Rio Grande rift are coeval to the Lower Bandelier Tuff and Cerro Toledo Rhyolite (Fig. 4). The Lower Bandelier Tuff has recently been dated by the $^{40}Ar/^{39}Ar$ method at 1.608 ± 0.01 Ma (Spell et al., 1994; Izett and O'Bradovich, 1994), a date that is similar to that of the pumice beds at Rincon Arroyo, Las Cruces, Jornada Experimental Station, and the lower bed at La Union. The 1.3 Ma pumice-clast conglomerates (upper and middle beds at La Union) correlate with tephra deposits of the Cerro Toledo Rhyolite, which yield $^{40}Ar/^{39}Ar$ dates ranging from 1.212 ± 0.009 to 1.593 ± 0.009 Ma (Spell et al., 1994). It is also possible that the upper pumice bed at La Union (1.32 ± 0.12 Ma) was derived from the Upper Bandelier Tuff (1.225 ± 0.008 Ma; Spell et al., 1994).

5. Conclusions

Pumice-clast conglomerates deposited by the ancestral Rio Grande represent a type of volcaniclastic sedimentary rock that is rare in the rock record and provide a distal record of pyroclastic volcanism in the Jemez volcanic field. Although pumiceous sandstones and conglomerates are common in volcanic aprons, transportation of individual pumice floods for hundreds of kilometers by a major rift-axial river system has not been described to our knowledge outside of the Rio Grande rift. Moreover, the pumice beds set constraints on the age of the Camp Rice Formation and provide accurate time markers for correlation of the nonmarine strata. Existing questions concerning the age and correlation of pumice beds in the study area may be resolvable by continued magnetostratigraphic sampling, as well as geochemical fingerprinting.

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