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MIOCENE SEDIMENT DISPERSAL IN THE CENTRAL ESPAÑOLA BASIN, RIO GRANDE RIFT, NEW MEXICO, U.S.A.

WILLIAM CAVAZZA

Department of Earth and Space Sciences, University of California, Los Angeles, CA 90024 (U.S.A.)

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ABSTRACT

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The central Española basin in north-central New Mexico represents one of the best opportunities to examine deposits related to the development of the Rio Grande rift. The Miocene Tesuque Formation represents the bulk of the Española basin fill. It is composed of a 2000–2500 m thick sequence of alluvial–fluvial and, subordinately, lacustrine deposits with numerous interbedded ash-fall tuff layers.

The overall detrital composition of the Tesuque Formation is very similar throughout the central Española basin. Provenance is primarily from basement uplifts composed of Precambrian igneous and high-grade metamorphic rocks. Nevertheless, the combined use of paleocurrent analysis, and sandstone and conglomerate petrology allows a detailed reconstruction of the sediment paleodispersal system.

Two sedimentary provinces are present within the Tesuque Formation: Province A, present in the eastern, central and southern portions of the study area, has a predominantly plutoniclastic and metamorphiclastic composition, and shows systematic paleocurrents toward the west. The sediments were derived from the Precambrian-cored Santa Fe block of the Sangre de Cristo Mountains, located directly to the east of the study area. Province B, present only in the northwestern portion of the study area, is characterized by a minor but significant amount of volcaniclastic and sedimentaclastic detritus, and shows consistent SSW-directed paleocurrents. The source area was possibly located in the area of the Taos Plateau and Latir volcanic fields. An intermediate narrow and discontinuous belt (province A + B) represents a hybrid province, where directional and compositional parameters are gradational.

INTRODUCTION

The Rio Grande rift (RGR) is a late Cenozoic continental rift which extends from central Colorado to southern New Mexico over a distance of more than 1000 km (Fig. 1). The rift widens irregularly southward from a narrow graben in Colorado into a broad extended region in southern New Mexico, where multiple horsts and grabens are present. In its southern portion, the RGR merges with the Basin and Range extensional province and is no longer physiographically distinguishable.

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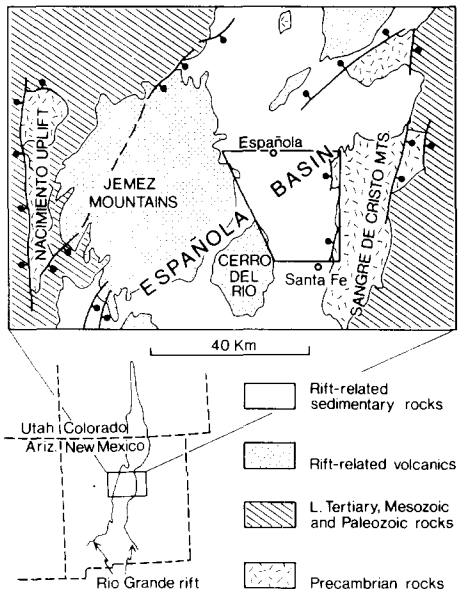

Fig. 1. Simplified geologic map of the Española basin. The study area is outlined (adapted from Manley, 1979a).

Rifting began between 32 and 27 Ma ago, initiating earlier in the southern segment of the rift (Chapin, 1979). According to Chapin (1979), by 26 Ma ago, the developing rift was characterized by broad, shallow basins in which mafic flows and ash beds were intercalated with a predominantly alluvial–fluvial fill. These early basins have been interpreted both as broad synclines (Baltz, 1978) or as being bounded by low-angle normal faults (Baldridge et al., 1984). Preservation within rift basins of complete pre-rift and syn-rift alluvial–volcanic sections argues against regional doming (i.e., active-mantle-rifting model of Sengor and Burke, 1978) as a rifting process. The modern physiography of the RGR began to form between about 7 and 4 Ma ago, when the southern Rocky Mountain and adjacent areas where strongly uplifted (Chapin, 1979). Block faulting accompanied epeirogenic uplift, disrupting the broad basins of the early RGR and forming the modern topography, with narrower, more sharply defined basins. The Rio Grande, as an integrated drainage system, developed during Pliocene time (Chapin and Seager, 1975).

The Española basin represents a segment of the central RGR in northern New Mexico (Fig. 1). The basin is bounded by the Nacimiento uplift on the west and by the Santa Fe block of the Sangre de Cristo Mountains on the east. Both uplifts are mostly composed of Precambrian igneous and medium- to high-grade metamorphic rocks (Miller et al., 1963; Manley, 1979a). The western part of the Española basin is concealed by the Jemez Mountains and Cerros del Rio volcanic fields, which were active from about 13 Ma ago (middle Miocene) to < 1 Ma ago (Bailey and Smith, 1978; Gardner and Goff, 1984).

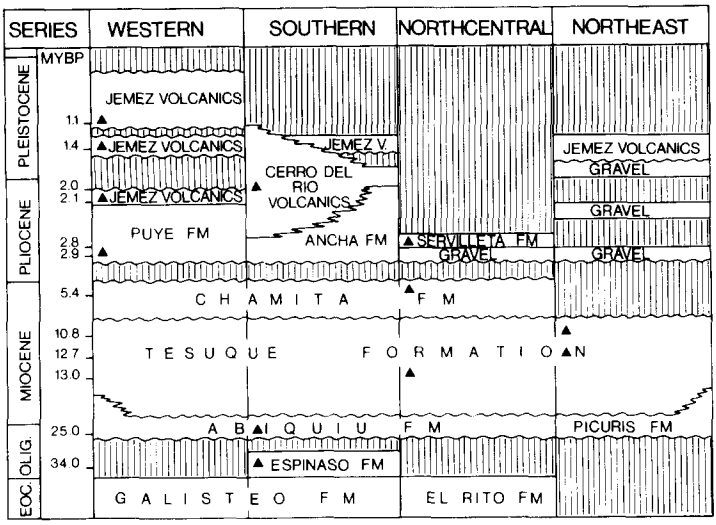

Fig. 2. Stratigraphic correlation chart for the Española basin. Radiometric ages are indicated by solid triangles (modified from Manley, 1979a).

The Española basin contains sedimentary and volcanic rocks of Eocene to Quaternary age (Fig. 2). The rock units in the basin have been described by several authors working on different areas, the resulting terminology being confusing. Broadly speaking, the sequence exposed in the Española basin can be divided into two parts: (1) a pre-rift section composed of the El Rito, Galisteo and Espinaso formations (Eocene–Oligocene); and (2) a rift-related section composed of the Abiquiu, Picuris, Tesuque, Chamita, Puye and Ancha formations (upper Oligocene–Pliocene). The rift-related section also includes the volcanic rocks of the Jemez Mountains and Cerros del Rio volcanic fields (middle Miocene–Pleistocene). Volumetrically, the bulk of the Española basin fill is represented by the Miocene Tesuque Formation, whose deposition took place from about 21 to 7 Ma ago (Manley, 1979a, b, 1984a, b). The Tesuque Formation, the object of this study, is composed of a 2000–2500 m thick sequence of conglomerate (20%), sandstone (45%), mudrock (34%), volcanic ash and carbonate (1% combined) of continental origin. Conglomerate maximum grain size (a-axis) is 40 cm. Coarsest conglomerates are concentrated along the eastern margin of the Española basin, at the contact with the Precambrian basement of the Sangre de Cristo Mountains. The Tesuque Formation was deposited in an alluvial-fan/braidplain/sandflat/ephemeral-lake depositional system (Cavazza, 1985). The age of the unit is well constrained by means of radiometric ages obtained from the tuffs (see Manley, 1979a), the large number of vertebrate fossils collected in the area by the American Museum of Natural History (Galusha and Blick, 1971) and magnetic-polarity stratigraphic data (Barghoorn, 1981).

THE STUDY AREA

The study area comprises the east-central part of the Española basin (Fig. 1). This region represents one of the best opportunities to examine deposits related to the development of the RGR. Exposure is excellent, whereas along much of the rift valley most of the syn-rift sedimentary rocks are covered by Quaternary alluvium and/or volcanic rocks.

The northern boundary of the study area is located near the town of Española. This limit is not arbitrary, since north of this imaginary line, the Nambé, Skull Ridge and Pojoaque members (Galusha and Blick, 1971), which represent the entire Tesuque Formation in the study area, interfinger with other members of the same unit (i.e., Chama–El Rito and Ojo Caliente members of Galusha and Blick, 1971; Dixon Member of Steinpress, 1981; Cejita Member of Manley, 1979b). The southern boundary of the study area is located at the latitude of Santa Fe; south of Santa Fe, the Tesuque Formation is covered by extensive gravel deposits (Kelley, 1978).

In the study area, the Tesuque Formation has a homoclinal dip toward the west. Average dip is about 20–25° in the eastern part of the basin and 0–10° in the western part. The shallow dip, as well as the small-scale intrabasinal faulting, precludes the measurement of thick stratigraphic sections at any one location. Nevertheless, the entire basin-fill sequence is well exposed across the basin.

PALEOCURRENT ANALYSIS

Current systems that deposited ancient clastics can be reconstructed by mapping directional structures as well as by mapping of the dispersal pattern of clastic particles (Potter and Pettijohn, 1977). A combined approach was used here in order to reconstruct the paleodispersal system active during deposition of the Tesuque Formation in the east-central Española basin.

The paleocurrent indicators which were measured include, in order of decreasing abundance: imbricated clasts, crossbeds, trough axes, ripples, parting lineations and channel axes. However, clast imbrications alone account for > 80% of the readings. This is due, in part, to the abundance of such sedimentary structures, and, in part, to their relatively high level of reliability (Miall, 1974). Particular care was taken in measuring only clasts having maximum clast size (a-axis) $\geqslant 5$ cm. In fact, in an alluvial environment, larger clasts are imbricated only during high stage or major flood events, and therefore, they are better paleoslope recorders. No paleocurrents from bartops or from the tops of beds were measured, since they are likely to record diverging flows during waning stage. The effect of structural tilt was removed from the readings through a graphic method (Potter and Pettijohn, 1977, fig. 10-6). Means, standard deviations and rose diagrams were calculated and constructed using a computer program based on the use of circular statistics (Batschelet, 1981), thus avoiding the errors introduced by using linear statistics (Curray, 1956; Watson, 1966).

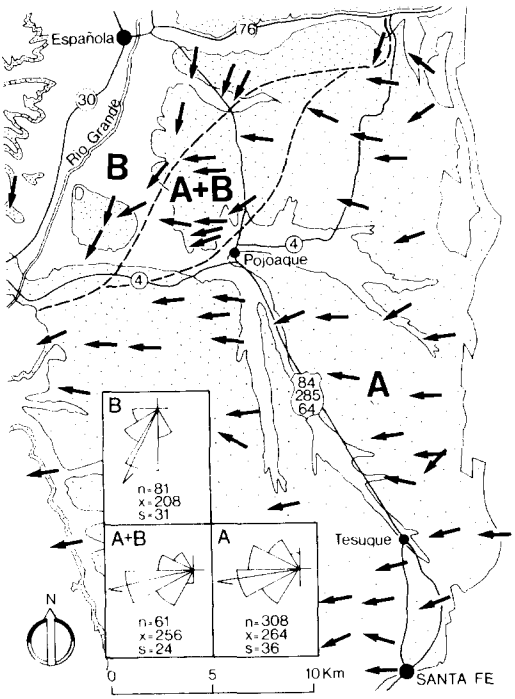

Fig. 3. Paleocurrent vector azimuths within the Tesuque Formation (stippled) in the east-central Española basin. Arrows indicate the vector mean at each location. 1–20 measurements were taken at each location, the average being eight. Paleocurrent rose diagrams refer to sedimentary provinces *A*, *A* + *B* and *B* discussed in the text, *n* indicates the number of measurements, *x* indicates the mean and *s* indicates the standard deviation from the mean.

The vector means display systematic paleoflow toward the west across most of the basin (Fig. 3). In the northwestern part of the study area, equally consistent SSW-directed paleocurrents are present. The areal distribution of the vector means was divided into two groups: Province A and A + B include the westward paleocurrents; whereas the northwestern part of the study area, where SSW-directed paleocurrents are predominant, was called province B. The W-directed paleocurrents were divided into two provinces (A and A + B) because they have different petrologic characteristics (see following section). Nevertheless, provinces A and A + B have the same paleocurrent trend and, in this respect, they can be considered as a single province.

SANDSTONE PETROLOGY

As clastic sediments are generated and dispersed by currents or sediment gravity flows, they are subjected to various forms of physical and chemical weathering. In

spite of these processes, sediments may retain a distinctive detrital composition, particularly in tectonically active settings, where sediment erosion, transport and burial are rapid. Therefore, within a given basin, a particular lithosome may become fingerprinted with a distinctive size range and composition, and detrital composition can be used as a paleodispersal indicator (Miall, 1984).

Forty-two coarse- to fine-grained arenite samples from the study area were point-counted. This number includes three samples taken at the very base of the Tesuque Formation. These three samples, located along the eastern margin of the basin, are volcaniclastic, due to erosion of a few basalt flows locally interbedded with the sedimentary section. The maximum thickness of these local, basal Tesuque Formation deposits is 20–25 m. They grade upward into the more arkosic sandstones of the "normal" Tesuque Formation. The basalt flows and related epiclastic deposits rest directly on Precambrian basement. They were deposited during the earliest stage of rifting and may be equivalent to the Abiquiu (Smith, 1938; Vazzana and Ingersoll, 1981) and Picuris (Cabot, 1938) formations, which are present just north and northeast of the study area.

All sandstone samples were cut perpendicular to bedding, and impregnated; half of each section was stained for both plagioclase and potassium feldspar. Point counts were performed with sample locations unknown to avoid bias. The maximum possible grid spacing was chosen that allowed 500 points to be counted on each slide. Sandstone point counts were performed following the procedures outlined by Gazzi (1966) and Dickinson (1970), and discussed by Gazzi et al. (1973), Zuffa (1980) and Ingersoll et al. (1984). Point-counting parameters are explained in Table 1, whereas Table 2 reports the recalculated parameters for each sample. Point-counting raw data and location of samples are available from the author upon request (see Cavazza, 1985).

Walker et al. (1978) demonstrated how the mineralogy, texture and chemical composition of first-cycle desert alluvium can be drastically changed diagenetically. Particular care was taken during the course of this study in order to recognize any diagenetic alteration of the framework grains which might affect the determinations. No significant alterations were detected and, therefore, detrital modes can be safely utilized to reconstruct provenance.

The Tesuque Formation sandstones can be broadly classified as "arkoses" (i.e., quartz–feldspar-rich arenites). The average Tesuque sandstone, not including the thin and discontinuous volcaniclastic basal unit, is composed of 55% quartz, 38% feldspars and 7% lithic fragments (recalculated to QFL%). In spite of the overall similarity in sandstone composition, there are several parameters that allow significant subdivision (Fig. 4).

The sample population can be divided into two groups. The first group, corresponding to province A in Fig. 4, is composed of quartzofeldspathic, lithic-poor arenites (average QFL%L = 3). The second group is characterized by a significant influx of volcanic and sedimentary lithic fragments (average QFL%L = 10; average

TABLE 1

Explanation of petrographic parameters

Q = Qm + Qp	where	Q	= total quartzose grains
		Qm	= monocrystalline quartz grains
		Qp	= polycrystalline quartz grains
F = P + K	where	F	= total feldspar grains
		P	= plagioclase feldspar grains
		K	= potassium feldspar grains
Lt = L + Qp	where	Lt	= total aphanitic lithic grains
		L	= total unstable aphanitic lithic grains
L = Lm + Lv + Ls	where	Lm	= metamorphic aphanitic lithic grains
		Lv	= volcanic-hypabyssal aphanitic lithic grains
		Ls	= sedimentary aphanitic lithic grains
L = Lvm + Lsm	where	Lvm	= volcanic-hypabyssal and metavolcanic aphanitic lithic grains
		Lsm	= sedimentary and metasedimentary aphanitic lithic grains
Framework = Q + F + L + M + Mc	where	M	= monocrystalline phyllosilicate grains
		Mc	= miscellaneous and unidentified framework grains

Further description of the parameters can be found in Dickinson (1970).

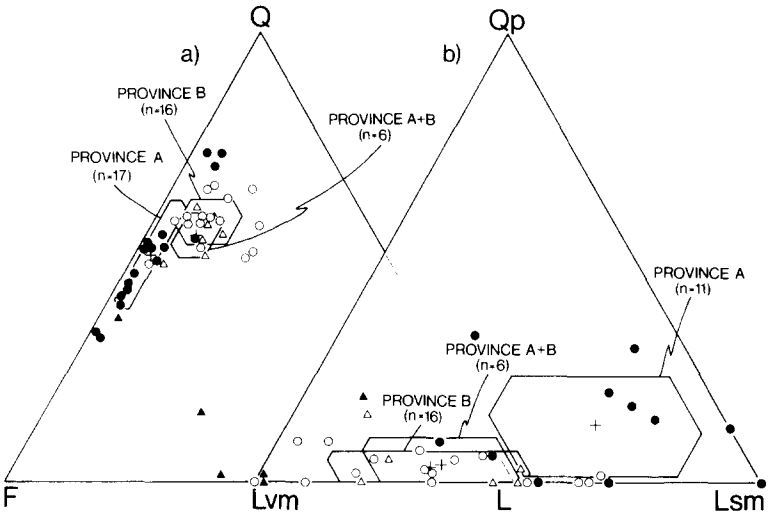

Fig. 4. (a) Sandstone QFL triangular diagram. *Q* indicates quartz (including polycrystalline quartz), *F* indicates feldspars and *L* indicates unstable lithic fragments. (b) Sandstone QpLvmLsm triangular diagram. *Qp* indicates polycrystalline quartz (including chert), *Lvm* indicates volcanic-metavolcanic lithics and *Lsm* indicates sedimentary–metasedimentary lithics. For both diagrams, crosses and polygons represent means and standard deviations, respectively, for sedimentary provinces *A* (solid circles), *A* + *B* (open triangles) and *B* (open circles). Solid triangles represent three samples from the very base of the Tesuque Formation (see text); the mean and standard deviation for these samples have not been calculated because of the small sample population. Numbers in parentheses indicate number of samples for each province. Only eleven out of seventeen samples from province *A* are included in the QpLvmLsm diagram since they are the only ones with a statistically significant population of lithic fragments.

TABLE 2

Sandstone point-counting data

Sample	QFL%					FRMW%				QpLvmLsm%			LmLvLs%		
	Q	Qm	F	L	Lt	M	P/F	Lv/L	Qp/Q	Qp	Lvm	Lsm	Lm	Lv	Ls
Basal Tesuque															
7-1	36	35	60	4	5	5.2	0.77	0.85	0.02	19	69	12	15	85	0
29-1	1	1	57	42	42	0	0.94	1	0	0	100	0	0	100	0
33	15	15	54	31	31	1.5	0.83	1	0	0	100	0	0	100	0
X	17	17	57	26	26	2.2	0.85	0.95	0.01	6	90	4	5	95	0
SD	18	17	3	20	19	2.7	0.09	0.09	0.01	11	18	7	9	7	0
Province A															
2-2	52	51	43	5	6	5.4	0.55	0.12	0.01	6	50	44	76	12	12
4	46	45	52	2	3	0.5	0.73	0	0.01	20	20	60	63	0	37
8	53	53	46	1	1	6.8	0.58	1	0.01	33	67	0	0	100	0
9-2	49	48	46	5	5	8	0.50	0.50	0.04	33	40	27	30	50	20
14-1	55	54	42	3	4	4.8	0.55	0.10	0.01	17	17	66	60	10	30
15-2	44	43	54	2	3	4	0.71	0.08	0.01	14	14	72	25	8	67
25	53	53	46	1	1	7.8	0.72	0	0.01	50	0	50	0	0	100
30	73	72	21	6	6	2.9	0.43	0.55	0.01	9	59	32	15	55	30
34	73	73	24	3	3	1.2	0.32	0.33	0	0	44	56	33	33	33
36	39	39	58	3	3	5.3	0.67	0.30	0	0	30	70	60	30	10
43	41	41	57	2	2	2.8	0.70	0	0	0	0	100	100	0	0
44	43	43	55	2	2	4.3	0.69	0.40	0	0	40	60	60	40	0
56	54	54	36	10	10	0	0.58	0	0	0	0	100	10	0	90
57	70	68	24	6	7	0.8	0.66	0	0.01	12	0	88	0	0	100
58	33	33	66	1	1	4.7	0.70	0	0	0	0	100	100	0	0
59	32	31	66	2	3	1.4	0.70	0	0.03	30	10	60	43	0	57
77	53	53	46	1	1	0.8	0.57	0	0	0	50	50	50	0	50
X	51	50	46	3	4	3.6	0.61	0.18	0.01	13	26	61	38	18	44
SD	12	12	14	2	3	2.6	0.12	0.21	0.01	12	20	22	25	21	30

Province A + B															
46-1	57	57	32	11	11	1.8	0.68	0.48	0	0	48	52	6	48	46
48	61	61	32	7	8	0.8	0.54	0.72	0.01	5	71	24	11	72	17
49-2	55	55	30	15	15	0.7	0.45	0.74	0	0	79	21	12	74	14
50-1	50	50	36	14	14	2.4	0.69	0.44	0.01	3	46	51	5	44	51
68-3	54	54	36	10	10	2.4	0.70	0.53	0	0	53	47	11	53	36
72	49	48	46	5	5	0.8	0.64	0.82	0.02	15	70	15	0	82	18
X	55	54	35	10	11	1.5	0.62	0.62	0.01	4	61	35	8	62	30
SD	5	5	6	4	4	0.8	0.10	0.16	0.01	6	14	17	5	16	16
Province B															
12-1	52	52	26	22	21	1.8	0.66	0.30	0.01	1	32	67	21	30	49
17-2	57	57	22	21	21	1.5	0.66	0.25	0	0	34	66	21	25	54
22	58	58	29	13	13	3.7	0.54	0.36	0	0	36	64	6	36	58
27-1	59	59	35	6	6	0	0.65	0.78	0.01	5	74	21	5	78	17
28	50	49	27	23	24	0.4	0.71	0.55	0.02	5	58	37	12	55	33
62	49	49	47	4	4	3	0.67	0.47	0	0	65	35	29	47	24
63	59	59	32	9	9	2.4	0.70	0.42	0	0	45	55	10	42	48
64	58	58	31	11	11	0.4	0.62	0.81	0	2	79	19	13	81	6
69	65	65	28	7	7	0.8	0.70	0.67	0	3	65	32	6	67	27
70	63	63	25	12	12	0	0.67	0.90	0	0	90	10	2	90	8
71-1	58	57	38	4	4	0.6	0.62	0.54	0.01	7	64	29	31	54	15
71-2	58	58	35	7	7	0	0.67	0.64	0	3	65	32	5	64	31
73	53	52	36	11	12	0.2	0.60	0.86	0.02	9	81	10	8	86	6
75	66	65	26	8	10	0	0.63	0.82	0.02	9	87	4	16	82	2
76	65	64	19	16	17	0	0.42	0.51	0.01	6	50	44	4	51	45
81	58	58	32	10	10	0.7	0.59	1	0	0	100	0	0	100	0
X	58	58	31	11	12	1	0.63	0.62	0.01	3	64	33	12	62	26
SD	5	5	7	6	6	1.1	0.08	0.63	0.01	3	28	22	9	23	20

X and SD indicate mean and standard deviation from the mean for each province.

Lv/L = 0.62), and corresponds to provinces A + B and B in Fig. 4. In the samples from province A, volcanic lithics are rare (average Lv/L = 0.18). Therefore, although the overall sandstone petrology in the Española basin varies little, the abundance or scarcity of volcanic and sedimentary lithic fragments allows the distinction of two lithosomes (sedimentary petrographic provinces of Suttner, 1974; petrofacies of Mansfield, 1971, and Ingersoll, 1983), which have slightly different provenance. Another petrographic parameter which allows a distinction between the two petrofacies is the percentage of monocrystalline phyllosilicate grains within the total framework grains (FRMW%M). The average percentage for province A is 3.6, whereas the average for province for A + B and B together is only 1.1.

The boundary between the two provinces, as defined by the sandstone petrology, does not precisely correspond to the boundary between the two paleocurrent provinces, as previously defined. There is a narrow and discontinuous zone (province A + B; Fig. 3), which appears to be part of one group with respect to paleocurrent direction, and part of the other group with respect to sandstone composition. Province A has westward paleocurrent directions and pure "arkosic" composition; province A + B has westward paleocurrent directions but also a significant volcaniclastic input; and province B is characterized by SSW-directed paleocurrents and volcaniclastic input.

Sandstone petrologic parameters indicate that the detritus of province A was exclusively derived from Precambrian basement (dominated by granite and phyllosilicate-rich metasedimentary rocks). Provinces A + B and B also show an additional detrital component derived from volcanic and sedimentary rocks.

CONGLOMERATE PETROLOGY

The petrologic study of sandstones and conglomerates proved to be a powerful tool in reconstructing the sediment dispersal system active in the central Española basin during Miocene time. Conglomerate clast counts allow a relatively quick compositional determination and can be performed in the field, thus giving immediate information, which can be used during the field season. Sandstone point counts are more time-consuming and cannot be performed in the field, but on the other hand allow a very precise assessment of sand-sized detrital modes.

Conglomerate clast counts were performed by identifying 100 pebble-to-cobble clasts at each location. The spacing of the grid which was used for this purpose was dependent on the maximum clast size at each location, in order to avoid counting the same clast twice.

Conglomerate clast counts confirmed the compositional differences identified in the study of sandstone petrology (Table 3; Fig. 5). Conglomerates of province A are composed of, in order of decreasing abundance: granitoid, medium- and high-grade metamorphic and very rare sedimentary rocks; volcanic clasts are absent. Conglomerates of province B are composed of approximately equal amounts of granitoid,

metamorphic and sedimentary rocks; volcanic clasts are significantly present (average 17% of the whole clast population). Conglomerates of province A + B are dominated by plutonic clasts and do not show any trace of volcanic rocks (like province A).

DISCUSSION

The features of province A, A + B and B are summarized in Table 4. The characteristics of the two main provinces (A and B) are consistently different with respect to paleocurrent direction, sandstone petrology and conglomerate petrology. Therefore, the two main provinces can be discriminated by means of both physical and compositional parameters. On the other hand, province A + B has affinities to both province A (paleocurrent trend, absence of volcanics and scarcity of sedimentary clasts in the conglomerate clast population) and B (overall sandstone petrology). The difference between sandstone and conglomerate composition in province A + B could be due to: (1) selective destruction of labile gravel-sized volcanic clasts during transportation; or (2) interaction between the two sediment dispersal routes. According to the latter hypothesis, sandstone of province A + B would have been

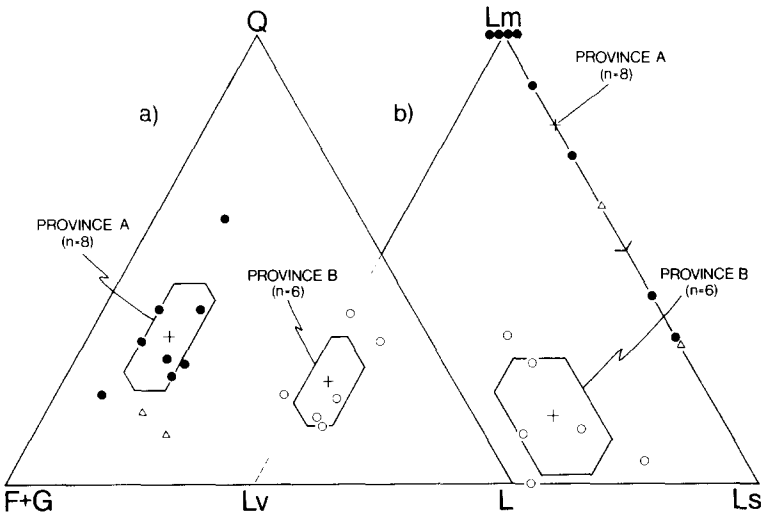

Fig. 5. (a) Conglomerate Q/F + G/L triangular diagram. *Q* indicates quartz–quartzite, *F* + *G* indicates feldspar–granitoid lithics and *L* indicates other lithics. (b) Conglomerate LmLvLs triangular diagram. *Lm*, *Lv* and *Ls* indicate, respectively, metamorphic, volcanic and sedimentary lithics. For both diagrams, crosses and polygons indicate means and standard deviations, respectively, for provinces *A* (solid circles) and *B* (open circles). Open triangles represent two clast counts of province *A* + *B*; mean and standard deviation for this province have not been calculated because of the limited sample population.

TABLE 3

Conglomerate clast counts

Categories	Province A									
	3	67	83	85	86	89	90	91	X	SD
Quartz	7	4	4	–	–	–	6	14	4	5
Quartzite	20	24	20	39	59	20	26	25	29	14
Feldspar	–	–	–	–	–	–	2	–	0	1
Granite	37	43	44	42	23	71	49	48	45	13
Granitic pegmatite	4	9	11	–	4	–	6	2	5	4
Other plutonic	10	2	–	–	–	–	–	–	2	4
Schist	15	11	15	–	2	2	6	–	6	6
Gneiss	7	7	6	6	2	6	5	8	6	2
Greenstone	–	–	–	2	–	–	–	–	0	1
Amphibolite	–	–	–	–	–	–	–	–	0	0
Lm (unspecified)	–	–	–	–	–	–	–	–	0	0
Volcanics	–	–	–	–	–	–	–	–	0	0
Siltstone	–	–	–	–	4	–	–	3	1	2
Sandstone	–	–	–	–	1	–	–	–	0	0
Conglomerate	–	–	–	–	–	–	–	–	0	0
Limestone	–	–	–	11	5	1	–	–	2	4
Q(F+G)L%Q [b]	27	28	24	39	59	20	32	39	33	12
%F+G	51	54	55	42	27	71	57	50	51	13
%L	22	18	21	19	14	9	11	11	16	5
LmLvLs %Lm	100	100	100	42	33	89	100	73	80	28
%Lv	–	–	–	–	–	–	–	–	0	0
%Ls	–	–	–	58	67	11	–	27	20	28

[a] Mean (X) and standard deviation (SD) for province A+B have not been calculated because of the limited sample population

[b] Clast count recalculated parameters are explained in Fig. 5.

TABLE 4

Sedimentary provinces

	Paleocurrent direction	Sandstone petrology	Conglomerate petrology
Province A	Westward	no volcaniclastic input	no volcanics abundant metamorphics very rare sedimentary rocks
Province A+B	Westward	significant volcaniclastic input	no volcanics common metamorphics rare sedimentary rocks
Province B	South-southwestward	significant volcaniclastic input	common volcanics common metamorphics common sedimentary rocks

Province B								Province A + B [a]	
22	70	93	102	104	106	X	SD	96	99
2	12	7	5	5	4	6	3	8	–
36	7	13	8	27	11	17	12	8	12
–	3	3	3	2	–	2	1	5	4
9	17	22	20	8	25	17	7	41	46
–	5	10	8	–	6	5	4	19	13
4	–	–	–	–	–	1	2	–	–
–	–	–	–	–	–	0	0	4	6
3	3	12	4	–	6	5	4	9	–
–	–	–	–	–	–	0	0	–	–
–	–	–	–	–	–	0	0	–	2
13	–	–	–	–	–	2	5	–	–
16	11	14	10	26	22	17	6	–	–
8	10	6	10	3	7	7	3	–	4
5	5	–	4	–	–	2	6	6	–
–	10	–	6	–	3	3	4	–	–
4	17	13	22	29	16	17	8	–	13
38	19	20	13	32	15	23	10	16	12
13	25	35	31	10	31	24	10	65	63
49	56	45	56	58	54	53	5	19	25
33	5	27	12	0	11	15	13	68	32
33	20	31	29	45	41	33	9	–	–
34	75	42	59	55	48	52	14	32	68

deposited by the SSW-directed dispersal system, whereas the conglomerate would represent episodic influx of coarse sediment directly from the Sangre de Cristo Mountains to the east. The consistent westward paleocurrents of province A + B were mostly measured as clast imbrications, which supports the latter hypothesis.

Upper Paleozoic and Mesozoic sedimentary units commonly overlie Precambrian basement in many parts of north-central New Mexico. However, within the Tesuque Formation, there is no petrologic evidence of progressive unroofing of a hypothetical sedimentary sequence overlying basement of the Sangre de Cristo Mountains. Unroofing might have preceeded deposition of the Tesuque Formation, being possibly recorded in early-rift sedimentary units now buried in the Española basin. Alternatively, the basement was already unroofed before the evolution of the RGR, that is, during Laramide time. Present-day geologic knowledge of the area cannot resolve between the two hypotheses.

CONCLUSIONS

Continental rift basins can be characterized by an overall basement provenance due to thermotectonic uplift of the rift region (Dickinson and Suczek, 1979).

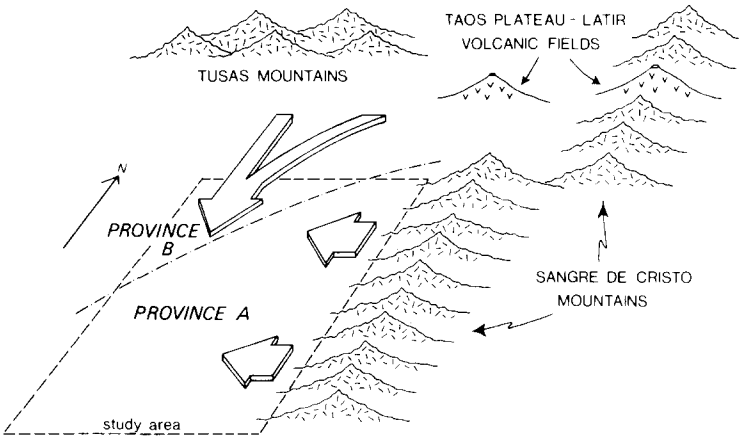

Fig. 6. Reconstruction of the sediment dispersal system in the central Española basin during deposition of the Tesuque Formation.

Sedimentary detritus (due to erosion of the sedimentary cover overlying uplifted continental blocks) and local and sporadic sources of volcanic detritus (due to syn-rift volcanism) can be used as "tracers" to delineate the sediment dispersal system active during the rifting process. Therefore, continental rift basins are ideal settings for detailed provenance studies and basin analyses.

The combined use of paleocurrent analyses and conglomerate and sandstone petrology made possible a careful reconstruction of the Miocene sediment dispersal system in the east-central Española basin. The Tesuque Formation, which represents the bulk of the basin fill, can be subdivided into two main lithosomes, whose surficial expressions are called provinces A and B. Province A is characterized by westward paleocurrents and by a predominantly plutoniclastic and metamorphiclastic composition. The sediments were derived from the Precambrian-cored Santa Fe block of the Sangre de Cristo Mountains, located directly to the east (Fig. 6). Province B shows consistent SSW-directed paleocurrents and is characterized by a significant amount of volcaniclastic and sedimentaclastic detritus. The source area was possibly located in the Taos Plateau–Latir volcanic fields area, located to the northeast. This inferred source area satisfies both geographic and geologic constraints (Lipman and Mehnert, 1979; Reed et al., 1983; Lipman and Reed, 1984). Although the Taos Plateau volcanic field is mostly composed of rocks of Pliocene age, Lipman and Mehnert (1979) documented the presence of several small windows of early-rift volcanic rocks. These units might well have been source of detritus for the Tesuque Formation. A contribution from the Tusas Mountains area, immediately to the north of the study area, cannot be ruled out.

The paleodispersal system active in the east-central Española basin during Miocene time was, thus, characterized by two main sediment dispersal routes that

can be traced in a relatively easy way by means of physical and compositional parameters. Province A + B represents a narrow and discontinuous transition zone between the two sediment dispersal routes.

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