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Abstract

Stratigraphic studies and geologic mapping on the Abiquiu 7.5-min quadrangle have led to revision of the stratigraphic nomenclature for the Oligocene to Miocene Abiquiu Formation in north-central New Mexico. The Abiquiu Formation had previously been defined to include informal upper, middle (Pedernal chert member), and lower members. The basement-derived conglomeratic lower member in the northern Jemez Mountains and Abiquiu embayment is here redefined. We propose removing the "lower member" from the Abiquiu Formation because provenance of these coarse sediments is dramatically different than the volcaniclastic strata of the "upper member." Furthermore, we propose that the term "lower member of the Abiquiu Formation" be replaced with an existing unit name, the Ritito Conglomerate of Barker (1958), and that the name Abiquiu Formation be restricted to the volcaniclastic succession. The lower part of the Ritito Conglomerate in Arroyo del Cobre on the Abiquiu quadrangle is 47 m (155 ft) thick and is composed of arkosic conglomeratic beds interbedded with arkosic sands and siltstones. Clasts include, in descending order of abundance, Proterozoic quartzite, granite, metavolcanic rocks, quartz, schist, and gneiss and a trace of Mesozoic sandstone and Paleozoic chert. Clasts are predominantly of pebble and cobble size but range from granule to boulder size. Paleocurrent data collected in the Arroyo del Cobre area indicate that the Ritito Conglomerate was deposited by a south-flowing river system during the Oligocene, eroding Laramide highlands such as the Tusas Mountains to the northeast, which contain predominantly Proterozoic rocks. This depositional setting has also been suggested by previous workers. The middle member or Pedernal chert member is present both at the top of the Ritito Conglomerate and as lenses within the lower part of the Abiquiu Formation. This post-depositional diagenetic chert remains an informal unit called the Pedernal chert.

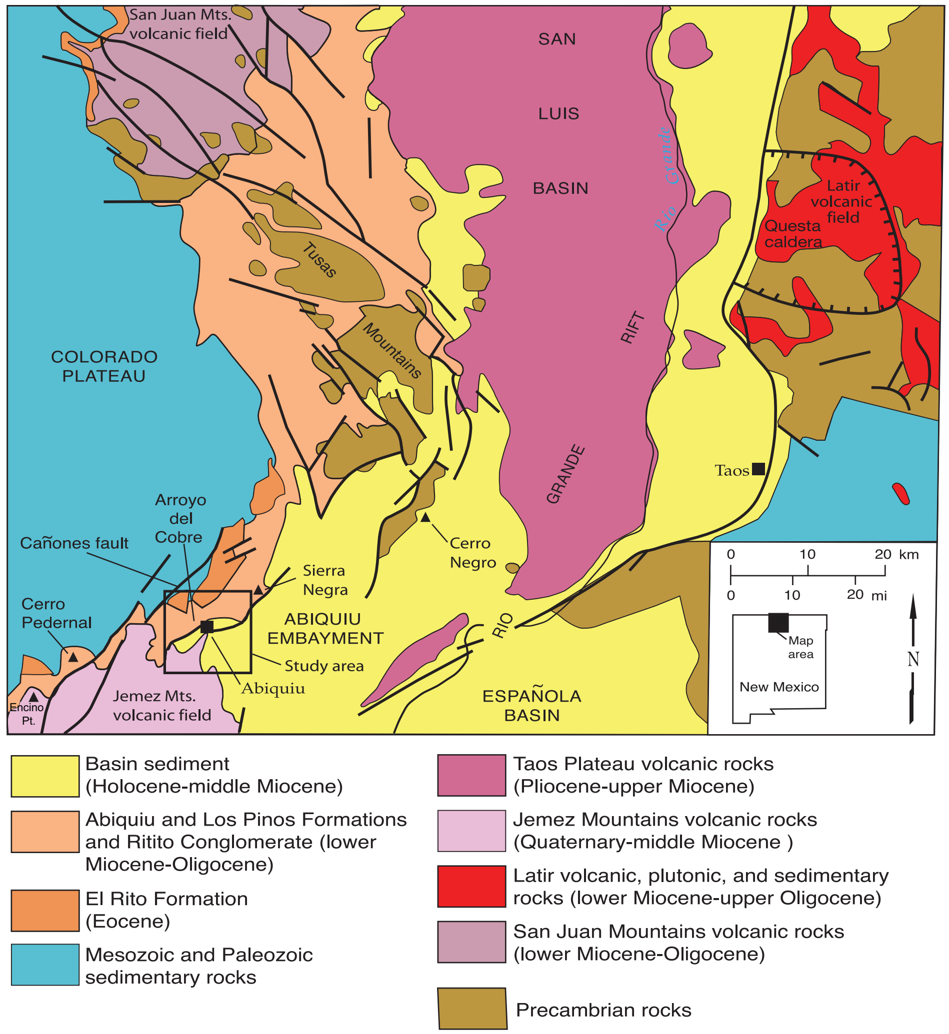

FIGURE 1—Location map (modified after Smith 1995) of the study locality of the Ritito Conglomerate. Measured section for Ritito Conglomerate is located at Arroyo del Cobre in southwest part of map.

Introduction

The Oligocene to Miocene Abiquiu Formation of north-central New Mexico (Fig. 1), as traditionally defined, includes a basal conglomeratic unit derived primarily from Proterozoic basement source terranes. In this paper, we revise the nomenclature of the Oligocene-age basement-derived conglomerate exposed in the vicinity of Abiquiu, removing the conglomerate from the basal part of the Abiquiu Formation and restricting the name Abiquiu Formation to the volcaniclastic strata (Fig. 2). The basement-derived conglomerate is herein reassigned to the Ritito Conglomerate, named by Barker (1958) for the Ritito Arroyo area located approximately 1.5 km (1 mi) northeast of Cañon Plaza, approximately 45 km (28 mi) northeast of the study area (Fig. 3). Clasts in the type Ritito Conglomerate include Proterozoic quartzite, amphibolite, and metarhyolite (Barker 1958). The Ritito Conglomerate in the type area rests on Proterozoic basement and is overlain by the Cordito Member of the Los Pinos Formation (Fig. 3), which is one of the youngest members of this volcaniclastic deposit. This investigation is focused on exposures of Ritito Conglomerate and Abiquiu Formation in the Abiquiu embayment on the western edge of the Rio Grande rift, north-central New Mexico (Fig. 1). Rocks exposed in the vicinity of the Abiquiu embayment area include Mesozoic rocks of the Colorado Plateau, Laramide syntectonic strata, Cenozoic rift-basin-fill deposits, and lava flows of the Jemez Mountains volcanic field (Maldonado 2004, 2008; Kelley et al. 2005; Kempter et al. 2007; Moore 2000).

The Abiquiu Formation was originally named the "Abiquiu Tuff" by Smith (1938). Subsequent workers changed the name to Abiquiu Formation because the unit contains sandstone and conglomerate with minor thin tephra deposits and a few fine-grained ash beds (Woodward and Timmer 1979; Vazzana 1980; Vazzana and Ingersoll

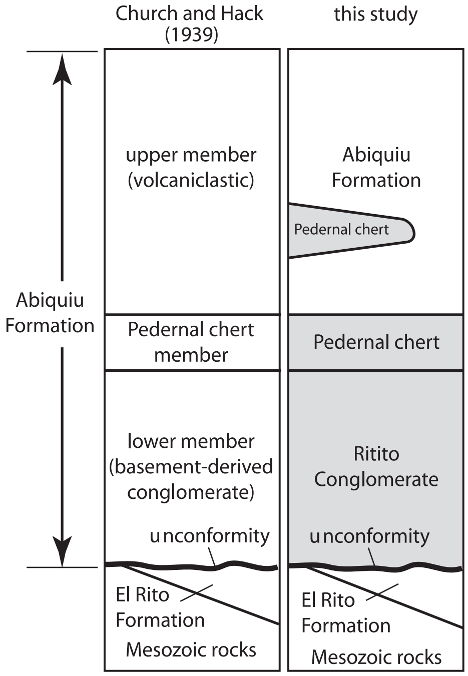

FIGURE 2—Chart showing previous and present stratigraphy for the Abiquiu Formation, Abiquiu, New Mexico area.

1981; Smith 1995; Moore 2000; Smith et al. 2002). The Abiquiu Formation was divided into an upper unnamed tuffaceous member, middle Pedernal chert member, and lower unnamed gravel member (Fig. 2) by Church and Hack (1939), and these divisions have been used by subsequent workers (Moore 2000; Smith 1995; Vazzana and Ingersoll 1981; Ingersoll and Cavazza 1991; Ingersoll et al. 1990).

The upper member is correlative to the Cordito Member of the Los Pinos Formation (Barker 1958; Bingler 1968; Manley 1981). Both the Cordito Member of the Los Pinos Formation and the volcaniclastic Abiquiu Formation have high quartz and alkali-feldspar contents in the sand fraction and clasts of dacite and Amalia Tuff in the gravel fraction, indicative of a source in the Latir volcanic field located northeast of the Abiquiu area (Fig. 1; Bingler 1968; Manley 1981; Smith 1995).

The lower member of the Abiquiu Formation (Moore 2000; Smith et al. 2002) is equivalent to the Ritito Conglomerate of Barker (1958) and Kelley (1978), and to the conglomerate of Arroyo del Cobre of Maldonado and Miggins (2007). The volcaniclastic Gilman Conglomerate of Kelley et al. (2008) in the southwestern Jemez Mountains is also stratigraphically equivalent to the lower Abiquiu member. Although Barker (1958) did not directly tie the Ritito Conglomerate to the basal gravel of Smith's (1938) Abiquiu Tuff, Bingler (1968), Kelley (1978), and Manley (1981) clearly state that the Ritito Conglomerate correlates with the lower member. The lower member in the Abiquiu area is composed of conglomerate that predominantly contains clasts derived from the Proterozoic metamorphic basement of the Tusas Mountains, located north of the study area (Fig. 1; Smith 1938; Vazzana 1980; Smith 1995). Cenozoic volcanic clasts are found only near the gradational top of the unit. Between Cerro Pedernal and the Sierra Nacimiento (Figs. 1 and 3), the lower member includes abundant limestone clasts from the Pennsylvanian Madera Group exposed in the Sierra Nacimiento (Vazzana 1980; Timmer 1976). Based on the conglomerate's distinctive lithology, mappability, and the scarcity of Tertiary volcanic clasts, the lower member is separated from the Abiquiu Formation and elevated to formational status. Here, the name Ritito Conglomerate of Barker (1958) is formally applied to this unit in the Abiquiu area. The term Abiquiu Formation will be restricted now to strata previously referred to as the "upper member."

The Pedernal chert member (middle member) is not exposed in the study area but is mapped west of the Cañones fault zone (Fig 1; Church and Hack 1939; Manley 1982; Moore 2000; Lawrence et al. 2004; Kelley et al. 2005). The chert has been described by Bryan (1938, 1939), Church and Hack (1939), Smith (1938), Vazzana (1980), Moore (2000), and Smith and Huckell (2005). As defined by Church and Hack (1939), the Pedernal chert member is composed of conglomerate, limestone, chalcedony, and chert, and commonly is present within the uppermost part of the lower member (previous usage), on Cerro Pedernal (Moore 2000) and Encino Point (Fig. 1). Mappable lenses of Pedernal chert are also in the "upper member" at several localities in the western Jemez Mountains volcanic field, particularly in the Jarosa region (Fig. 3; Timmer 1976, Timmer et al. 2006). Because the upper and lower members have been assigned to formational status, the middle member becomes an orphan. Following the interpretation of Vazzana (1980) and Moore (2000), we consider the Pedernal chert member to be a replacement deposit in the upper part of the Ritito Conglomerate and in the restricted Abiquiu Formation (see discussion below regarding the Pedernal chert unit). Because this post-depositional diagenetic unit crosses formational contacts, we herein refer to this deposit informally as the Pedernal chert (Fig. 2).

Ritito Conglomerate

The Ritito Conglomerate is gradationally overlain by the Abiquiu Formation (formerly upper member of the Abiquiu Formation) and is unconformably underlain by reddish-orange Eocene El Rito Formation (Fig. 4), Mesozoic sedimentary rocks, or Permian red beds. The unit is Oligocene based on K-Ar ages of ca. 27 Ma on a basalt near the base of correlative units in the San Juan Mountains located north of the study area (Lipman and Mehnert 1975). Basalt is interbedded with Ritito Conglomerate approximately 27 km (16.8 mi) northeast of Abiquiu; the altered basalt has not been dated but is assumed to be ca. 27 Ma (Moore 2000). The gravels in the underlying Eocene syntectonic Laramide-age El Rito Formation are dominated by clasts of Ortega Quartzite with minor gneiss, schist, and metavolcanic clasts; in contrast, the Ritito Conglomerate contains quite a diverse mix of Proterozoic metavolcanic and metasedimentary rock types from the Tusas Mountains. The Eocene and Oligocene gravels record the unroofing of the Tusas Mountains.

Outcrops of the bottom part of the Ritito Conglomerate located at UTM: Zone 13, 0379688E 4010584N (NAD 27) in Arroyo del Cobre (Fig. 1) in the northwest part of the Abiquiu 7.5-min quadrangle (Maldonado 2008) were examined in detail (Table 1). The top part of the conglomerate in this area was not described as carefully due to poor exposure and faulting. The well-exposed lower part of the unit is 47 m (155 ft) thick, but the Ritito Conglomerate can be as much as 210 m (689 ft) thick elsewhere in the quadrangle. In Arroyo del Cobre the unit is composed of moderate-orange-pink (10R7/4) to moderate-reddish-orange (10R6/6) and moderate-reddish-brown (10R5/4) arkosic conglomeratic beds interbedded with moderate-orange-pink (10R7/4) and moderate-reddish-brown (10R5/4), fine- to coarse-grained arkosic sands and siltstones with muscovite. The matrix of the Ritito Conglomerate in the Abiquiu area has a distinct red-brown color, compared to the gray to tan colors of the matrix in areas to the northeast and southwest.

The conglomerates contain angular to well-rounded but predominantly subrounded clasts in a coarse, sandy, moderate-orange-pink (10R7/4) matrix. The clasts are primarily of pebble (>4 to <64 mm) size, but they range in size from granule (2 to 4 mm) to boulder (>26 cm). Clasts are composed in variable proportions, in descending order, of Proterozoic quartzite (44%), granite (25%), metavolcanic rocks (13%), quartz (10%), schist (5%), gneiss (3%), chert (trace), and Mesozoic and Permian(?) sandstone (trace). Most of the Proterozoic quartzite is reddish brown and may come from the Cerro Colorado area near Ojo Caliente (K. Karlstrom, pers. comm. 2008); some of the quartzite was eroded from the Ortega Quartzite located in the Tusas Mountains, northeast of the map area.

The bottom of the unit has pronounced imbrication that indicates flow toward the north (Fig. 5A). Above 30 m (100 ft), the unit is finer grained; pebbles and cobbles are common, and the stratification is better developed. Gravel imbrication in this interval indicates flow toward the south (Fig. 5B). Imbrication data collected by Vazzana and Ingersoll (1981) in Red Wash Canyon show flow toward the southwest (250°) and toward the southeast (160°) in Arroyo del Cobre. Overall, the imbrication data indicate that the Ritito Conglomerate was deposited by a south-flowing river system with a few northward-directed meanders. The basal contact is disconformable and sharp. Arkosic carbonate that is ~1 m (3 ft) thick has been described at the

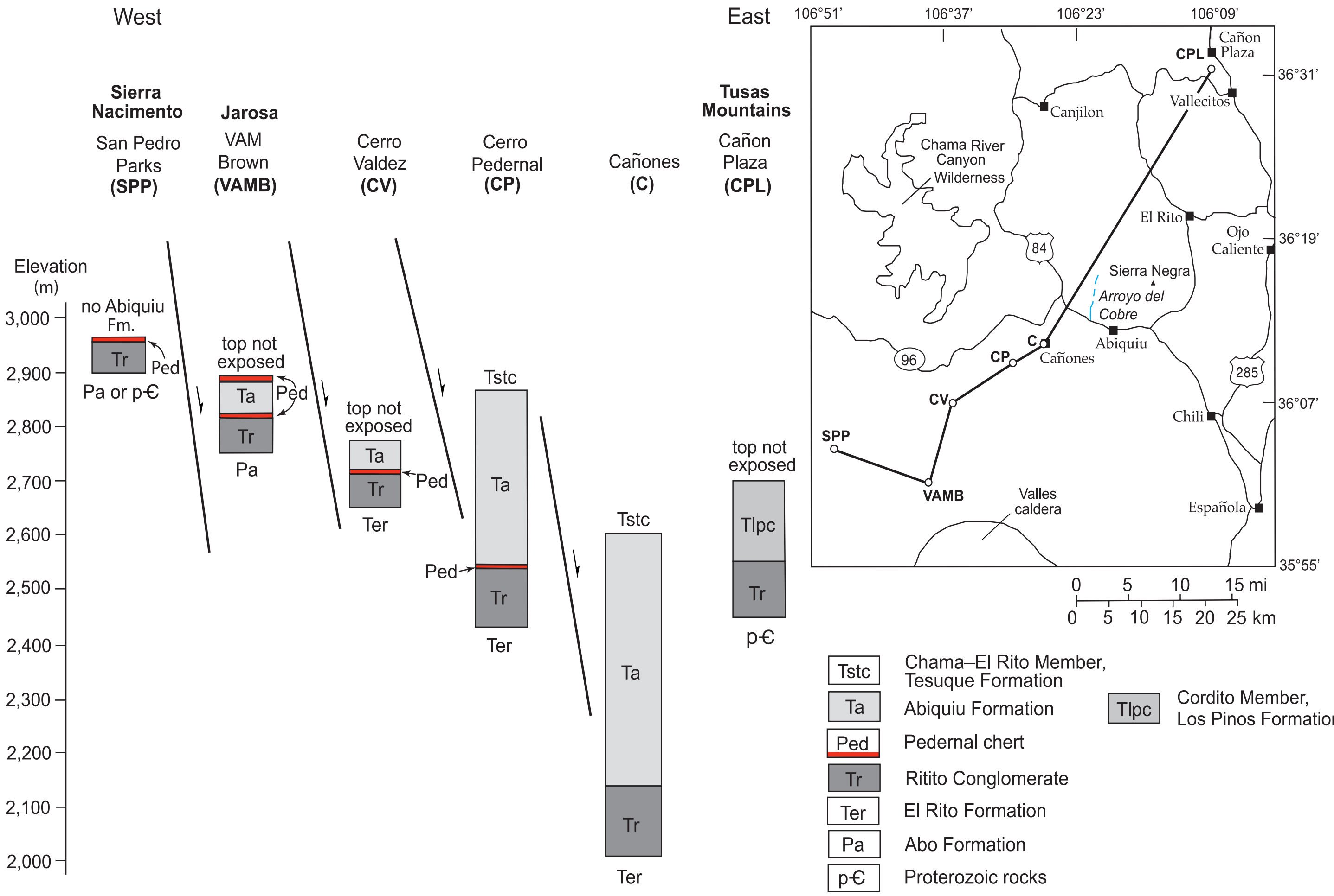

FIGURE 3—Simplified stratigraphic sections of the Ritito Conglomerate and Abiquiu Formation in the Sierra Nacimiento, the Abiquiu embayment, and the Tusas Mountains. Data from Vazzana (1980), Moore (2000), Barker (1958), and this study.

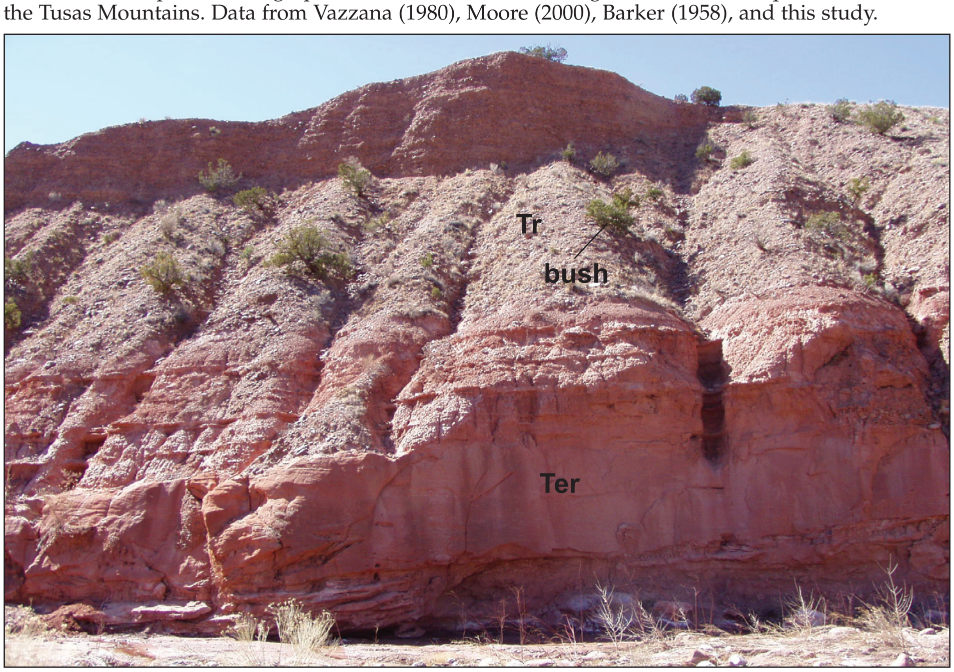

FIGURE 4—Photograph showing Ritito Conglomerate (**Tr**) overlying El Rito Formation (**Ter**). Labeled bush is approximately 2 ft high. View looking west, Arroyo del Cobre area.

base of the Ritito Conglomerate in Red Wash Canyon west of Arroyo del Cobre (Smith 1938; Smith 1995; Moore 2000). The carbonate, located in the hanging wall of the Cañones fault zone, may be a younger, post-emplacement deposit (G. Smith, pers. comm. 2008). The lower part of the conglomerate does not contain Tertiary volcanic clasts, whereas the overlying Abiquiu Formation is volcaniclastic.

The top of the unit is best exposed at UTM: Zone 13, 0380806E 4010069N to the east of Arroyo del Cobre. Equally good exposures are present southwest of a minor fault in the Arroyo del Cobre area (Maldonado 2008). The upper part of the Ritito Conglomerate at Arroyo del Cobre is a conglomeratic sandstone with pebble- to granule-sized fragments of Proterozoic rocks. The top is transitional with the overlying Abiquiu Formation, with fine-grained beds of volcaniclastic sandstone interbedded with arkosic conglomeratic sandstone over an interval of 10–15 m (33–50 ft). The upper section of the Ritito Conglomerate west of Arroyo del Cobre south of the location of the examined section (Table 1) is the finest-grained interval observed in this deposit in the northern Jemez Mountains.

The Ritito Conglomerate is broadly distributed across north-central New Mexico in the northern Jemez Mountains, along the southeastern flank of the Tusas Mountains, and on the eastern flank of the Sierra Nacimiento (Fig. 3). The southernmost exposure is in the northwest corner of the Valles caldera along the northwest side of San Antonio Creek (Kelley et al. 2004). Western exposures are on the crest of the Sierra Nacimiento in San Pedro Parks Wilderness (Church and Hack 1939; Woodward et al. 1974). Easterly exposures are

TABLE 1—Measured section of Ritito Conglomerate. Base of measured section at UTM: Zone 13, 0379688E 4010584N.

Unit	Description	Thickness (m)
Conglomerate (Subunits 1–4)	Moderate-orange-pink (10R7/4) to moderate-reddish-orange (10R6/6) and moderate-reddish-brown (10R5/4) arkosic conglomeratic beds, composed of subangular to subrounded quartzite, granite, metavolcanic rocks, quartz, schist, gneiss, sandstone, and chert clasts. Clasts range in size from granule to boulder.	3.3
Sandstone with conglomerate lens	Moderate-orange-pink (10R7/4) and moderate-reddish-brown (10R5/4), fine- to coarse-grained, arkosic sandstone, and siltstone with muscovite. Thin interbedded moderate-orange-pink (10R7/4) to moderate-reddish-orange (10R6/6) and moderate-reddish-brown (10R5/4) arkosic conglomeratic lens, composed of subangular to subrounded quartzite, granite, metavolcanic rocks, quartz, schist, gneiss, sandstone, and chert clasts. Clasts range in size from granule to boulder.	1.4
Conglomeratic sandstone	Moderate-orange-pink (10R7/4) to moderate-reddish-orange (10R6/6) and moderate-reddish-brown (10R5/4), crossbedded, arkosic conglomeratic sandstone, composed of subangular to subrounded, mostly pebble size, quartzite, granite, metavolcanic rocks, quartz, schist, gneiss, sandstone, and chert clasts. Clasts range in size from granule to boulder. Thin Quaternary terrace deposit overlies subunit.	2.7
Siltstone	Moderate-orange-pink (10R7/4) to moderate-reddish-orange (10R6/6) and moderate-reddish-brown (10R5/4) clayey arkosic siltstone with muscovite as large as 1 mm.	1.0
Conglomerate	Moderate-orange-pink (10R7/4) to moderate-reddish-orange (10R6/6) and moderate-reddish-brown (10R5/4) arkosic conglomeratic beds, composed of subangular to subrounded quartzite, granite, metavolcanic rocks, quartz, schist, gneiss, sandstone, and chert clasts. Clasts range in size from granule to boulder.	38.6

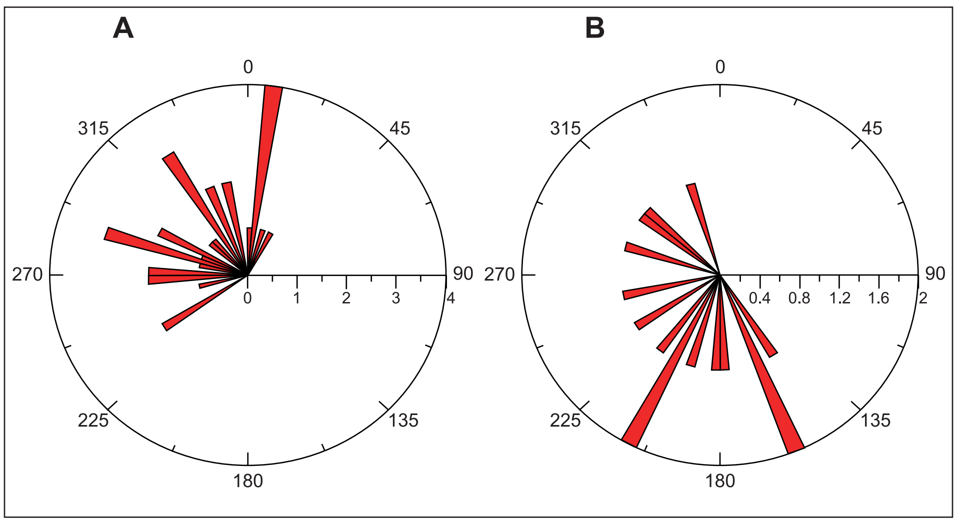

FIGURE 5—**A**—Rose diagram showing paleocurrent data from basal part of the Ritito Conglomerate in Arroyo del Cobre. Measurements at UTM: Zone 13, 0379688E 4010584N. **B**—Rose diagram showing paleocurrent data from the bottom part of Ritito Conglomerate in Arroyo del Cobre.

truncated by the northeast-trending faults that define the northwest margin of the Abiquiu embayment.

Pedernal chert

The middle member of the Abiquiu Formation (Pedernal chert member) is here referred to as Pedernal chert. The chert at Cerro Pedernal is interlayered with conglomerate and lenses and nodules of pedogenic carbonate in the upper part of the Ritito Conglomerate. The unit is 4–8 m (13–26 ft) thick and is composed of as many as four irregular bodies of multicolored (shades of red, gray, white, and yellow) chert and chalcedony (Smith and Huckell 2005). The unit was originally named the "Pedernal chert member" by Church and Hack (1939) and was interpreted to represent an exhumed peneplain or silica-replaced calcic soil. Vazzana (1980), Moore (2000), and Smith and Huckell (2005) have accepted this interpretation as a pedogenic alteration of the upper part of the lower member of the Abiquiu Formation, now the Ritito Conglomerate. This soil has been altered to chert and chalcedony by circulating waters rich in silica derived from the overlying volcaniclastic-rich unit (Vazzana 1980; Moore 2000; Smith and Huckell 2005).

In addition to the silica replacement observed near the contact of the Ritito Conglomerate and the Abiquiu Formation, we have noticed chert replacement of root casts and soil horizons in the Abiquiu Formation tens to hundreds of meters above the Ritito–Abiquiu contact south and southwest of Cerro Pedernal (e.g., Timmer et al. 2006).

The timing and the temperature of the silica replacement event is at present uncertain, but the <20 Ma volcanism associated with the Jemez Mountains volcanic field is one probable source of silica-enriched fluids. Geochemical data for chert samples collected at the base of Cerro Pedernal are shown in Table 2. Although the low silica values indicate the presence of abundant detrital material in the chert, the elevated gold values for sample A-100 are intriguing and may suggest a high-temperature origin for the silica replacement. Low-temperature thermochronology data on apatite-bearing sandstones and clasts in and near and well away from the chert horizons and additional geochemical data would be useful for constraining the timing and temperature of chert formation.

Abiquiu Formation

Locally, the lower beds of the Abiquiu Formation are interbedded and transitional with upper beds of Ritito Conglomerate (Fig. 6). The contact with the overlying Chama–El Rito Member of the Tesuque Formation is also gradational. Vazzana (1980), Smith (1995), and Moore (2000) have described the Abiquiu Formation in detail. The Abiquiu Formation is more than 200 m (650 ft) thick approximately 6 km (3.7 mi) west of Arroyo del Cobre and is more than 400 m (1,312 ft) thick near Cañones 13 km (8 mi) to the southwest of the Abiquiu area (Moore 2000). About 150 m (492 ft) of the revised Abiquiu Formation is exposed in the Abiquiu 7.5-min quadrangle, and the deposit consists of light-gray (N7) to yellowish-gray (5Y8/1), locally crossbedded, thin- to thick-bedded tuffaceous sandstone, siltstone, pebbly sandstone, and a few gravel beds, with locally thin, interbedded, moderate-orange-pink (10R7/4), moderate-reddish-brown (10R4/6), or pale-reddish-brown (10R5/4) mudstone.

TABLE 2—Major and trace elements for Pedernal chert unit, (samples A-100 and A-101). All values (trace elements) in ppm unless noted.

Elements	A-100	A-101	Elements	A-100	A-101	Major oxides	Percent (sample A-100)
Fe(%)	0.09	0.08	Ho	0.02	0.01	SiO_2	54.2
Ca(%)	0.14	0.10	Tm	0.01	0.00	Al_2O_3	13.8
Na(%)	0.01	0.02	Yb	0.06	0.03	Fe_2O_3	13.9
K(%)	0.03	0.08	Lu	0.01	0.00	MgO	3.59
Rb	0.66	0.75	Zr	9.76	8.74	CaO	7.24
Sr	7.27	3.63	Hf	0.02	0.02	Na_2O	3.29
Cs	0.01	0.02	Ta	0.02	0.01	K_2O	1.74
Ba	19.20	30.70	W	1.61	2.01	TiO_2	2.31
Th	0.04	0.03	Sc	0.07	0.05	PO_2O_5	0.37
U	18.30	21.00	Cr	2.30	2.48	MnO	0.2
La	0.29	0.14	Co	0.28	0.22	Cr_2O_3	<0.01
Ce	0.52	0.27	Ni	1.66	0.94	V_2O_5	0.08
Nd	0.32	0.23	Zn	1.02	0.64	LOI	0.21
Sm	0.09	0.05	As	4.54	0.11	Total	100.9
Eu	0.01	0.01	Sb	0.14	0.10		
Gd	0.04	0.05	Au(ppb)	5.96	0.80		
Tb	0.01	0.01	—	—	—		

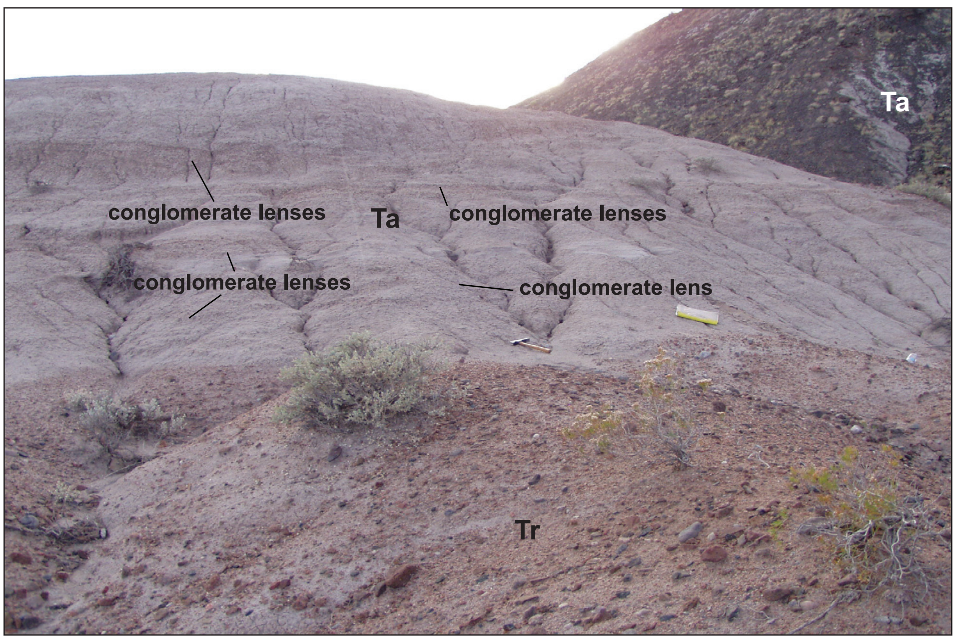

FIGURE 6—Transitional zone of overlying Abiquiu Formation (**Ta**) and Ritito Conglomerate (**Tr**). View looking southwest, east of Arroyo del Cobre area.

The gravel and pebbly zones contain mostly intermediate to rhyolitic volcanic clasts (lavas and ash-flow tuffs) with some Proterozoic clasts. Proterozoic clasts consist of pebble- to boulder-sized quartzite, granite, schist, and gneiss. Volcanic clasts consist of Amalia Tuff, a distinctive ~25 Ma (Miggins et al. 2002; Smith et al. 2002) lithic-bearing tuff erupted from the Latir volcanic field north of Taos, New Mexico, and a biotite- and hornblende-rich volcanic rock classified as trachydacite and trachyandesite based on geochemistry using the Le Bas et al. (1986) classification (Maldonado et al., unpub. data). Amalia Tuff clasts and pumice lapilli and the Amalia Tuff have $^{40}Ar/^{39}Ar$ ages that range from 27 to 23 Ma (Peters 2000; Peters and McIntosh 2000; Smith et al. 2002; Lipman et al. 1986; Miggins et al. 2002); these clasts are common throughout most of the unit and are as large as 55 by 40 cm. Biotite- and hornblende-rich trachyandesite clasts are common toward the base of the unit and are as large as 60 by 50 cm; these clasts are possibly from the Latir volcanic field (Questa caldera, Fig. 1).

An olivine-nephelinite lava flow near the top of the redefined Abiquiu Formation south of Cerro Negro, approximately 32 km (20 mi) northeast of Abiquiu (Fig. 1) has yielded a K-Ar age of 18.9 Ma (Baldridge et al. 1980), but the 19.6-Ma Cerrito de la Ventana dike intrudes the Abiquiu Formation (Maldonado et al. 2007). Gibson et al. (1993) report ca. 18 Ma ages for lavas in the overlying Chama–El Rito Member of the Tesuque Formation. Manley and Mehnert (1981) reported a K-Ar age of 15.9 Ma for a dike that intrudes the Abiquiu Formation 6 km (3.7 mi) north of Sierra Negra (Fig. 1). Basalts dated at 26.8, 24.3, 18.8, 17.7, and 15 Ma (Lipman and Mehnert 1975, 1979) are interlayered with the Los Pinos Formation, a unit stratigraphically equivalent to the Abiquiu Formation (May 1980; Manley 1981). Baldridge et al. (1980) dated basalts interlayered in the Abiquiu Formation at about 25 Ma (Arroyo El Rito area; 36°17′45″, 106°05′20″) and 22 Ma (west-southwest of Petaca; 36°30′23″, 106°01′02″).

If the Abiquiu Formation is equivalent to the Cordito Member of the Los Pinos Formation, then the age of the restricted Abiquiu Formation is ~19 to 26 Ma, but this unit may be as young as 18 Ma and as old as about 27 Ma based the ages of Gibson et al. (1993) and the upper end of the age range of the Amalia Tuff. Smith et al. (2002) indicate that the base of the unit is no older than 26.8 ± 0.3 Ma and the top of the unit is younger than 23 Ma. Several subunits have been identified within the Abiquiu Formation, as defined in this paper, and these subunits thicken across the Cañones fault zone, indicating early syn-rift development deposition of this unit (Moore 2000; Smith et al. 2002).

Summary

The distinctly different provenance of the basement-derived gravels and the volcaniclastic clasts, as well as the significant thickness of each of these units, suggests that each deposit is a mappable unit. The unit previously referred to as the lower Abiquiu member should be raised to formational status as the Ritito Conglomerate. In addition, the middle member of the Abiquiu Formation, referred to as the Pedernal chert member, is reassigned as the Pedernal chert. The previously defined upper member of the Abiquiu Formation is simply referred to as the Abiquiu Formation.

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