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RECENT MAPPING OF THE OLIGO-MIOCENE LOS PINOS FORMATION AND ASSOCIATED UNITS IN THE TUSAS MOUNTAINS, NEW MEXICO

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Abstract—The Los Pinos Formation is a volcaniclastic unit derived mostly from intermediate volcanic sources but containing mafic-to-silicic components and some primary volcanic intervals. First described by Atwood and Mather (1932), the Los Pinos Formation is found in the Tusas Mountains of northern New Mexico and the San Juan Mountains of southern Colorado. Butler (1946) first divided the Los Pinos into members, and several other authors have revised his member subdivisions in their mapping. Recent mapping of the Los Pinos on the Las Tablas quadrangle (Aby et al., 2010) has given new insights into the Los Pinos and provides some new context for member-rank subdivisions. Most importantly, a poorly welded tuffaceous unit found near Las Tablas (The Las Tablas tuff) has been recognized as partly(?) a 'megabreccia' containing abundant volcanic and sedimentary debris and large blocks of older granitic(?), intermediate volcanic, volcaniclastic and clastic rocks. Some of these large blocks have previously been interpreted as distinct units (either individual members of the Los Pinos or other, older formations) and this has lead to a lack of uniformity in previous mapping. Additionally, the Los Pinos has traditionally been defined mostly by its stratigraphic position relative to an ignimbrite (the Treasure Mountain Tuff) that is not present in all areas. We propose that member-rank subdivisions eventually be formally defined by the clast types each member contains so that, even in poorly exposed areas, individual members can be objectively identified. This type of definition will then allow the source areas of the various members to be distinguished and the geologic history of the area to be reconstructed more easily. Additional mapping is needed before a final, formal definition of the Los Pinos Formation is possible.

INTRODUCTION

Like other sedimentary and volcanic units that fill the Rio Grande Rift, the Los Pinos Formation was originally defined broadly and in the absence of radiometric dating or the framework provided by plate tectonic theory. This, along with the inherently complex architecture of volcanic and volcaniclastic rocks, has led to a somewhat confusing nomenclature and numerous revisions as mapping has become increasingly detailed. As large scale mapping in northern New Mexico continues under the STATEMAP program of the New Mexico Bureau of Geology, resolution of long standing ambiguities concerning the relations of various Neogene units in separate, well studied areas becomes possible. Long-standing ambiguities concerning the nomenclature/definition of various complexly interfingering rocks should also be possible once their boundaries are well mapped and their internal complexities well described. The Los Pinos Formation is one such group of rocks; in this case spanning the area between the extensively studied San Juan volcanic field and Latir volcanic field/Rio Grande rift.

HISTORY OF STUDY

The Los Pinos *Gravel* was first described in detail by Atwood and Mather (1932), who attribute the name to Cross and Larsen (presumably through personal communication). The formation is named for the Rio de los Pinos in northernmost New Mexico and the area "used to designate them" is near San Miguel, NM (Fig. 1). Atwood and Mather (1932) correlated the Los Pinos with other fluvial deposits described as overlying a peneplain developed on older volcanic and volcaniclastic rocks of the San Juan volcanic field and underlying the basalts of the Hinsdale volcanic series. They used the Treasure Mountain latite (now Treasure Mountain Tuff), where present, to differentiate the Los Pinos from the underlying, lithologically similar Conejos Formation. In northern New Mexico the Treasure Mountain Tuff is not always present and it was therefore "well-nigh impossible" (Atwood and Mather, 1932, pg. 96) to differentiate the Conejos and Los Pinos. Their definition is implicitly based on the relative stratigraphic position of these rocks and no description of the clast types in the Los Pinos is given. Cross and Larsen (1935) made the Los Pinos a member of their Hinesdale Formation but otherwise used the term in much the same way as Atwood and Mather (Larson and Cross, 1956).

The next significant changes to the definition of the Los Pinos in northern New Mexico are those of Butler (1946). He separated the Los Pinos from the Hinsdale volcanic series and elevated it to formation rank. He also divided the unit into four members (the Biscara, Esquibel, Jarita Basalt, and Cordito; Table 1). "Thus redefined, the formation includes all rocks in the Tusas-Tres Piedras area that overlie the Treasure Mountain formation and that underlie and are separated from the Cisneros basalt and associated younger rocks by an unconformity." (Butler, 1946, p 46.). The "Cisneros basalt" has recently been shown to be interbedded within the Cordito Member of the Los Pinos Formation (Aby et al., 2010), but at the time of Butler's definition the Cisneros was believed to be correlative with other basalts that geographically define the top of the Taos Plateau. Although Butler did give descriptions of some of the clast types in the various members of the Los Pinos his definition of 1946 was explicitly based on

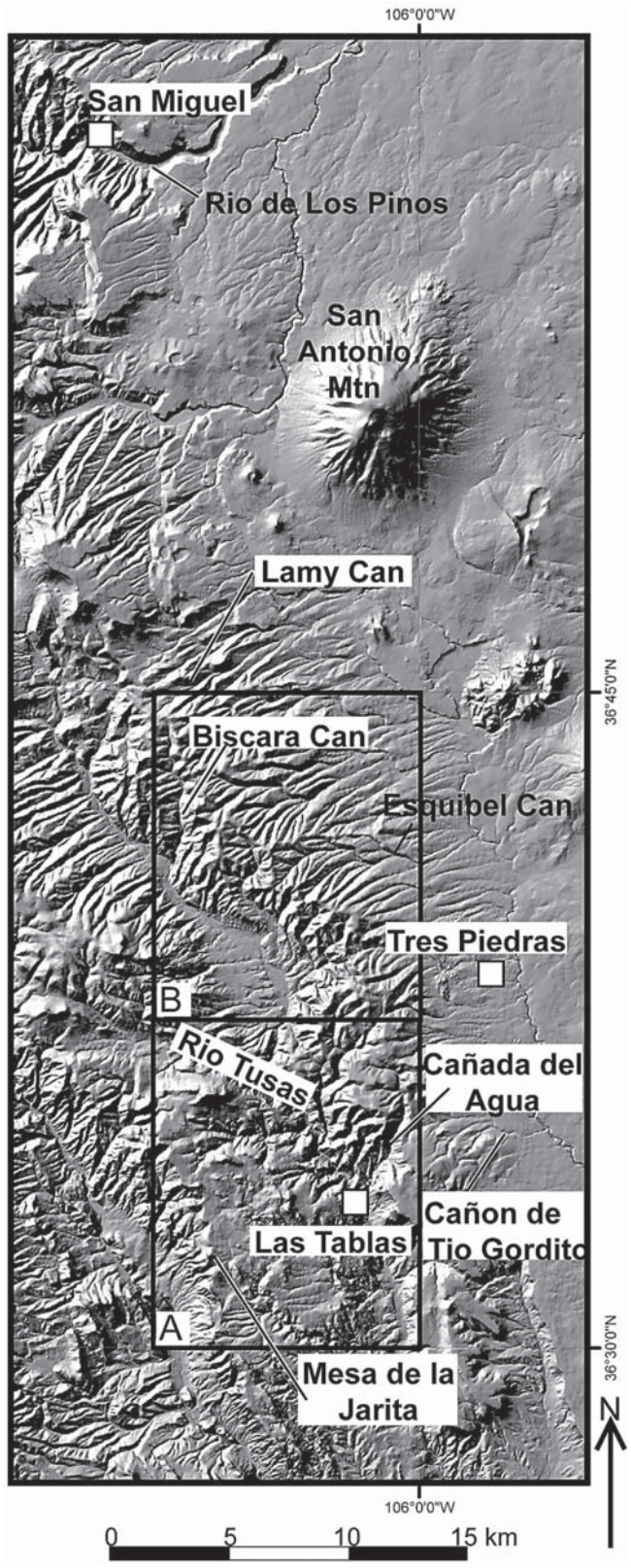

FIGURE 1. Shaded relief map showing locations mentioned in text. A = Las Tablas 7.5-minute quadrangle; B = Mule Canyon 7.5-minute quadrangle.

stratigraphic position. Butler's definition included all Proterozoic clast conglomerate in his map area in the Los Pinos. At a later date Butler (1971) abandoned three of his member names in favor of informal, lithology-based designations (quartz latite-andesite, coarsely porphyritic quartz latite, Jarita Basalt, and rhyolite members; Table 1). We agree that a lithology-based approach is preferable.

Barker (1958) did not redefine the members of Butler (1946), but replaced the Esquibel Member with a combined Biscara-Esquibel Member in his mapping (Table 1). He distinguished the Biscara and Biscara-Esquibel Members by the presence "... of gray, brown, and dark red andesite and quartz latite" in the former and "...gray or purple-pink quartz latite containing feldspar phenocrysts as much as 8mm long..." in the latter. Barker explicitly included sections of Proterozoic-clast conglomerate in his Biscara Member, but also gave formation rank to such rocks (Rititio Conglomerate) in some areas.

Manley (1981) redefined the Los Pinos Formation by abandoning the Biscara Member but retaining Butler's (1946) other three members (Table 1). In reconnaissance mapping of the Las Tablas and Mule Canyon quadrangles (Manley and Wobus 1982a, 1982b) the Biscara Member of Butler (1946) or Biscara-Esquibel Member of Barker (1958) was mapped as Conejos Formation. Manley and Wobus (1982a) identified an ash-flow tuff (the tuff of Las Tablas) associated with the Los Pinos near the town of Las Tablas on the Las Tablas quadrangle that had previously been mapped as an undifferentiated part of the Los Pinos Formation (Butler, 1946; Barker, 1958). They interpreted the tuff of Las Tablas to interfinger with the Cordito Member of the Los Pinos Formation (Table 1). Manley (1981) proposed extending the Esquibel Member to the north to include rocks mapped as undivided Los Pinos by previous workers (e.g. Butler, 1946, Barker, 1958). Manley and Wobus (1982b) described the Esquibel as containing "...intermediate volcanic rocks with large feldspar phenocrysts, vitrophyre, pumice, Precambrian rocks of several lithologies, and a few mafic volcanic rocks.". They included some sections of Proterozoic-clast conglomerate in the Esquibel while mappping some others as El Rito Formation. Many workers have mapped all clastic rocks of the Los Pinos as "undivided" (e.g. Bingler, 1968; Doney, 1968; Muehberger, 1968; Thompson and Lipman, 1994a, 1994b).

RECENT WORK

Our recent strategy for subdividing the Los Pinos Formation (Aby et al., 2010) on the Las Tablas quadrangle (Fig. 1) attempts to take several considerations into account. First, exposures in the mountains of northern New Mexico are often poor or nonexistent and much mapping is necessarily done in 'float'. Second, available exposures are often small and discontinuous and local faulting can make determination of stratigraphic position (by which the Los Pinos has been primarily defined previously) uncertain. Third, provenance studies can most easily be completed if members correspond to deposits derived from distinct sources. All of these considerations can be addressed for the Los Pinos Formation and associated units if they are distinguished (as

TABLE 1. Comparison of member-rank subdivisions of the Los Pinos Formation.

Atwood and Mather (1932)	Butler (1946)	Barker (1956)	Butler (1971)	Manley and Wobus (1982) Manley (1981)	This Report
	Cordito	Cordito	Rhyolite member	Cordito and Tuff of Las Tablas	Cordito
	Jarita Basalt	Jarita Basalt	Jarita Basalt	Jarita Basalt	Jarita Basalt
Los Pinos Gravel Undivided					
	Esquibel	Biscara-Esquibel	porphyritic quartz latite mbr		Esquibel
				Esquibel	
	Biscara	Biscara	Quartz latite-andestite mbr		Biscara(?) and Las Tablas Tuff

much as possible) by the clast types they contain. Recent mapping of the Las Tablas quadrangle (Aby et al., 2010) has led to several insights that we believe can eventually lead to an objective, lithology-based subdivision of the Los Pinos Formation and associated units. Below we outline recent findings unit-by unit, from oldest to youngest.

Ritito Conglomerate

We have mapped all clastic rocks on the Las Tablas quadrangle composed exclusively of Proterozoic clast types as Ritito Conglomerate (Barker, 1958); with the exception of a few large blocks of this material found within the Las Tablas tuff. This unit was proposed by Barker (1958) but he included some beds of this type in the Biscara Member and restricted the Rititio to areas west of the Mesa de la Jarita (Fig. 1). Other authors have included Proterozoic clast conglomerate in the Conejos (Atwood and Mather, 1932), the Esquibel (Manley, 1981), and Biscara (Butler, 1946). As we have defined it the Ritito undelies much of the Los Pinos Formation but also interfingers with it higher in the section near bedrock highs (Aby et al., 2010). This approach allows individual, isolated outcrops to be objectively assigned to a specific unit, and lends insight into the geologic history by identifying periods dominated by deposition of basement derived sediment. This usage also follows recent work (Maldonado and Kelley, 2009) that assigns broadly correlative Proterozoic-clast conglomerates formerly included in the Abiquiu Formation to the Ritito Conglomerate.

Las Tablas tuff

The "tuff of Las Tablas" of Manley and Wobus (1982a) has been informally renamed the Las Tablas tuff and interpreted as a more extensive unit than previously shown. K. Kempter (*in* Aby et al., 2010) interprets the Las Tablas tuff as an ignimbrite that incorporated large volumes of older volcanic and sedimentary material, possibly by syn-eruptive mass wasting events. This unit is approximately 200 m thick and underlies several square kilometers north and east of the town of Las Tablas. Although we believe this unit deserves either member or formation rank, we reserve formal designation until all possible exposures have been mapped and until geochemical correlation either confirms or denies its affinity with other ignimbrites in the region (Zimmerer, 2011). The fluvial material in the Las Tablas tuff is distinct from that found in the overlying members of the Los Pinos Formation (the Esquibel and Cordito) on the Las Tablas quadrangle. The most distinctive clast type in the fluvial material of the Las Tablas tuff is a light-colored, brownish-to-tan or reddish intermediate composition rock ("dacite"* and/or andesite) with ~8-20%, 0.3-5 mm long phenocrysts of amphibole +/- biotite. This clast type is commonly seen in float derived from the Las Tablas tuff. The fluvial component also sometimes contains abundant, dark-colored intermediate volcanic rock types and some mafic rocks. Some of this material is similar to intermediate rocks of the Conejos Formation (e.g. along the Rio de Los Pinos), while some is similar to certain clasts found in members of the Los Pinos. Some outcrops of Proterozoic Tres Piedras Granite, Ritito Conglomerate, and some of the "dacite" bodies within and adjacent to the outcrop area of the Las Tablas tuff (Aby et al., 2010, Manley and Wobus, 1982a) may represent "megabreccia" blocks within an ignimbrite matrix. Alternatively, some of the Proterozoic and Ritito Conglomerate outcrops may be paleotopographic highs buried by the tuff, while some or all of the "dacite" may be intrusive into it. Broad lenses or irregular blocks of fluvial sediment are common within the Las Tablas tuff. These bodies of sediment can be mistaken for a distinct fluvial unit as they do not usually have discordant bedding attitudes and exposures often do not show their contact with the ignimbrite matrix. The extent and varied composition of the Las Tablas tuff explains the lack of uniformity in previous mapping, nomenclature, and interpretation in this area (Barker,1958; Butler, 1946; Manley and Wobus, 1982a).

The source of the Las Tablas tuff is still uncertain. An $^{40}Ar/^{39}Ar$ age of ~28.28 +/- 0.07 Ma has been obtained for the tuff (Zimmerer, 2011), and "dacite" that is either a block within it or intrudes it has an identical $^{40}Ar/^{39}Ar$ age of 28.28 +/- 0.09

*We use the term "dacite" for volcanic rocks with abundant feldspar (+/- hornblende and/or biotite) phenocrysts in a fine-grained, generally light-colored matrix that varies through a wide range of colors. Our designation of ''dacite"' is based on inferences about the likely alkali-silica ratio of these rocks (Le Bas, et al, 1986) that are based on chemical analysis of similar rocks regionally (Ekas et al., 1984, Koning et al., 2007). Some of these rocks have previously been described as quartz-latite or andesite (e.g. Atwood and Mather, 1932; Butler, 1946).

Ma (Aby, et al., 2010) and is therefore clearly cogenetic. Geochronologic correlation suggest that the Las Tablas tuff may be equivalent to the Tuff of Tetilla Peak (Lipman and Reed, 1989) of the Latir volcanic field or the Fish Canyon Tuff of the San Juan volcanic field, but geochemical correlation is still uncertain (Zimmerer, 2011). A third possibility that would account for the "megabreccia" aspect of this unit is derivation from an unidentified, nearby vent now buried beneath the Taos Plateau.

Biscara Member of the Los Pinos Formation

We have conducted reconnaissance to the north of the Las Tablas quadrangle (Fig. 1) in the 'type area' of the Los Pinos along the Rio de los Pinos (Atwood and Mather,1932) and in Biscara Canyon, the 'type area' for the Biscara Member of Butler (1946). Along the Rio de los Pinos, rocks mapped as undivided Los Pinos (Manley, 1982; Thompson and Lipman, 1994b) consist of a wide range of silicic-to-mafic clast types but are dominated by intermediate types. A similar range of non-distinctive clast types is found in the lower part of the mapped Los Pinos in Biscara Canyon. These clasts are similar to the wide range of clasts seen in the Las Tablas tuff except that in Biscara Canyon most of the (poorly exposed) section seems to be fluvial. The lateral relations between the Las Tablas Tuff and the fluvial rocks of Biscara Canyon are not yet clear (Fig. 2) and the clasts in the Biscara have not been described. Distinctive, phenocryst-rich "dacite" like that characterizing the Esquibel Member (see below) are found near the divide between Biscara and Lamy Canyons in the northwest corner of the Mule Canyon quadrangle (Fig. 1). These preliminary observations lead us to suspect that a separate, mappable, fluvial unit (the Biscara Member of Butler, 1946 or "quartz-latite-andesite member" of Butler, 1971) does exist here. For simplicity we would suggest retaining the name Biscara Member for this unit if it indeed proves mappable.

Esquibel Member of the Los Pinos Formation

Butler (1946) noted distinctive "quartz latite with conspicuous phenocrysts" as the characteristic clast in the Esquibel Member. Butler (1971) went so far as to rename the Esquibel the "coarsely porphyritic quartz latite" member (Table 1). Barker (1958) noted rocks with large (up to 8mm) feldspars in his Biscara-Esquibel member and Manley (1981, p. 987) also noted that clasts of "intermediate composition with large feldspar phenocrysts" could be used to distinguish the Esquibel in the northern Tusas Mountains. We describe these same clasts as "dacite" (see above). Excellent exposures of the Esquibel (and Cordito) are found in roadcuts along highway 64 west of Tres Piedras. These roadcuts would make an ideal type section for this member and were noted by Butler (1946). The Esquibel at this locality always contains the distinctive, plagioclase-rich ''dacite"' clasts. These slightly friable (Compton, 1985) clasts contain 15-50% snow-white-to glassy-white (sometimes greenish or pinkish), subhedral ('blocky") plagioclase phenocrysts that range in size from <1-15 mm and usually have 3-10% mafics (biotite +/- amphibole). Other members of the Los Pinos do contain some "dacite" clasts, but the characteristic "dacites" of the Esquibel are distinct and show up well in float. In our experience the appearance of these clasts in significant (>3%) numbers in the stratigraphic sequence is abrupt and distinctive. We would therefore suggest that >5% of this clast type be used as the cut off for designation of the Esquibel Member.

Jarita Basalt Member of the Los Pinos Formation

The Jarita Basalt was defined by Butler (1946) as "...widespread, but discontinuous, basalt flows that underlie the Cordito Member." These flows are named for Mesa de la Jarita in the central part of the Las Tablas quadrangle (Fig. 1) where the basalt overlies Ritito Conglomerate. To the north the Jarita Basalt is found between the Esquibel and Cordito Members and at the top of the Las Tablas Tuff. A recent $^{40}Ar/^{39}Ar$ date of 22.72 ± 0.53 Ma on the "type" Jarita Basalt at Mesa de la Jarita is younger than Jarita Basalt to the northeast in Cañada del Agua (Figure 1) that underlies the 25 Ma Amalia Tuff (Aby et al., 2010). However, the age spectra for this sample is disturbed and the 'true' age is probably between 23-25 Ma (W.C. McIntosh, personal commun., 2011).

Cordito Member of the Los Pinos Formation

The Cordito Member is named for the Cañon de Tio Gordito (sic) south of Tres Piedras (Fig. 1). It is the youngest member of the Los Pinos and is very distinct from the other members. Silicic debris derived from the Latir volcanic field (Lipman and Reed, 1989) characterizes this unit although much "dacite" and minor basalt is also found. The lower contact of the Cordito Member is easily identifiable by the presence of abundant grey-to-bluish grey, sparsely porphyritic rhyolite that is not found in the Esqui-

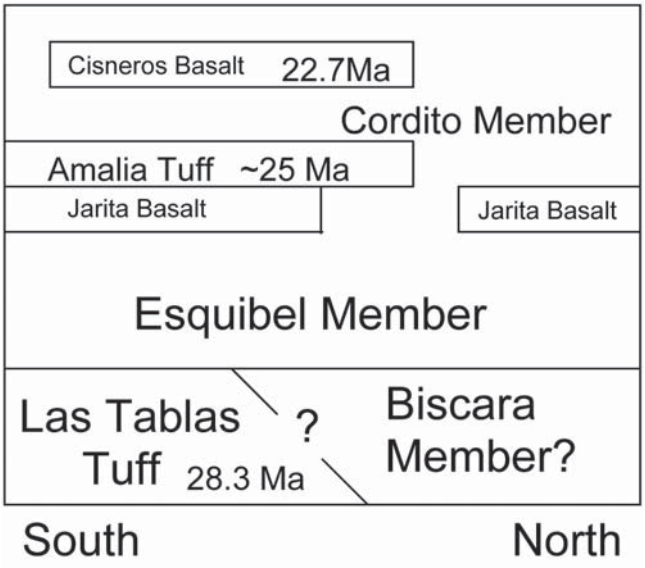

FIGURE 2. Stratigraphic relations between volcanic and volcaniclastic rocks of the Los Pinos Formation and Las Tablas tuff.

bel Member. Recent dating of clasts in the Cordito indicates that these rhyolites are the same age as the Amalia Tuff (Zimmerer, personal commun., 2011). Poorly welded ~25.4 Ma Amalia Tuff (Zimmerer and McIntosh, 2009) is found near the base of the unit in the Cañada del Agua (Aby et al., 2010) and clasts of welded Amalia Tuff are common in many parts of the Cordito. A recent date of 22.77 +/- 0.52 Ma (Aby et el., 2010) for a flow of Cisneros Basalt indicates that this flow is interbedded in the Cordito Member, and not correlative with flows found overlying the Cordito as previously thought (Butler, 1946; Barker, 1958). The Cisneros Basalt is found near (or at?) the top of the exposed Cordito Member on the Las Tablas quadrangle. The Cordito Member on the Las Tablas quadrangle therefore has a maximum age of ~25.4 Ma and a minimum age near 22.7 Ma. The upper contact of the Cordito Member on the Las Tablas quadrangle is an angular unconformity with ~4.1-4.6 Ma Dorado Basalt (Aby et al., 2010) along the eastern quadrangle boundary. In the southern part of the quadrangle the Cordito is gradationally overlain by the Duranes Member of the Tesuque Formation (Aby et al., 2010).

CONCLUSIONS

The Los Pinos Formation is a complex volcaniclastic unit deposited between ~28.3 and ~22.7 Ma on the Las Tablas quadrangle and is probably derived from both the San Juan and Latir volcanic fields. Recent mapping confirms the existence of multiple members of the Los Pinos Formation on the Las Tablas quadrangle (Aby, et al., 2010). Distinct members of the Los Pinos Formation are distinguishable by their clast composition, but only the rhyolitic part of the Cordito Member can be definitively linked to its source (The Latir volcanic field) at his time. The Los Pinos Formation has never been formally designated in accordance with the most recent versions of the stratigraphic code (North American Commission on Stratigraphic Nomenclature, 2005). Our member (and sometimes formation) designations differ from previous mapping (Table 1; Butler, 1946; Barker, 1958; Manley and Wobus, 1982a). The arealy restricted tuff of Las Tablas of Manley and Wobus (1982a) is a more extensive unit (our Las Tablas tuff) of varied composition and enigmatic origin that is possibly related to the Tuff of Tetilla Peak (Lipman and Reed, 1989) or the Fish Canyon Tuff (Zimmerer, 2011). Alternatively, this tuff may represent a "new" ignimbrite in northern New Mexico derived from an unknown, nearby(?) source. This unit contains a wide variety of rocks in an ignimbrite matrix. Megablocks and broad lenses of older volcanic and sedimentary debris were incorporated into the ignimbrite during emplacement. Some of this material may be derived from the Los Pinos or Conejos Formations, or some unidentified source that may be a part of the Latir volcanic field to the east. The Biscara Member of the Los Pinos Formation is probably a distinct, mappable unit north of the Las Tablas quadrangle. The Esquibel Member should be distinguished from all other volcaniclastic units in the area by the presence of >5% distinctive "dacite" clasts described above. To avoid complication of the nomenclature of these rocks, and in recognition of the poor exposure in much of the area underlain by them, formal designation of members should be based on clast type(s) if possible. We recommend that this formal designation wait until correlation of the rocks on the Las Tablas quadrangle with those to the north is complete and that the characteristics outlined here be used informally until then.

ACKNOWLEDGMENTS

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