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WHAT IS THE COCHITI FORMATION?

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Abstract—A variety of Neogene strata have been assigned to the Cochiti Formation in and adjacent to the southern Jemez Mountains in north-central New Mexico. Considerable ambiguity now exists on what constitutes the Cochiti Formation. This problem originated with inconsistencies in the original definition by Bailey et al. (1969) and has been perpetuated by varying approaches to the regional stratigraphy by basin-fill stratigraphers and volcanic-field stratigraphers. We suggest that the name be retained but the formation redefined to include only sedimentary strata of entirely volcaniclastic composition that overlie Miocene Keres Group volcanic rocks and correlative volcaniclastic sediment south of the Jemez Mountains and are unconformably overlain, in many places, by a variety of Pliocene and lower Pleistocene gravels. If adopted, this redefinition would preserve most, although not all, of what was mapped as Cochiti Formation by Smith et al. (1970) while not including strata mapped as Cochiti Formation by Manley (1978) and Goff et al. (1990). Alternatively, the name could be suspended and new stratigraphic units defined in its place. Regardless of the approach taken, there is a distinct lithostratigraphic unit that can be mapped in both surface and subsurface, which will be useful in establishing the hydrostratigraphic framework of the northern Albuquerque Basin. The stratigraphic nomenclature problems reflected in the history of use of the name "Cochiti Formation" are not unique to the Jemez Mountains but are illustrative of the problems of effectively representing the common interfingering of volcanic and sedimentary strata in all volcanic provinces and the inherent biases of geologists who are either primarily volcanic stratigraphers or basin-fill stratigraphers.

INTRODUCTION

The definition of stratigraphic units is fundamental to geological mapping and the interpretation of the geological history of a region. Disputes among stratigraphers with regard to nomenclature and boundary definition of units are common, and in some cases legendary. Although viewed by some as trivial, any stratigraphic-nomenclature dispute actually reflects a lack of understanding or a change in the understanding of the distribution of distinctive rock types and is, therefore, an important process in the evolving interpretation of the geological framework of a region.

This paper reviews the usage of the name "Cochiti Formation" for various Neogene deposits, in and near the southern Jemez Mountains, and highlights the problems that commonly arise in accurately depicting the stratigraphy of interbedded sedimentary and volcanic rocks. The problem goes beyond the oft-presumed triviality of stratigraphic-nomenclature disputes because of increased interest in characterizing the subsurface hydrostratigraphy of the northern Albuquerque Basin and the desire to better understand the groundwater-recharge pathways from the Jemez Mountains to the basin-fill aquifer. Related to this problem is the difficulty of accurately representing the stratigraphic relationships between proximal volcanic rocks and age-equivalent sedimentary strata in adjacent depositional basins. Therefore, the problems and alternative stratigraphic treatments presented in this paper have application beyond the Jemez Mountains region.

Our primary objectives are to (1) call attention to the extreme ambiguity of what is currently referred to as the Cochiti Formation based on inconsistencies in use that began with the original definition; and (2) illustrate how such problems are to be expected in areas of interbedded volcanic and sedimentary strata. We also propose an alternative stratigraphic nomenclature scheme that is a compromise of the intentions of sedimentary and volcanic stratigraphers while maintaining the most objective criteria possible for defining units in both surface and subsurface investigations. We emphasize that the proposed revision is tentative, however, and requires testing by further study in the region.

PROBLEMS WITH THE DEFINITION OF THE COCHITI FORMATION

The Cochiti Formation was formally defined by Bailey et al. (1969) and first portrayed on a geological map by the same workers (Smith et al., 1970). These publications were the result of two decades of geological investigations of the stratigraphy, composition, and distribution of volcanic rocks comprising the Jemez Mountains. Bailey et al. (1969) assembled volcanic-rock formations into the Keres, Polvadera and Tewa Groups. The southern Jemez Mountains are largely composed of Miocene (13-6 Ma; Gardner et al., 1986) Keres Group rocks unconformably overlain by the Pleistocene Bandelier Tuff, a component of the Tewa Group. The Keres Group was defined (Bailey et al., 1969) to include the Canovas Canyon Rhyolite, Paliza Canyon Formation (consisting of basaltic, andesitic, and dacitic rocks), Bearhead Rhyolite and basalt of Chamisa Mesa, which was subsequently included within the Paliza Canyon Formation (Gardner et al., 1986). Bailey et al. (1969, p. 8-9) defined the Cochiti Formation as "a thick sequence of volcanic gravel and sand, consisting of basalt, andesite, dacite, and rhyolite detritus derived from penecontemporaneous erosion of units of the Keres Group." The type area for the Cochiti Formation (Bailey et al., 1969) is poorly exposed, largely unconsolidated sediment underlying a broad dissected piedmont between the Jemez Mountains and the Jemez River, to the west and southwest of Cochiti Pueblo (Fig. 1).

In defining the Cochiti Formation, Bailey et al. (1969) did not stipulate a type section nor did they make it clear how to distinguish the formation from neighboring stratigraphic units. Two ambiguities became most problematic for future workers. First, how was the Cochiti Formation distinct from the Santa Fe Group, especially since Bryan and McCann (1937), Spiegel (1961), and Galusha (1966) had previously mapped part or all of this newly designated Cochiti Formation as Santa Fe Group? Second, how was the Cochiti Formation to be mapped where sediment was intimately interbedded, at a fine scale, with volcanic rocks of the Keres Group?

Bailey et al. (1969) offered contradictory statements related to the distinction of Santa Fe Group and Cochiti Formation. Although they stipulated that the Cochiti Formation postdates arkosic sediment of the Santa Fe Group they also agreed with Spiegel (1961) that the volcanic debris intertongues with and grades into the arkosic sediment, requiring instead that the Cochiti and Santa Fe strata "are, in large part, time equivalent" (Bailey et al.,1969, p. 9). The base of the Cochiti Formation was described from exposures on Chamisa Mesa (Fig. 1) where Santa Fe Group strata lacking volcanic detritus are overlain by arkosic sediment that contains volcanic detritus from the Jemez Mountains. The inclusion of arkosic sediment within the Cochiti Formation violates the explicit definition of the formation as composed *only* of volcanic detritus. The inclusion of arkosic sediment within the Cochiti Formation was also necessitated by the southward gradation of volcanic sand and gravel into sediment of mixed composition below the basalt of Santa Ana Mesa (Fig. 1). The strata below Santa Ana Mesa were mapped as Santa Fe Group by Spiegel (1961) but were incorporated in the Cochiti Formation by Smith et al. (1970). Thus, although acknowledging that rock types typical of Santa Fe Group and Cochiti Formation are intercalated, no definition of how to distinguish the stratigraphic units was provided by Bailey et al. (1969) although Smith et al. (1970) mapped the two units as mutually exclusive.

The geological map of Smith et al. (1970) notably does not illustrate

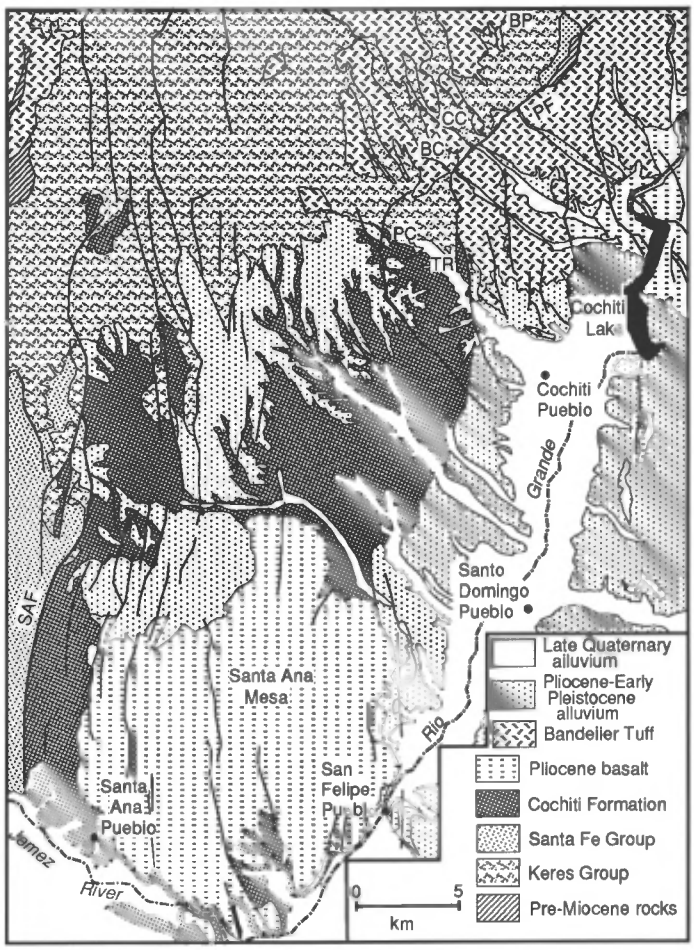

FIGURE 1: Generalized geologic map of the southern Jemez Mountains and northern Albuquerque Basin based on Smith et al. (1970). The Cochiti Formation is portrayed as mapped by Smith et al. (1970). The Plio-Pleistocene alluvium unit includes the Quaternary-Tertiary alluvium (QTal), Quaternary-Tertiary gravel (QTg) and Quaternary-Tertiary pediment gravel (QTpg) units of Smith et al. (1970). Key to features mentioned in text: BP - Boundary Peak, CC - Cochiti Canyon, PC - Peralta Canyon, PF - Pajarito fault, SAF - Santa Ana fault, TR - Tent Rocks.

Cochiti Formation as being present within the physiographic Jemez Mountains and shows the principal outcrop belt, near Cochiti Pueblo, as strata overlying all Keres Group rocks. At, and south of, Tent Rocks (Fig. 1) the Cochiti Formation was mapped as overlying the Peralta Tuff Member of the Bearhead Rhyolite, which is the youngest constituent of the Keres Group (Bailey et al., 1969; Gardner et al., 1986; Smith et al., 1991). Therefore, the strata in the type area of the Cochiti Formation largely fail to meet the restriction of the formation to be penecontemporaneous with the Keres Group volcanic rocks. Although age cannot be a criterion for naming lithostratigraphic units (North American Commission on Stratigraphic Nomenclature, 1983, article 22e) the definition of the Cochiti Formation implies that it is laterally equivalent to and coeval with Keres Group volcanic rocks.

If the Cochiti Formation is defined as being penecontemporaneous with the Keres Group then intertonguing of sedimentary and volcanic strata of the two units is expected. Bailey et al. (1969) mentioned such relationships in the lower reaches of canyons extending from the volcanic massif of the Jemez Mountains and emphasized interbedding of Cochiti Formation with the Peralta Tuff Member of the Bearhead Rhyolite at Tent Rocks. The geological map of Smith et al. (1970) does not, however, portray intertonguing of the Cochiti Formation and Peralta Tuff Member. Although this omission, in part, reflects the limitations of mapping at a scale of 1:125,000, it has led to further ambiguity as to the authors' intentions for the composition of the Cochiti Formation. At Tent Rocks, Smith et al. (1970) portrayed the Cochiti Formation and Peralta Tuff Member juxtaposed by a normal fault (Fig. 1). The stratigraphy of the pyroclastic deposits within the Peralta Tuff Member (Smith et al., 1991) indicates, however, that the strata mapped as Cochiti Formation to the east of the fault are equivalent to what was mapped as Peralta Tuff on the west side of the fault. The dominantly pyroclastic deposits of the Peralta Tuff Member grade away from vents into sections dominated by gravel and sand interbedded with distal pyroclastic units (Bailey et al., 1969; Smith et al., 1991). Alluvial gravel and sand in Peralta and Bland Canyons that are mappable at a scale of 1:125,000 were included within the Peralta Tuff Member by Smith et al. (1970), producing ambiguity in the intentions of the original authors in the definitions of both the Peralta Tuff Member and Cochiti Formation.

LATER VIEWS FROM THE NORTHERN ALBUQUERQUE BASIN

Subsequent stratigraphic and mapping endeavors within the principally sedimentary fill of the northern Albuquerque Basin have taken different approaches to the problem of distinguishing the Santa Fe Group and the Cochiti Formation. The nomenclature of the variously termed Santa Fe Formation or Santa Fe Group has also undergone changes. The Santa Fe Formation in the Albuquerque Basin was simply divided into lower gray, middle red, and upper buff members by Bryan and McCann (1937). This tripartite division has been maintained by many subsequent workers (e.g., Kelley, 1977; Hawley, 1978; Hawley and Haase, 1992), with the lower Santa Fe being regarded as a general equivalent to the Zia Sandstone, while the upper member is generally equivalent to the Sierra Ladrones and Ceja Formations of Machette (1978) and Kelley (1977). The Zia Sandstone, and its temporal equivalent the Abiquiu, were excluded from the Santa Fe Formation (or Group) by Galusha (1966) and Smith et al., (1970) although they were included by Kelley (1977) and Hawley (1978) in the spirit of the proposal by Bryan and McCann (1937) that all sedimentary deposits of the Rio Grande rift be considered constituents of the Santa Fe Formation.

Within the context of previous treatment of the Santa Fe Formation (especially by Spiegel, 1961, and Spiegel and Baldwin, 1963), Kelley (1977) took strong exception to the definition and mapping of the Cochiti Formation by Bailey et al. (1969) and Smith et al. (1970). Noting that Soister (1952) and Speigel (1961) had previously recognized the intertonguing of Jemez volcanic rocks with Santa Fe Formation basin-fill strata, Kelley (1977, p. 11) stated that the rocks mapped as Cochiti Formation by Smith et al. (1970) "are the heart of the Santa Fe, and therefore the Cochiti member is at best only a facies of the Santa Fe Formation"; mapping the Cochiti Formation "well into central areas of the basin (Smith, Bailey, and Ross, 1970) was a mistake, especially without experience in the larger basin stratigraphy." In addition, Kelley (1977) questioned the distinction of Cochiti Formation and Santa Fe Formation by Bailey et al. (1969) based on the presence of intermediate-composition clasts in the former because both he and Soister (1952) noted the presence of similar clasts in outcrops mapped as Santa Fe Formation by Smith et al. (1970) west of the Santa Ana fault (Fig. 1).

Finally, Kelley (1977) commented on the unlikelihood of successfully separating the volcanic-clast facies of the Cochiti Formation from the main body of the Santa Fe Formation. The Cochiti Formation "being a facies derived from volcanic and other older rocks (some granitic) in the Jemez, its characterizing beds grade and thin into more regular Santa Fe beds south and southeasterly in the basin... This facies, like all facies in flat-lying beds, is essentially impossible to map rigorously because its lithologies intertongue up and down sections as well as laterally and longitudinally with respect to the direction of transport" (Kelley, 1977, p. 13)

Manley (1978) took the very different approach of adopting Zia Sand (i.e., Zia Sandstone) and Cochiti Formation and dropping use of Santa Fe Formation in her map of the Bernalillo NW quadrangle located immediately south of the area mapped by Smith et al. (1970). Manley (1978) attempted to supercede use of "Santa Fe" at the formation level by extension of the Cochiti Formation to not only include the strata loosely defined as Cochiti Formation by Bailey et al. (1969) but also to include strata that Smith et al. (1970) mapped as Santa Fe Formation. Following

Manley's lead, Tedford (1982) proposed reassignment of Kelley's (1977) Ceja Member of the Santa Fe Formation to the Cochiti Formation. Efforts to dispense with the term Santa Fe Formation or Group in the Albuquerque Basin have not been adopted by most other workers (e.g., Hawley, 1978; Lozinsky and Tedford, 1991; Hawley and Haase, 1992; Chapin and Cather, 1994; Hawley et al., 1995). The consensus has rather been to stay with the broad view of the Santa Fe Group as the entire Neogene sedimentary fill of the Rio Grande rift basin system that accumulated prior to valley incision (Bryan and McCann, 1937; Spiegal and Baldwin, 1963; Kelley, 1977; Chapin, 1988).

LATER VIEWS FROM THE SOUTHERN JEMEZ MOUNTAINS

Originating with the dissertation research of Gardner (1985), geologists at Los Alamos National Laboratory undertook detailed investigations of the volcanic stratigraphy, petrology, and geochronology of Keres Group rocks (Gardner and Goff, 1984; Gardner et al., 1986; Goff et al., 1990). With more detailed mapping (1:62,500 and 1:24,000) these workers were able to discriminate individual lava flows and, in places, pyroclastic units within the Keres Group. Locally, these volcanic rocks are interbedded with volcaniclastic strata, largely but not entirely of sedimentary origin, that were assigned (Gardner, 1985; Gardner et al., 1986; Goff et al., 1990) to the Cochiti Formation in the spirit of the definition of Bailey et al. (1969) that sediment deposited contemporaneously with Keres Group volcanic rocks should be so treated. In addition, because of the intimate relationship of the volcaniclastic sediment facies to Keres Group volcanic rocks, Gardner et al. (1986) placed the Cochiti Formation, as they mapped it, within the Keres Group.

The Cochiti Formation, as described and mapped in the Jemez Mountains consists "primarily of lahars, vent breccias, and gravel. The gravels contain angular cobbles of dacite and andesite of Paliza Canyon Formation, with subordinate amounts of Paliza Canyon basalt and Canovas Canyon Rhyolite, set in a volcanic sand matrix" (Gardner et al., 1986, p. 1772). Gardner et al. (1986) viewed the Cochiti Formation as rift-basin-fill sediment that accumulated synchronously with Keres Group volcanism. The volcaniclastic strata were observed to thicken eastward, consistent with the interpretation of erosion and deposition of detritus from Keres Group volcanoes into an actively subsiding rift basin.

Notably, the usage of Cochiti Formation by Gardner et al. (1986) makes no mention of a relationship between the volcaniclastic sediments and the Bearhead Rhyolite, even though Bailey et al. (1969) had explicitly described the interbedding of Cochiti Formation and the Peralta Tuff Member. Although mapping Cochiti Formation volcaniclastic strata within outcrops previously mapped as Paliza Canyon Formation (Smith et al., 1970), Gardner (1985) and Goff et al. (1990) did not differentiate sedimentary strata interbedded with Peralta Tuff. Rather, these later maps followed Smith et al. (1970) to portray sedimentary deposits interbedded with and overlying pyroclastic deposits related to the Bearhead Rhyolite volcanism as belonging to the Peralta Tuff Member, rather than Cochiti Formation. In the Cochiti Canyon and Boundary Peak areas, the Cochiti Formation mapped by Goff et al. (1990) is approximately 9 - 12 Ma based on $^{40}Ar/^{39}Ar$ ages of associated lavas and tuffs (Lavine et al., this volume) and completely predates the Peralta Tuff.

The Cochiti Formation, as used by Gardner et al. (1986) and Goff et al. (1990) includes primary volcanic rocks as well as sedimentary materials. The later description of the Cochiti Formation as including vent breccias (Gardner et al., 1986) is curious for a unit that was originally defined as being sedimentary in origin. Our work in the southern Jemez Mountains (Lavine et al., this volume) also shows that the Cochiti Formation as mapped by Goff et al. (1990) includes numerous andesitic lava flows, thick (>150 m) sequences of cone-forming flow breccias, and pyroclastic breccias in addition to debris-flow deposits and poorly sorted fluvial facies. This mixture of volcanic and sedimentary deposits leads to ambiguity in the distinction of the Cochiti and Paliza Canyon Formations and precludes a tectonic interpretation of the Cochiti Formation based on its thickness alone. Thick flow breccias and debris-flow breccias in upper Cochiti Canyon (Lavine et al., this volume) that were mapped as Cochiti Formation by Goff et al. (1990) were cited as being among the best representative exposures of Paliza Canyon Formation by Bailey et al. (1969). Bailey et al. (1969) listed breccias and tuffs within their definition of rocks included the Paliza Canyon Formation. Therefore, the flow breccias, vent breccias, and debris-flow and fluvial deposits composed of angular clasts that Goff et al. (1990) mapped as Cochiti Formation can arguably be mapped as Paliza Canyon Formation, as was done by Smith et al. (1970).

The strata mapped as Cochiti Formation by Goff et al. (1990) bear little resemblance to those mapped as Cochiti Formation by Smith et al. (1970). The true sedimentary components of the Cochiti Formation mapped within the Jemez Mountains are dominated by debris-flow breccias and fluvial facies (Lavine et al., this volume) typical of volcaniclastic aprons that form adjacent to intermediate-composition composite volcanoes (cf., Smith, 1991). Facies distributions within the volcaniclastic-sedimentary strata are more consistent with representing debris aprons flanking volcanic centers (Lavine et al.,this volume) than with accumulation driven by rift-basin subsidence. The younger Cochiti Formation mapped by Smith et al. (1970) in Peralta Canyon, as well as sedimentary strata mapped within the Peralta Tuff, is represented by shallow-braided stream deposits that contain an abundance of rhyolitic debris eroded from older Bearhead Rhyolite domes and related pyroclastic aprons (Smith et al., 1991).

Goff et al. (1990) also mapped the Cochiti Formation to include gravels underlying the Bandelier Tuff that Smith et al. (1970) assigned to an unnamed unit, designated QTal, that unconformably overlies the Cochiti Formation. Our reconnaissance indicates the widespread distribution of post-Cochiti Formation (and post-Peralta Tuff) gravel that rests disconformably upon the older units and is overlain, with no obvious unconformity, by Bandelier Tuff. These younger sediments include ancestral Rio Grande gravels and locally enclose Pliocene basalt flows. Gardner et al. (1986) and Goff et al. (1990), therefore, not only extended the Cochiti Formation to include volcanic rocks previously considered Paliza Canyon Formation but also extended the Cochiti Formation to enclose younger Pliocene and early Pleistocene strata.

BASIN-FILL STRATIGRAPHY VERSUS VOLCANIC-FIELD STRATIGRAPHY

All workers accept the observation that the Keres Group volcanic rocks formed during Miocene subsidence of the Albuquerque and Española basins and the contemporaneous accumulation of rift-basin sediment. Within and adjacent to the volcanic field, the sedimentary record is composed of detritus eroded from the volcanic rocks. These volcaniclastic sediments form local volcano-flanking debris aprons as well as contributing to the more voluminous fill of the subsiding rift basins. At increasing distance from the Jemez Mountains, the volcanic detritus is mixed with greater proportions of sediment derived from nonvolcanic sources and becomes less distinct from the main body of the rift-basin fill. Basin-fill stratigraphers, therefore, prefer assignment of these strata to the rift-filling Santa Fe Group (e.g., Kelley, 1977). Conversely, volcanic-field stratigraphers prefer assignment of these deposits to a separate Cochiti Formation (Bailey et al., 1969) that, most recently (Gardner et al., 1986) has been assigned to the Keres Group that includes the volcanic rocks. A reasonable solution to this dispute goes beyond the biases of sedimentary and volcanic stratigraphers to the designation of criteria for objectively defining stratigraphic units and mapping them at a scale of 1:24,000 as required by the North American Stratigraphic Code.

It is not clear that sedimentary deposits found interbedded with Keres Group volcanic rocks can be accurately depicted as a separate lithostratigraphic unit of formation rank. Just as the intimate lateral and vertical intertonguing of rock types was cited by Kelley (1977) as a reason to not accept separate Cochiti and Santa Fe Formations, such relationships preclude mapping of Cochiti Formation separate from Keres Group volcanic units. Hence, in areas where lava flows and tuffs are thin and subordinate in volume to sedimentary facies, Goff et al. (1990) included these deposits within the Cochiti Formation even though they are inconsistent with any definition of the Cochiti Formation. Within the Peralta Tuff Member, primary pyroclastic deposits are interbedded with sedimentary facies on the scale of a few meters (Smith et al., 1991 and unpubl.) so that even at 1:12,000 scale it is not possible to represent the volcanic and sedimentary facies as different formations.

Because it is usually impractical to map finely interbedded sedimentary and volcanic rocks in separate formations, they are typically included within the same unit in most volcanic provinces. Such stratigraphic treatment has, for example, been used successfully in the Cascade Range (Priest et al., 1984; Vance et al., 1987) and in the definition of the San Juan and Conejos Formations in the San Juan Volcanic Field of Colorado (Lipman, 1975). Similar stratigraphic treatment had been applied in the usage of Datil Group, Spears Formation, and Rubio Peak Formation in southwestern New Mexico until Cather et al. (1994) recently proposed a new stratigraphic scheme that separates volcanic and sedimentary units. It remains to be demonstrated whether or not the proposal of Cather et al. (1994) will suffice for accurate and consistent geological mapping. The problem of mapping and defining intimately interbedded volcanic and sedimentary facies is one of the objections to the revision raised by Elston (1994).

ALTERNATIVE STRATIGRAPHIC TREATMENT

A solution to the stratigraphic ambiguities of the Cochiti Formation is not easily accomplished at this time. The Cochiti Formation, as mapped by Smith et al. (1970) is poorly exposed and distributed primarily on pueblo tribal lands that have not subsequently been easily accessible for detailed field study. Outcrops illustrating the lateral transition from Keres Group volcanic rocks to coeval fluvially deposited basin-fill sedimentary facies, rather than proximal volcaniclastic aprons, are largely restricted to the stratigraphic level of the Peralta Tuff Member of the Bearhead Rhyolite. The coarse-grained debris-flow and flood facies that are interbedded with Paliza Canyon Formation lava flows must grade basinward into finer grained strata typical of the Santa Fe Group but this transition is almost entirely restricted to the subsurface and is not documented by current data. Because of the many ambiguities summarized above, it arguably is best to abandon "Cochiti Formation" and define new stratigraphic units as research progresses in this region.

We previously proposed (Smith and Lavine, 1993), in a preliminary fashion, a revision that may serve as a working model of the stratigraphy but will require verification or further revision during future mapping and subsurface stratigraphic investigations in the northern Albuquerque Basin (Fig. 2). This proposal, slightly revised here, would maintain but redefine and restrict the Cochiti Formation to sedimentary strata of *entirely* volcanic composition that *overlie* Keres Group volcanic rocks and their correlative sedimentary strata south of the Jemez Mountains and are unconformably overlain locally by gravels related to Pliocene and early Pleistocene partial filling of incised valleys (i.e., the QTal unit of Smith et al., 1970 and equivalent strata not shown on published maps). The Cochiti Formation, thus redefined, would constitute most, but not all, of the strata mapped as Cochiti Formation by Smith et al. (1970), would exclude all deposits mapped as Cochiti Formation by Goff et al. (1990), and would not follow the restriction in the definition of Bailey et al. (1969) that the Cochiti Formation detritus be derived from penecontemporaneous erosion of Keres Group volcanic rocks. As redefined, the Cochiti Formation could be included within the upper part of the Santa Fe Group and may be correlative, in part, with the Puye, Totavi and Ancha Formations of the Española Basin (Galusha and Blick, 1970; Waresback and Turbeville, 1990) and the Sierra Ladrones of the Albuquerque Basin while recognizing the Cochiti Formation as a distinct, mappable unit of entirely volcanic detritus. Further work may demonstrate that the Pliocene-early Pleistocene deposits overlying the Cochiti Formation are the lateral equivalents of the Puye, Totavi, and Ancha Formations.

We further recommend that older *entirely* volcaniclastic sedimentary strata that are interbedded with and laterally correlative to Keres Group volcanic rocks remain in the Keres Group (Fig. 2). Where appropriate they may be mapped as components of the individual formations that comprise the Keres Group or simply be considered as undifferentiated volcaniclastic strata within the Keres Group until sufficient information exists for adequate subdivision and nomenclature. If this revision is adopted, strata containing *any* nonvolcanic detritus would be assigned to the appropriate formation (Zia, unnamed middle unit, Sierra Ladrones) within the Santa Fe Group. Therefore, Keres Group volcaniclastic strata and the Cochiti Formation would be recognized as distinctive sedimentary units of entirely volcanic composition and those that are laterally equivalent to penecontemporaneously erupted volcanic rocks would be most closely associated with the volcanic rocks in the same group. By restricting definition of the Cochiti Formation and the Keres Group volcaniclastic units to sediment of only volcanic composition, they would be recognizeable units only within 5-15 km of the Jemez Mountains. Traditional Santa Fe Group nomenclature would be used elsewhere, negating the extension of Cochiti Formation undertaken by Manley (1978) and Tedford (1982).

We are optimistic that the units described above can be recognized and mapped both on the surface and in the subsurface. Although intertonguing of beds containing only volcanic detritus with beds containing both volcanic and nonvolcanic fragments may be extensive in the vicinity of the Jemez River it is likely that this relationship will be no more complicated for mappers and stratigraphers to resolve than the common intercalation of shoreface sandstones and offshore shales that are routinely considered within the stratigraphy of marine sedimentary facies. We propose that the contact between the Peralta Tuff Member of the Bearhead Rhyolite and the Cochiti Formation be placed at the top of the highest pyroclastic-flow or fall deposit within a local section. Thus, most of the sand and gravel exposed at Tent Rocks would be assigned to the Cochiti Formation whereas sand and gravel beds interbedded with tuff and lapilli-tuff beds would be assigned to the Peralta Tuff Member. Ongoing study in the Peralta Canyon area indicates that this definition can be objectively applied in this area and that the strata thus assigned to the Cochiti Formation contain a much greater proportion of devitrified rhyolite clasts than the underlying Peralta Tuff sedimentary units, which

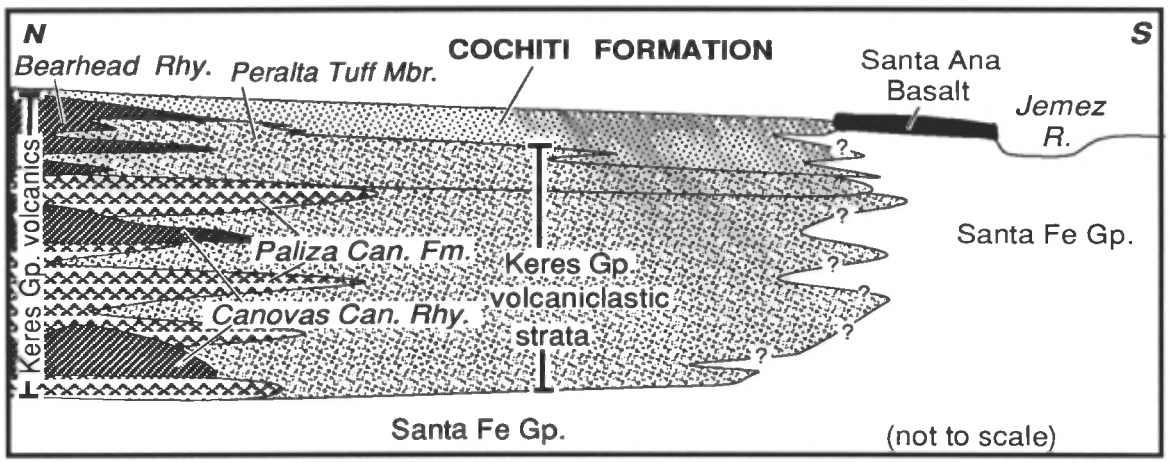

FIGURE 2: Schematic cross-section of the southern Jemez Mountains and northern Albuquerque Basin illustrating distribution of lithostratigraphic units and stratigraphic nomenclature proposed in this paper.

are dominated by glassy rhyolite (Smith et al., 1991). Farther south, beyond the extent of recent stratigraphic studies, the distinction of strata belonging to the Cochiti Formation and those of the Keres Group that are correlative to the Peralta Tuff could become more challenging but may possibly be resolved by noting the presence of both primary and reworked tephra that would likely be more prevalent in the older unit.

We anticipate that such a redefinition will be significant in the definition of subsurface hydrostratigraphic units. It is reasonable to suspect that the textural attributes and diagenesis of wholly volcanic sediment derived from proximal sources will produce different hydrologic properties when compared to sedimentary facies comprised in part or whole of nonvolcanic detritus derived from more distant sources. In addition, the restricted composition of the redefined Cochiti Formation should make it more easily traceable in the subsurface. Lastly, as redefined the Cochiti Formation would not contain axial Rio Grande gravels correlative to the high-hydraulic-conductivity aquifers of the Totavi Formation, to the north, or the upper Santa Fe Group farther south. Based on existing studies (Anderson, 1960; Hoge, 1970) these facies are restricted to the QTal unit of Smith et al. (1970).

CONCLUSION

Varied prior usage of the name Cochiti Formation in the Jemez Mountains and northern Albuquerque Basin has befallen difficulties commonly encountered in other volcanic provinces. The primary difficulty is how to objectively define and map a formation composed of volcaniclastic sediment as distinct from units composed of coeval volcanic rocks and correlative, largely nonvolcaniclastic sedimentary units. Intimate interfingering of these rock types precludes ready distinction on geological maps, and mixing of rock types within single formations that are not so defined can obscure genetic interpretations based on thickness trends or facies variability within the unit. Biases emerge as different stratigraphers, with competing emphasis on volcanic or sedimentary geology, attempt to define units. These problems have been exacerbated in the case of the Cochiti Formation by inconsistencies in the original definition of the formation (Bailey et al., 1969), inconsistency in how the unit was defined and mapped by the same workers (Bailey et al., 1969; Smith et al., 1970), and subsequent extensions (Gardner et al., 1986; Goff et al., 1990) that were both internally inconsistent and inconsistent with the original definition while not explaining the discrepencies. On this basis, one could argue that there are now so many "Cochiti Formations" with different, vaguely defined boundaries that the name should be abandoned altogether. Alternatively, we *tentatively* propose a revision of the Cochiti Formation that would retain most of what was originally mapped as such by Smith et al. (1970), while retaining little of any previous definition of the formation. We emphasize that this revision is simply proposed as a working model during anticipated new geological mapping and subsurface investigations to be undertaken in this area.

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