Tertiary stratigraphy and nomenclature for western New Mexico and eastern Arizona

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TERTIARY STRATIGRAPHY AND NOMENCLATURE FOR WESTERN NEW MEXICO AND EASTERN ARIZONA

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Abstract—This report delineates new lateral boundaries between lithostratigraphic units of Tertiary age in western New Mexico and eastern Arizona, including the Eocene Baca, Eagar and Mogollon Rim Formations and the Mio-Pliocene Santa Fe Group, Gila Group, Fence Lake Formation, Bidahochi Formation, Quemado Formation and Sheep Crossing Formation. New group-rank units for the upper Eocene to Oligocene rocks of the Mogollon-Datil volcanic field are also proposed. In the proposed nomenclature, all sedimentary rocks of the volcaniclastic apron surrounding the field are subsumed into the Spears Group. Volcanic rocks below a locally prominent disconformity representing a previously recognized 31.4 to 29.0 Ma hiatus in ignimbrite volcanism are assigned to the Datil Group (redefined); volcanic rocks above the disconformity are assigned to the Mogollon Group.

INTRODUCTION

Throughout western New Mexico and eastern Arizona, nomenclature for Tertiary stratigraphic units has typically been conceived in isolated and disparate areas of local study. Through further work, nomenclature within correlative rock units then commonly spreads amoeba-like until it collides with an adjoining nomenclatural domain. Several things may then occur. Due to precedence or the preferred use by geologists in the region, one of the competing terminologies may be abandoned and replaced by the neighboring nomenclature. Alternatively, adjoining stratigraphic terminologies may be delimited by the perceived paleogeography, such as paleodrainage divides between basins, or by lithologic differences (i.e., provenance or paleoenvironmental factors) between sediments within the same basin. In some cases, the interface between adjacent nomenclatures has been defined arbitrarily by modern geographic or political boundaries, such as drainage divides or state lines.

Western New Mexico and eastern Arizona are areas where collisions between competing nomenclatures for Tertiary rocks are presently occurring, and this paper is an attempt to resolve some of these conflicts and their resulting confusion. We divide our discussion into three parts: (1) middle to upper Eocene rocks (late Laramide synorogenic deposits of the Baca, Eagar and Mogollon Rim Formations), (2) upper Eocene-Oligocene rocks (volcanic and sedimentary rocks of the northern Mogollon-Datil volcanic field); and (3) Miocene-Pliocene rocks (extension-related deposits of the Santa Fe Group, Gila Group, Fence Lake Formation, Bidahochi Formation, Quemado Formation, and correlative units).

MIDDLE TO UPPER EOCENE

Late Laramide synorogenic sediments were deposited in two structurally related basins in west-central New Mexico and eastern Arizona. The largest and westernmost of these basins, the Baca basin, extended westward from Socorro, New Mexico, to near Show Low, Arizona (Fig. 1). Correlative middle to upper Eocene deposits within the Baca basin have been assigned, from east to west, to the Baca Formation (Wilpolt et al., 1946; Snyder, 1971; Cather and Johnson, 1984; 1986), the Eagar Formation (Sirrine, 1956), and the Mogollon Rim Formation (Hunt, 1956; Cooley and Davidson, 1963; Peirce et al., 1979; Potochnik, 1989). Although the term Baca Formation should have precedence due to first usage, the terms Eagar Formation and Mogollon Rim Formation (or gravels) are firmly entrenched in the geologic literature for the western Baca basin. We advocate that all three of these formational terms be retained, as extension of the term Baca to eastern Arizona would result in needless confusion. Instead, we propose to define lateral boundaries between the three correlative formations.

The Eagar and Mogollon Rim Formations are compositionally similar, both consisting of fluviatile conglomerate, sandstone and mudstone derived largely from Paleozoic and Mesozoic sedimentary strata and Precambrian quartzites, metavolcanics and granitoids. Much of the Mogollon Rim Formation, however, is significantly coarser and more conglomeratic than the Eagar. Intermediate-composition, porphyritic volcanic clasts are also present throughout both formations. These clasts increase in abundance upsection and, in the Mogollon Rim Formation, have yielded early Tertiary K-Ar ages (Peirce et al., 1979). Potochnik (1989) defined the top of the Mogollon Rim Formation at the first up-section occurrence of greater than 50% volcanic clasts within a pebbly sandstone or conglomerate. A similar top to the Eagar Formation may also be defined, although conglomeratic horizons are much more sparse and future workers may have to resort to sandstone compositions to precisely place the contact. In some areas, the lower contact of the Eagar Formation has been incorrectly placed within the Upper Cretaceous section by previous workers (Sirrine, 1956; Akers, 1964; Reynolds, 1988; see minipaper by Cather in Day Two road log, this guidebook) due to the local, strongly reddened nature of Cretaceous strata beneath the Tertiary unconformity within the Baca basin (e. g., Chamberlin, 1981).

Prior to the recognition that the Mogollon Rim and Eagar Formations are elements within a tract of contiguous depositional systems (e. g. Johnson, 1978, Cather and Johnson, 1984; 1986; Potochnik, 1989), mapping utilized the large volcanic-covered interval of the Eocene outcrop belt north of the White Mountains as the divide between the outcrop areas of the two formations (Fig. 1). We advocate the continuation of this practice, although future drilling beneath the interval covered by the Springerville and White Mountains volcanic fields may require a more rigorous definition of the units based on composition or grain size.

The contact between the laterally equivalent Eagar and Baca Formations has been arbitrarily placed at or near the state line by previous workers. Recent reconnaissance mapping (Chamberlin et al., 1994), however, has revealed a mappable lithologic contact between the two units. As noted above, the Eagar and Mogollon Rim Formations contain significant amounts of Tertiary volcanic detritus. In contrast, the Baca Formation is essentially free of volcanogenic material. The lateral transition between volcanic-bearing and volcanic-free lithologies within the Baca basin occurs about 20 km east of the Arizona-New Mexico state line, near Cimarron Mesa (Fig. 1). In this area, an uncommonly coarse boulder gravel intervenes between the volcanic-bearing Eagar Formation to the west and the Baca Formation to the east. The boulder gravel itself contains volcanic clasts so we also assign it to the Eagar Formation. The anomalously coarse-grained deposits of the Eagar Formation appear to overlie, and possibly intertongue with, the typical volcanic-free deposits of the Baca Formation near Cimarron Mesa. The origin of the lithologic and textural variations in this area is in need of further study.

Because of the near absence of volcanic materials in the Baca

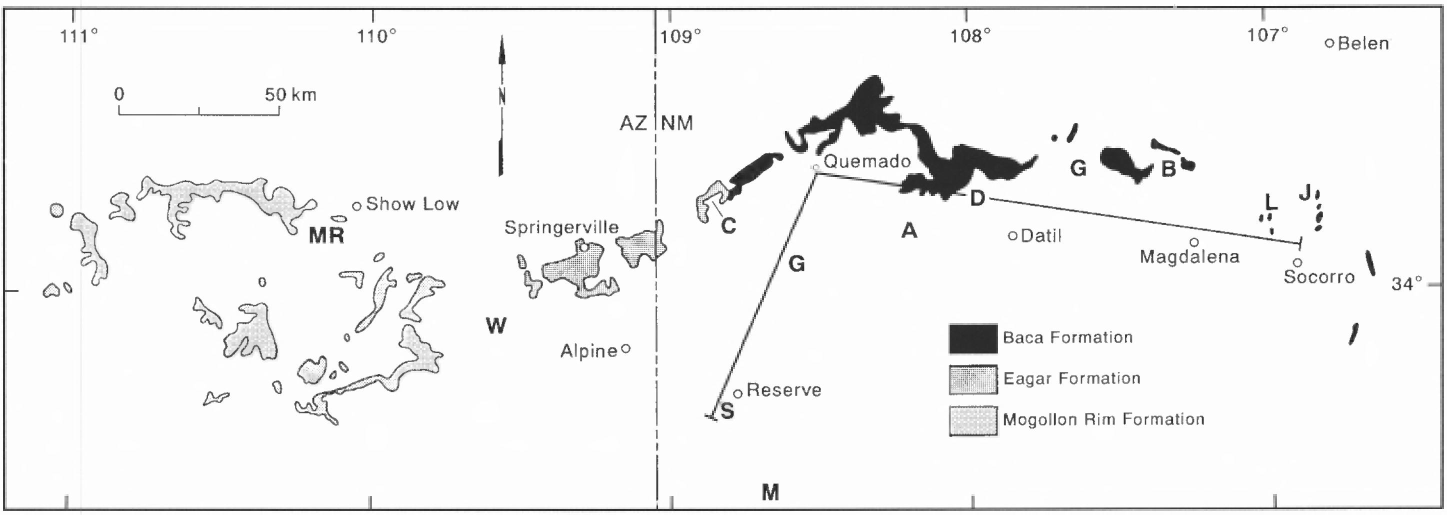

FIGURE 1. Outcrop map for Eocene deposits in western New Mexico and eastern Arizona, showing outcrop areas of Baca, Eagar and Mogollon Rim Formations. Line connecting Reserve, Quemado, and Socorro areas is location of fence diagram in Fig. 2. Physiographic features are MR, Mogollon Rim; W, White Mountains; C, Cimarron Mesa; G, Gallo Mountains; S, Saliz Mountains; M, Mogollon Mountains; A, Allegres Mountain; D, Datil Mountains; G, Gallinas Mountains; B, Bear Mountains; L, Lemitar Mountains; and J, Joyita Hills. Modified from Reynolds (1988) and New Mexico Geological Society (1982).

Formation, the upper contact typically has been defined at the first occurrence of megascopically visible volcanic detritus (e. g. Cather, 1980; 1986). This contrasts with equivalent rocks to the west, where the top of the Mogollon Rim Formation is defined at the fifty-percentile abundance of volcanic detritus (Potochnik, 1989). For the sake of continuity, we recommend that in future studies the 50-percentile criterion also be applied to the upper contact of the Baca Formation. This would require only slight revision of existing maps and measured thicknesses for the Baca Formation, as the stratigraphic transition between the Baca and the overlying volcaniclastics of the Spears Formation (now Spears Group; see below) typically occurs within a few meters.

The inception of late Eocene volcaniclastic sedimentation may have been somewhat older in west-central New Mexico than in eastern Arizona. Ash-fall deposits in the upper Mogollon Rim Formation have yielded K-Ar ages of 37.6 ± 0.8 Ma and 37.5 ± 0.8 Ma (Potochnik, 1989). In contrast, rocks *above* the Baca Formation yield radioisotopic ages (mostly K-Ar) between 39.6 and 37.02 Ma (Cather et al., 1987) in west-central New Mexico, suggesting that the lower part of the Spears Group is chronostratigraphically equivalent to the upper Mogollon Rim Formation. Such time-transgressive behavior of the inception of mid-Tertiary volcaniclastic deposition may be an expectable consequence of the diachronous onlap and burial of proximal portions of the Baca basin in eastern Arizona. Alternatively, the apparent time-transgressive nature of the contact may simply be a statistical aberration due to the low precision of the K-Ar technique. More $^{40}Ar/^{39}Ar$ ages are needed to further test these hypotheses.

Lucas and Williamson (1993) recently proposed the term Hart Mine Formation (formerly Baca Formation) for the non-volcanic deposits of the Eocene Carthage-La Joya basin east of Socorro. They claimed (p. 148) that the deposits of the Carthage-La Joya basin are readily distinguished from those of the Baca basin by clast content. However, the granite- and limestone-bearing conglomerates that characterize the deposits of Carthage-La Joya basin near Socorro are also present in the eastern Baca basin, in the Bear and Lemitar Mountains areas. These conglomerates reflect derivation from the Laramide Sierra uplift that intervened between the two basins (Cather, 1983; Cather and Johnson, 1984; 1986), and are not solely restricted to the Carthage-La Joya basin. Because of the effects of later volcanism and rift-related tectonism, the boundaries of the Carthage-La Joya basin are highly interpretive. For example, Cather (1980) and Cather and Johnson (1984, 1986) interpreted the northern part of the basin to include a thick (1146 m) red-bed sequence in the subsurface of the modern southern Albuquerque Basin (Foster, 1978) and a conglomerate consisting entirely of clasts of Abo Formation on Hubbell bench east of Belen (Kelley, 1977). Lozinsky (1988) subsequently reinterpreted the subsurface red beds to be Triassic and regarded the conglomerates on the Hubbell bench to possibly pertain to the Santa Fe Group (see summary in Cather, 1992). As such, any definition of the Hart Mine Formation that depends on the paleogeographic reconstruction of the Carthage-La Joya basin would seem inadvisable at present. Furthermore, because no workable lithologic criteria has yet been devised to distinguish the rocks of the Carthage-La Joya basin from those of the eastern Baca basin, we recommended abandonment of the term Hart Mine Formation and a return to usage of Baca Formation for these rocks. Indeed, although named for Baca Canyon in the Bear Mountains, the term "Baca Formation" was first used by Wilpolt et al. (1946) to describe rocks in the Joyita Hills, in what is now considered to be part of the Carthage-La Joya basin.

UPPER EOCENE TO OLIGOCENE

Introduction

The evolution of stratigraphic nomenclature for the volcanic and volcaniclastic rocks (~ 40 to 24 Ma) of the northern Mogollon-Datil volcanic field has been extraordinarily convoluted (see summaries in Elston, 1976; Osburn and Chapin, 1983; and Cather, 1986). Lateral changes in the lithology of pyroclastic and sedimentary units between areas of local study and the relative imprecision of early K-Ar ages resulted in many ambiguities and errors in correlation. Recently, paleomagnetic correlations and precise $^{40}Ar/^{39}Ar$ geochronology of ignimbrites by McIntosh et al. (1991; 1992), have enabled the conceptualization of a regional stratigraphic framework spanning most or all of the Mogollon-Datil field. McIntosh et al. (1991, 1992) recognized four episodes of eruptive activity within the 36.2 to 24.3 Ma history of ignimbrite volcanism in the Mogollon-Datil field. These eruptive episodes are separated by hiatuses of 1.5 to 3.0 Ma duration that are of regional extent. Using the stratigraphic and geochronologic framework proposed by McIntosh et al. (1991, 1992) and our own mapping and stratigraphic analysis in the northern and western parts of the field, a new group-rank nomenclature for the upper Eocene-Oligocene rocks of the Mogollon-Datil field is proposed below.

Prior to this paper, the Datil Group was the only group-rank unit commonly recognized in the Mogollon-Datil volcanic field. Winchester (1920) coined the term Datil Formation, and applied it to a thick sequence of tuff, rhyolite, conglomerate and sandstone that forms the Datil Mountains. His type section, however, was measured in the Bear Mountains, and consists of a 480-m-thick section of rocks that begins at the Cretaceous-Tertiary unconformity and ends within or at the top of a thick quartz rhyolite (Hells Mesa Tuff, 32.0 Ma). Wilpolt et al. (1946) separated the lower, non-volcanic deposits from Winchester's Datil Formation and renamed them the Baca Formation.

Tonking (1957) then extended the Datil Formation upward to include the basaltic and basaltic andesite rocks above Winchester's section, thereby lumping the entire 1,500+-m-thick section of mid-Tertiary volcanic rocks of the northern Datil-Mogollon field into a single formation. Tonking also divided the Datil Formation into three members which, in ascending stratigraphic order, are the Spears, Hells Mesa and La Jara Peak Members. Willard (1959) removed the La Jara Peak Member from Tonking's Datil Formation, and Weber (1971) then raised the Datil Formation to group status (but not synonymous with the Datil Group of this report). Chapin (1971) raised the Spears, Hells Mesa, and La Jara Peak to formation rank. Elston (1976) noted that the term Datil had been extended so far geographically and stratigraphically as to virtually mean "mid-Tertiary volcanic rocks of the Mogollon-Datil province, undifferentiated". He recommended its abandonment.

Osburn and Chapin (1983) subsequently resurrected the Datil Group, but restricted usage to the volcanic and volcaniclastic rocks which occur *below* the Hells Mesa Tuff in the northeast part of the field. In this sense, the Datil Group is equivalent to the Spears Formation (or member) of previous studies. The main advantage of Osburn and Chapin's nomenclature is that it allows the regionally persistent and mappable tuffs below the Hells Mesa Tuff to be assigned formation status. The term Spears Formation was retained for the volcaniclastic sediments that underlie and interfinger with these tuffs.

The concept of the Datil Group as proposed by Osburn and Chapin (1983) is tenable and useful in the northeastern part of the field, where the Hells Mesa Tuff effectively divides the largely sedimentary strata below from the dominantly extrusive and pyroclastic rocks above. The usefulness of their concept, however, breaks down in other parts of the field because (1) The Hells Mesa Tuff occurs only in the northeastern and northern parts of the volcanic field (McIntosh et al., 1992) and thus cannot be used to define the top of the Datil Group in other parts of the field; and (2) The post-Hells Mesa (post-32 Ma) section in the western and northwestern parts of the field contains voluminous sedimentary rocks which, because the Hells Mesa Tuff is absent, cannot be readily distinguished from the underlying strata of Osburn and Chapin's Datil Group.

Based on the stratigraphic framework of McIntosh et al. (1991, 1992) and recent mapping and stratigraphic analysis by the authors, we believe a unifying, group-rank nomenclature may now be proposed that has applicability to most or all of the Mogollon-Datil volcanic field. To achieve this, we utilize locally prominent disconformities (e. g., Ratté, 1989; Osburn and Chapin, 1983) that represent a regional hiatus in ignimbrite volcanism between 31.4 and 29.0 Ma (McIntosh et al., 1992) to divide the *volcanic* rocks (tuffs, lavas, domes, etc.) of the field into upper (Mogollon Group) and lower (Datil Group, redefined) units. This disconformity appears to be manifested throughout the field, except possibly in the south-central part (see discussion below). We assign all of the *sedimentary apron deposits* in the field to the Spears Group, which interfingers with both of the aforementioned volcanic groups (Fig. 2). A similar subdivision of volcanic and sedimentary rocks within the Mogollon-Datil field will be utilized in the upcoming geologic map of New Mexico (Anderson and Jones, in preparation). Each of the three proposed groups consists of numerous formation-rank units, although some of the formations within the Spears Group are redefined or raised from member rank in this report (Fig. 3).

Datil Group

As redefined here, the Datil Group is restricted to the ignimbrites and lavas that were erupted prior to development of the regional disconformity that represents the 31.4 to 29.0 Ma hiatus in volcanism delineated by McIntosh et al. (1991; 1992); intercalated sedimentary apron deposits are assigned to the Spears Group. In the northeast part of the field, the stratigraphic range of the proposed Datil Group is similar to that of Winchester's (1920) Datil Formation, except that sedimentary rocks are omitted. We retain Winchester's original type section in the Bear Mountains but broaden the geographic range of the Datil by designating the type sections of constituent formations (Fig. 3) as reference sections (North American Commission on Stratigraphic Nomenclature, 1983, Article 22c). The Datil Group consists largely of intermediate to mafic lavas and numerous formation-rank ignimbrites of mostly low-silica rhyolite composition (Fig. 3). The contact between the Datil Group and the overlying Mogollon Group is typically marked by a disconformity, except in distal areas where sediments of the Spears Group intervene and serve to divide the volcanic groups. (Fig. 2; see discussion below). Our definition of the Datil Group differs from that of Osburn and Chapin in that we *exclude* all sedimentary rocks but *include* the Hells Mesa Tuff.

Mogollon Group

The name of this group derives from the Mogollon Mountains area (e.g. Ratté, 1981; Ratté and Gaskill, 1975), which contains widespread exposures of the upper part of the mid-Tertiary volcanic sequence. Herein, we reinstate and revise the term Mogollon, which was first applied by Ferguson (1927) to an andesite in the Mogollon mining district but has subsequently been abandoned (Ratté and Finnell, 1978; Ratté 1981). The base of the Mogollon Group marks the culmination of the great ignimbrite flare-up (pulse 3 of McIntosh et al., 1992) which terminated the post-Datil hiatus in ignimbrite volcanism. During early Mogollon Group volcanism, nine major regional ignimbrites and at least 11 subregional to local units were erupted within a period of 1.6 Ma. (McIntosh et al., 1991). Most of these ignimbrites are high-silica rhyolites. Mafic to intermediate lavas are widespread in the Mogollon Group, particularly in the upper part where thick sequences of flows comprise the Bearwallow Mountain Andesite (western part of field), La Jara Peak Basaltic Andesite (northeast), Uvas Basaltic Andesite (southeast) and correlative local units. The top of the Mogollon Group is typically unconformably overlain by Miocene rift-basin or rift-shoulder deposits (Santa Fe Group, Gila Group, Fence Lake Formation, Bidahochi Formation, and correlative units), although in some areas the upper contact of the Mogollon Group may be gradational with the younger units.

Spears Group

The Spears Member of the Datil Formation was originally defined by Tonking (1957) to include all volcanic and volcaniclastic rocks below his Hells Mesa Member (the basal part of which is now termed the Hells Mesa Tuff) in the Bear Mountains. Chapin (1971) raised the Spears to formation rank, and Osburn and Chapin (1983) restricted the Spears Formation (within their Datil Group) to include only the *volcaniclastic sedimentary rocks* beneath the Hells Mesa Tuff. We propose to raise the Spears to group rank and to broaden its scope to include *all* upper Eocene to Oligocene volcaniclastic sedimentary apron deposits in the field. In so doing, we retain the original type section of the Spears (Tonking, 1957), except that we exclude all volcanic rocks. We designate the type sections (or type areas) of the component sedimentary units of the proposed Spears Group (see Fig. 3) as supplementary reference sections (North American Commission on Stratigraphic Nomenclature, 1983, Article 22c). Further, we specifically exclude all sedimentary deposits not related to the sedimentary apron of the Mogollon-Datil field from the Spears Group, such as caldera-fill deposits. Our proposal causes only minor nomenclatural changes in the northeastern part of the field, as only minor volumes of sedimentary apron deposits are present above the 32.0 Ma Hells Mesa Tuff in this area. In other parts of the field, however, the Spears Group includes sedimentary rocks as young as 26-27 Ma (Fig. 2), considerably younger than can be encompassed by Osburn and Chapin's nomenclature.

We also recommend that the formal members of the Spears Formation of Osburn and Chapin (1983) be raised to formation rank. These units (Dog Springs Formation, Chavez Canyon Formation, and Rincon Windmill Formation) crop out in the northern part of the field and are readily mappable at the present scale of investigation (Harrison, 1980; Coffin, 1981; Robinson, 1981; Broulliard, 1984).

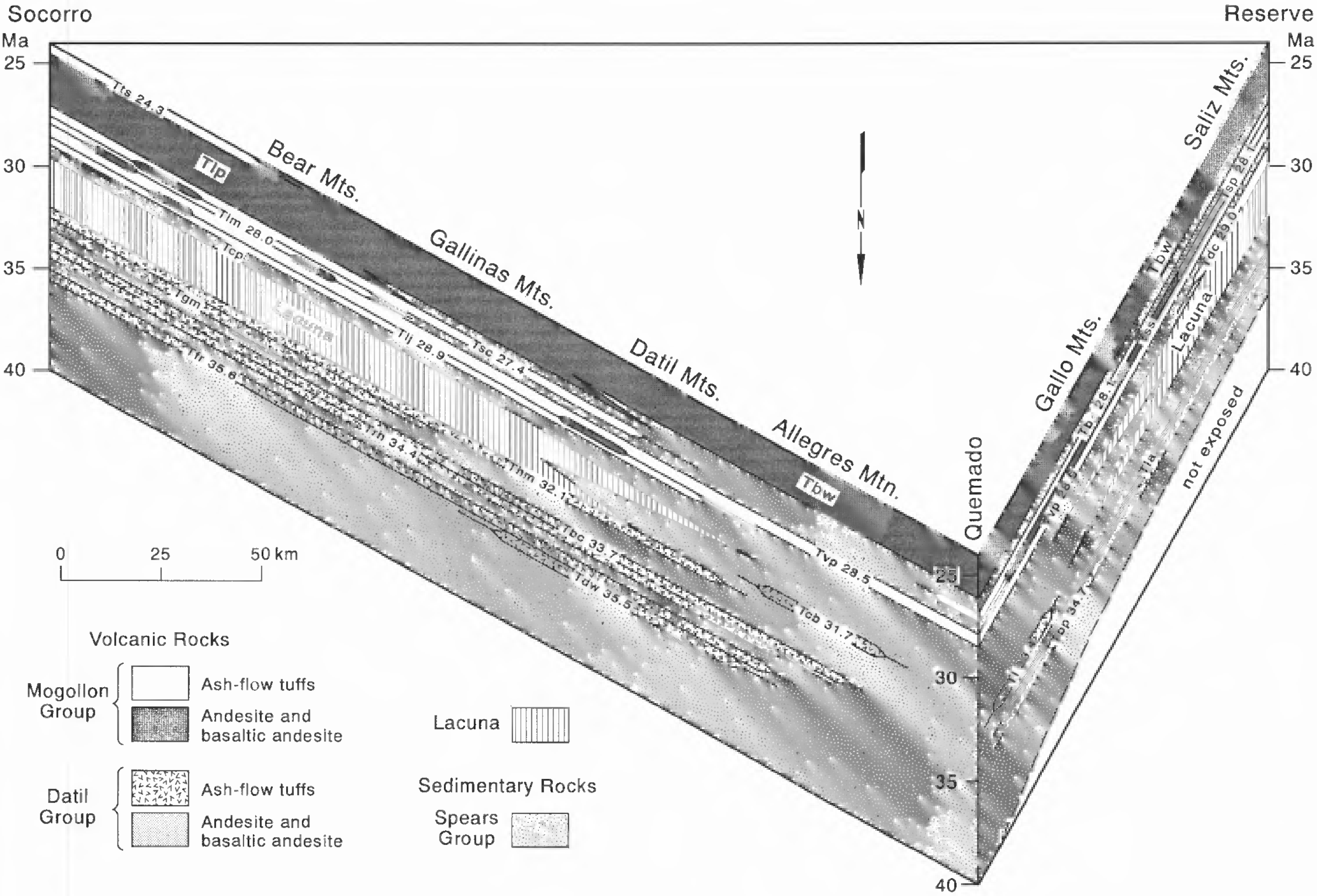

FIGURE 2. Schematic chronostratigraphic fence diagram for 40 to 24 Ma rocks of the northern Mogollon-Datil field, showing maximum inferred extent of units within the Datil, Mogollon, and Spears Groups. Note that the Spears Group interfingers with both the Datil Group and Mogollon Group and that the Datil and Mogollon Groups are separated in their proximal areas by a lacuna (i.e., a time-stratigraphic gap representing a period of non-deposition and erosion). Line of section for fence diagram is shown in Fig. 1. Numerals adjacent to unit abbreviations are $^{40}Ar/^{39}Ar$ ages (Ma) from McIntosh et al. (1991). Unit abbreviations are Tts, tuff of Turkey Springs; Tlp, La Jara Peak Basaltic Andesite; Tsc, South Canyon Tuff; Tlm, Lemitar Tuff; Tvp, Vicks Peak Tuff; Tlj, La Jencia Tuff; Tcp, South Crosby Peak Formation; Tcb, Caballo Blanco Tuff; Thm, Hells Mesa Tuff; Tgm, Tuff of Granite Mountain; Tbc, Blue Canyon Tuff; Trh, Rock House Canyon Tuff; Tfr, tuff of Farr Ranch; Tdw, Datil Well Tuff; Tbw, Bearwallow Mountain Andesite; Tbg, Bloodgood Canyon Tuff; Tsp, Shelley Peak Tuff; Tss, Squirrel Springs Canyon Andesite; Tdc, Davis Canyon Tuff; Tl, tuff of Luna; Tla, andesite of Dry Leggett Canyon; Tbp, tuff of Bishop Peak. See text for discussion.

Several previously defined formations within the Spears Group are present elsewhere in the Mogollon-Datil field (Fig. 3). Reconnaissance by the authors in the northwest part of the field has revealed several informal formations within the Spears Group (sandstone of Escondido Mountain, volcaniclastic unit of Cañon del Leon, volcaniclastic unit of Largo Creek; Chamberlin and Harris, this volume).

Discussion

Because of the complex lateral gradations between volcanic and sedimentary rocks in the Mogollon-Datil field, it seems doubtful that any lithologic unit of regional extent is present that would enable the stratigraphic subdivision of the entire volcanic field. Even the major 31.4 to 29.0 Ma hiatus in ignimbrite volcanism recognized by McIntosh et al. (1991) has no apparent correlative within the distal part of volcaniclastic aprons, such as that exposed near Quemado (Fig. 2). Based on these observations, we believe the best approach to the regional stratigraphy is for development of *separate* nomenclatures for volcanic versus sedimentary rocks in the field. In the proposed nomenclature, the sedimentary Spears Group interfingers with the volcanic rocks of the superposed Datil and Mogollon Groups in much the same manner as the Upper Cretaceous Mancos Shale interfingers with both the Dakota Group and the Mesaverde Group throughout New Mexico.

The principal difficulty created by the proposed nomenclature is that several existing formation-rank units in the Mogollon-Datil field contain *both* sedimentary and volcanic rocks [e. g., Rubio Peak Formation (Jicha, 1954; Elston, 1957; Jones et al., 1967), Palm Park Formation (Kelley and Silver, 1952; Seager et al., 1971), Pueblo Creek Formation (Ratté, 1989)]. In many outcrop areas of these hybrid formations, sedimentary strata have already been mapped separately from volcanic facies; we suggest that, in future studies, these sedimentary units be accorded separate nomenclatures as well. In areas where sedimentary and volcanic rocks are too finely intercalated to be separated at a given scale of mapping, we recommend group assignment based on the dominant lithology (e. g. 50 percentile abundance of volcanic versus sedimentary rocks). In such areas, the map segregation of volcanic from sedimentary rocks will increase as more detailed mapping is attempted. Alternatively, in near-vent areas where delineation of volcanic, plutonic, and sedimentary rocks is not feasible at a given scale of mapping, the lithodemic term "volcanic complex" may be employed (North American Commission on Stratigraphic Nomenclature, 1983, Article 37b).

We use the regional disconformity that resulted from the 31.4 to 29.0

	Volcanic Rocks		Sedimentary Rocks
Mogollon Group	tuff of Turkey Springs	Spears Group	South Crosby Peak Formation**
	Bearwallow Mountain Andesite		Rincon Windmill Formation*
	Uvas Basaltic Andesite		Chavez Canyon Formation*
	La Jara Peak Basaltic Andesite		Dog Springs Formation*
	South Canyon Tuff		Rubio Peak Formation**
	Lemitar Tuff		Palm Park Formation**
	Apache Springs Tuff		Pueblo Creek Formation**
	Bloodgood Canyon Tuff		Bell Top Formation**
	Squirrel Springs Andesite		Rock Springs Formation**
	Shelley Peak Tuff		Red Rock Ranch Formation**
	Vicks Peak Tuff		Piloncillo Sediments
	La Jencia Tuff		unit of East Red Canyon
	Davis Canyon Tuff		sandstone of Monument Park
	Sawmill Canyon Formation		sandstone of Escondido Mountain
	Luis Lopez Formation		volcaniclastic unit of Cañon del Leon
	basaltic andesite of Poverty Creek		volcaniclastic unit of Largo Creek
	— lacuna (31.4–29.0 Ma) —		
Datil Group	Tadpole Ridge Tuff		
	Caballo Blanco Tuff		
	Hells Mesa Tuff		
	Box Canyon Tuff		
	Blue Canyon Tuff		
	Cooney Tuff		
	andesite of Dry Leggett Canyon		
	Rock House Canyon Tuff		
	tuff of Bishop Peak (tuff of Lebya Well)		
	Kneeling Nun Tuff		
	Bell Top Formation tuffs		
	Sugarlump Tuff		
	tuff of Farr Ranch		
	Datil Well Tuff		
	andesite of White House Canyon		
	Doña Ana Tuff		
	Squaw Mountain Tuff		
	Achenback Park Tuff		
	Cueva Tuff		

*formerly member
**includes sedimentary part only

FIGURE 3. Chart showing selected major formation-rank units within proposed Mogollon, Datil and Spears Groups. Data sources are Elston (1976), Osburn and Chapin (1983), and McIntosh et al. (1992).

hiatus in major ignimbrite volcanism (McIntosh et al., 1991) to define the boundary between the Datil and Mogollon Groups, except in distal areas where sediments of the Spears Group intervene and serve to divide the volcanic groups. In some areas of the Mogollon-Datil field, this hiatus was slightly narrowed by intervening episodes of volcanism. Except possibly for the south-central part of the field, however, there is no evidence that volcanism entirely spanned the hiatus between the two volcanic groups.

The contact between the Datil and Mogollon Groups is not exposed in the central part of the field. Contact relations around the periphery of the field are as follows [except where noted, all age data are from McIntosh et al., 1992]:

Southwest. In the Summit Mountains area (Steeple Rock mining district; McLemore, 1993) about 60 km north-northwest of Lordsburg, New Mexico, the base of the Mogollon Group consists locally of either the Bloodgood Canyon Tuff (28.05 ± 0.04 Ma) or the Davis Canyon Tuff (29.01 ± 0.11 Ma). These tuffs unconformably overlie the 31.3 Ma Summit Mountain Formation (McLemore, 1993), which composes the upper part of the Datil Group in this area.

West. In the Saliz Mountains area near Reserve, New Mexico (Ratté, 1981), and in adjacent Greenlee County, Arizona (Fig. 4), a moderate-relief unconformity at the base of the Davis Canyon Tuff (29.01 ± 0.11 Ma) marks the contact between the Mogollon Group and the underlying

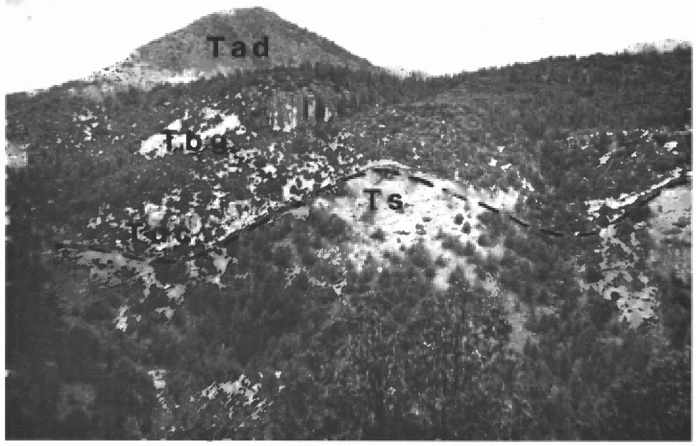

FIGURE 4. Erosional unconformity between the Davis Canyon Tuff, Tdc, at the base of the Mogollon Group and laharic breccias of the Spears Group, Ts, on the west side of Yam Canyon in the Alma Mesa 7½ minute quadrangle, Greenlee County, Arizona, about 15 km northwest of Alma, New Mexico. View is west toward Horse Mountain, a dacitic eruptive center, Tad, of Bearwallow Mountain Andesite age. Cliffs of Bloodgood Canyon Tuff, Tbc, overlie Shelley Peak Tuff (not shown) and Davis Canyon Tuff in center of photo (Ratté et al., 1969).

Spears Group. Tongues of Spears Group sediments are intercalated with underlying volcanic rocks of the Datil Group (~32 to 34.7 Ma; see Ratté, 1981 and Fig. 2) and separate the Datil Group from the Mogollon Group.

Northwest. In the Quemado area (Fig. 2), a 120-240-m-thick sequence of upper Spears Group strata intervene between the basal Mogollon Group (Vicks Peak Tuff, 28.56 ± 0.04 Ma) and the upper part of the Datil Group (Caballo Blanco Tuff, 31.65 ± 0.06 Ma; tuff of Luna, 33.39 ± 0.12 Ma; andesite of Dry Leggett Canyon, ± 34 Ma; Fig. 2).

North and Northeast. The basal ignimbrite of the Mogollon Group (La Jencia Tuff, 28.85 ± 0.04 Ma) is separated from the Datil Group by volcanic and volcaniclastic strata of the South Crosby Peak and the Luis Lopez Formations. The uppermost tuff of the Datil Group (Hells Mesa Tuff, 32.06 ± 0.10 Ma) is locally thin or missing beneath the basal disconformity of the South Crosby Peak Formation (Osburn and Chapin, 1983; Coffin, 1981), which we regard as part of the Mogollon Group. Recent $^{40}Ar/^{39}Ar$ dating of volcanic rocks from the Luis Lopez Formation (29.85 ± 0.31 Ma, 28.61 ± 0.17 Ma; W. C. McIntosh, unpublished dates) and the lower South Crosby Peak Formation (29.67 ± 0.86 Ma; McIntosh and Chamberlin, this volume) indicate these units are close in age to the overlying La Jencia Tuff. These new ages narrow, but do not span, the hiatus between major ignimbrites of Mogollon and Datil Groups and support the assignment of volcanic rocks within the South Crosby Peak and the Luis Lopez Formations to the Mogollon Group.

East. In the northern Black Range, a volcanic sequence about 200 m thick is assigned to the basaltic andesite of Poverty Creek (Eggleston, 1987; Harrison, 1990). The flows of the Poverty Creek intervene between the basal ignimbrite of the Mogollon Group (Tuff of Little Mineral Creek, 29.01 ± 0.10 Ma) and the upper ignimbrite of the Datil Group (Caballo Blanco Tuff, 31.65 ± 0.06 Ma). On the basis of the presence of a pronounced, regional disconformity with as much as 100 m of paleorelief at its base (Eggleston, 1987, p. 37), we assign the Poverty Creek to the Mogollon Group. This assignment is supported by the only age determination for the Poverty Creek (28.8 ± 0.6 Ma; K/Ar age in Woodard, 1982), which is slightly younger than (but within analytical error of) the age for the overlying tuff of Little Mineral Creek.

Southeast. In the Sierra de las Uvas area northwest of Las Cruces, New Mexico, a tongue of the Spears Group (the upper sedimentary member of the Bell Top Formation; Clemons, 1976) intervenes between the upper ignimbrite of the Datil Group (Bell Top 6 or Box Canyon, 33.51 ± 0.13 Ma) and the lower ignimbrite of the Mogollon Group (Bell Top 7 or Vicks Peak Tuff, 28.56 ± 0.04 Ma). No volcanic rocks intervene between the two groups in this area (W. R. Seager, oral commun., 1994).

South-central. In the southeastern Mogollon Mountains-Gila Cliff Dwellings-Mimbres Valley-southern Black Range area, the Alum Mountain Formation (or Group; Elston, 1968; Ratté and Gaskill, 1975; Krier, 1980; Farris, 1981) underlies or interfingers with the basal ignimbrites of the Mogollon Group and overlies with local unconformity the upper ignimbrites of Datil Group (Caballo Blanco Tuff, tuff of Terry Canyon, tuff of Monument Canyon). The Alum Mountain consists of a thick sequence of lavas, breccias and volcaniclastic sediments that has yielded K-Ar ages of 30.5 ± 1.0 Ma and 30.1 ± 1.0 Ma (Ratté and Gaskill, 1975). The great thickness and the existing K-Ar ages of the Alum Mountain Formation suggest that it represents an episode of volcanism in the southern Mogollon-Datil field that may have spanned the hiatus manifested between the Datil and Mogollon Groups elsewhere in the field. On the other hand, the local pronounced basal unconformity of the Alum Mountain Formation (Krier, 1980; Farris, 1981) is similar to that beneath the correlative basaltic andesite of Poverty Creek and may argue for inclusion of the Alum Mountain in the Mogollon Group. It is clear, however, that the hiatus between the Datil and Mogollon Groups must disappear at some point to the south, as the corresponding period in Chihuahua, Mexico was a time of voluminous volcanism (McDowell and Mauger, 1994). Whether or not the proposed volcanic nomenclature is applicable to the south-central part of the Mogollon-Datil field will require further study of the Alum Mountain Formation.

MIOCENE AND PLIOCENE

Extension-related deposits of late Tertiary age in western New Mexico and eastern Arizona have been assigned variously to the Santa Fe Group, Gila Group (or Formation or Conglomerate), Fence Lake Formation, Bidahochi Formation, and correlative local units. The Santa Fe and Gila Groups were mostly deposited in extensional basins, whereas the Fence Lake, Quemado (Cather and McIntosh, this volume; McIntosh and Cather, this volume), and Bidahochi Formations typically fill paleovalleys and broad, erosional basins on the Colorado Plateau (Chapin and Cather, in press). Most of the Gila and Santa Fe are middle Miocene to Pliocene in age, although in some areas beds may be as old as late Oligocene or early Miocene (Leopoldt, 1981; Osburn and Chapin, 1983; Marvin et al., 1987; Chapin, 1988; Chapin and Cather, in press; Cather et al., in press; Cross, in preparation). The Bidahochi Formation ranges from middle or late Miocene to early Pliocene in age (see summary by Love, 1989). The Fence Lake Formation appears to be mostly middle to late Miocene (McLellan et al., 1982, Lucas and Anderson, this volume) and may be correlative with the lower part of the Bidahochi Formation (Love, 1989). The Quemado Formation is early Pliocene to Pleistocene in age, and may be in part equivalent to the upper Bidahochi Formation (Cather and McIntosh, this volume).

Dane and Bachman (1965) utilized modern drainage divides to arbitrarily delimit the Santa Fe and Gila Groups. Their usage was summarized by Elston and Netelbeek (1965, p. 36):

> "The Santa Fe Group [is] restricted to all regions where the surface drainage is to the Rio Grande and to closed basins east of the Rio Grande. The Gila Conglomerate or Gila Formation [is] restricted to use in all areas where the surface drainage is to the Colorado River and its tributaries *or to closed basins west of the Rio Grande above Hatch*, and west of the Sierra de las Uvas and the West Potrillo Mountains" [italics added].

The above definition is unwieldy with regard to the assignment of deposits within "closed basins west of the Rio Grande above Hatch" to the Gila Group. By this criteria, deposits within the San Agustin Basin and the southern part of the La Jencia Basin, both areas of internal drainage, are Gila Group, but deposits within the intervening Abbe Spring Basin and in the northern part of the La Jencia Basin are Santa Fe Group. This is inelegant, at best.

Instead, we recommend usage of the continental divide as the arbitrary boundary between Gila and Santa Fe throughout the northern Mogollon-Datil field (Fig. 5). This avoids the problems inherent with the previous definition, and is conceptually simpler as the continental divide is well marked on all topographic maps. The main drawback of our proposed boundary is that it crosses an outcrop area of possible late Tertiary sediments (QToa of Richter, 1987; Richter and Lawrence, 1989) southwest of the San Agustin Basin (Fig. 5). We have arbitrarily and tentatively assigned these rocks to the Gila Group, although further

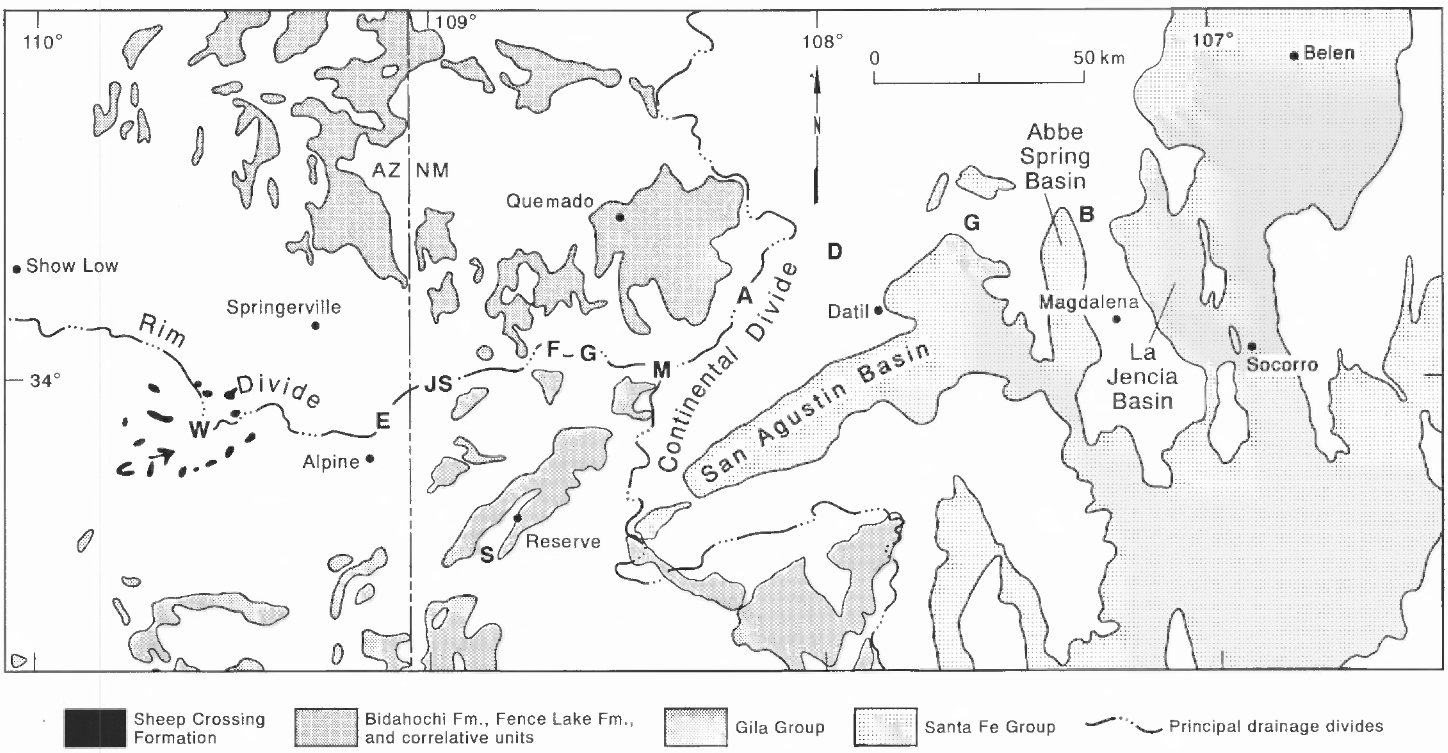

FIGURE 5. Generalized map of Miocene and Pliocene deposits in eastern Arizona and western New Mexico showing proposed nomenclature subdivision. See text for discussion. Abbreviations are W, White Mountains; E, Escudilla Mountain; JS, Jim Smith Peak; S, Saliz Mountains; F, Fox Mountain; G, Gallo Mountains; M, Mangas Mountains; A, Allegres Mountain; D, Datil Mountains; G, Gallinas Mountains; B, Bear Mountains.

study of the lithology and paleodrainage affinity of these deposits may argue for an alternative correlation.

We further recommend that the term Gila be restricted to the area *south* of the Rim Divide (Fig. 5; the Rim Divide separates the watersheds of the San Francisco and Salt Rivers to the south from the Little Colorado drainage to the north). This follows the usage of most workers (e.g., Repenning and Irwin, 1954; Sirrine, 1956; Marr, 1956; Repenning et al., 1958; Akers, 1964; McLellan et al., 1982; Love, 1989), who assigned Mio-Pliocene beds north of the Rim Divide to the Fence Lake or Bidahochi Formations. Reconnaissance mapping by Chamberlin et al. (1994) has delineated several previously unrecognized outcrop areas of the Fence Lake and Quemado Formations in west-central New Mexico, in the regions to the west, south and east of Quemado (Fig. 4).

Miocene and Pliocene rocks were not deposited, or have been removed by erosion, from most areas along the Rim Divide, except peripheral to the White Mountains where upper Miocene mafic lavas have buried and preserved the Miocene Sheep Crossing Formation (Fig. 5; Merrill and Péwé, 1971; 1977). Because the Sheep Crossing Formation straddles the Rim Divide, it is not amenable to the nomenclature proposed above. Due to its proximal location high on the Rim Divide and its partly pyroclastic nature, the Sheep Crossing Formation differs lithologically from correlative deposits to the north and south. We suggest that the term Sheep Crossing Formation be retained for such proximal deposits in the White Mountains area, as they are significantly more coarse and less sorted than their probable lateral equivalents (such as the Bidahochi outcrops north of Springerville). More work will be necessary to constrain the stratigraphic relations among Mio-Pliocene deposits in the Springerville-Quemado region.

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REFERENCES

Akers, J. P., 1964, Geology and ground water in the central part of Apache County, Arizona: U.S. Geological Survey, Water-supply Paper 1771, 107 p.

Anderson, O. J. and Jones, G., in preparation, Geologic map of New Mexico: New Mexico Bureau of Mines and Mineral Resources and U. S. Geological Survey, scale 1:500,000.

Broulliard, L. A., 1984, Geology of the northeastern Gallinas Mountains, Socorro County, New Mexico [M. S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 161 p.

Cather, S. M., 1980, Petrology, diagenesis, and genetic stratigraphy of the Eocene Baca Formation, Alamo Navajo Reservation, Socorro County, New Mexico [M. A. thesis]: Austin, University of Texas, 243 p.

Cather, S. M., 1983, Laramide Sierra uplift: Evidence for major pre-rift uplift in central and southern New Mexico: New Mexico Geological Society, Guidebook 34, p. 99-101.

Cather, S. M., 1986, Volcano-sedimentary evolution and tectonic implications of the Datil Group (latest Eocene-early Oligocene), west-central New Mexico [Ph. D. dissertation]: Austin, University of Texas, 482 p.

Cather, S. M., 1992, Suggested revisions to the Tertiary tectonic history of north-central New Mexico: New Mexico Geological Society, Guidebook 43, p. 109-122.

Cather, S. M., Chamberlin, R. M., Chapin, C. E. and McIntosh, W. C., in press, Stratigraphic consequences of episodic extension in the Lemitar Mountains, central Rio Grande rift: Geological Society of America, Special Paper 291.

Cather, S. M. and Johnson, B. D., 1984, Eocene tectonics and depositional setting of west-central New Mexico and eastern Arizona: New Mexico Bureau of Mines and Mineral Resources, Circular 192, 32 p.

Cather, S. M. and Johnson, B. D., 1986, Eocene depositional systems and tectonics in west-central New Mexico and eastern Arizona: American Association of Petroleum Geologists, Memoir 41, p. 623-652.

Cather, S. M. and McIntosh, W. C., 1994, The Plio-Pleistocene Quemado Formation of west-central New Mexico: New Mexico Geological Society, Guidebook 45.

Cather, S. M., McIntosh, W. C. and Chapin, C. E., 1987, Stratigraphy, age, and rates of deposition of the Datil Group (upper Eocene-lower Oligocene), west-central New Mexico: New Mexico Geology, v. 9, p. 50-54.

Chamberlin, R. M., 1981, Uranium potential of the Datil Mountains-Pie Town area, Catron County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Report 138, 51 p.

Chamberlin, R. M., Cather, S. M., Anderson, O. J. and Jones, G. E., 1994, Reconnaissance geologic map of the Quemado 60′x30′ quadrangle: New Mexico Bureau of Mines and Mineral Resources, Open-file Report, scale 1:100,000.

Chamberlin, R. M. and Harris, J. S., 1994, Upper Eocene and Oligocene volcaniclastic sedimentary stratigraphy of the Quemado-Escondido Mountain area, Catron County, New Mexico: New Mexico Geological Society, Guidebook 45.

Chapin, C. E., 1971, K-Ar age of the La Jara Peak Andesite and its possible significance to exploration in the Magdalena mining district, New Mexico: Isochron/West, no. 2, p. 43-44.

Chapin, C. E., 1988, Axial basins of the northern and central Rio Grande rift; a summary; *in* Riecker, R. E., ed., Rio Grande rift: Tectonics and magmatism: Washington, D. C., American Geophysical Union, p. 1-5.

Chapin, C. E. and Cather, S. M., in press, Tectonic setting of the axial basins of the northern and central Rio Grande rift: Geological Society of America, Special Paper 291.

Clemons, R. E., 1976, Sierra de las Uvas ash-flow field, south-central New Mexico: New Mexico Geological Society, Special Publication 6, p. 115-121.

Coffin, G. C., 1981, Geology of the northwestern Gallinas Mountains, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 202 p.

Cooley, M. E. and Davidson, E. S., 1963, The Mogollon highlands - their influence on Mesozoic and Cenozoic erosion and sedimentation: Arizona Geological Society Digest, v. 6, p. 7-35.

Cross, S. G., in preparation, Reconnaissance survey of Neogene clastic sediments in the southeastern Mogollon-Datil volcanic province, New Mexico [M. S. thesis]: Socorro, New Mexico Institute of Mining and Technology.

Dane, C. H. and Bachman, G. O., 1965, Geologic map of New Mexico: U. S. Geological Survey, 2 sheets, scale 1:500,000.

Eggleston, T. L., 1987, The Taylor Creek district, New Mexico: Geology, petrology, and tin deposits [Ph.D. dissertation]: Socorro, New Mexico Institute of Mining and Technology, 473 p.

Elston, W. E., 1957, Geology and mineral resources of Dwyer quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 38, 86 p.

Elston, W. E., 1968, Terminology and distribution of ash flows of the Mogollon-Silver City-Lordsburg region, New Mexico: Arizona Geological Society, Guidebook 3 to southern Arizona, p. 231-240.

Elston, W. E., 1976, Glossary of stratigraphic terms of the Mogollon-Datil volcanic province, New Mexico: New Mexico Geological Society, Special Publication 5, p. 131-144.

Elston, W. E. and Netelbeek, T. A., 1965, Road log from Mimbres Valley to Silver City: New Mexico Geological Society, Guidebook 16, p. 36-43.

Farris, S. R., 1981, Geology and mid-Tertiary volcanism of the McKnight Canyon area, Black Range, Grant County, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 87 p.

Ferguson, H. G., 1927, Geology and ore deposits of the Mogollon mining district: U. S. Geological Survey, Bulletin 787, 100 p.

Foster, R. W., 1978, Selected data for deep drill holes along the Rio Grande rift in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 163, p. 236-237.

Harrison, R. W., 1980, Geology of the northeastern Datil Mountains, Socorro and Catron Counties, New Mexico [M. S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 137 p.

Harrison, R. W., 1990, Cenozoic stratigraphy, structure, and epithermal mineralization of the north-central Black Range, New Mexico, in the regional geologic framework of south-central New Mexico [Ph.D. dissertation]: Socorro, New Mexico Institute of Mining and Technology, 402 p.

Hunt, C. B., 1956, Cenozoic geology of the Colorado Plateau: U.S. Geological Survey, Professional Paper 279, 99 p.

Jicha, H. L. Jr., 1954, Geology and mineral deposits of Lake Valley quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 37, 93 p.

Johnson, B. D., 1978, Genetic stratigraphy and provenance of the Baca Formation, New Mexico, and the Eagar Formation, Arizona [M. A. thesis]: Austin, University of Texas, 150 p.

Jones, W. R., Hernon, R. M. and Moore, S. L., 1967, General geology of Santa Rita quadrangle, Grant County, New Mexico: U.S. Geological Survey, Professional Paper 555, 144 p.

Kelley, V. C., 1977, Geology of the Albuquerque Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 33, 59 p.

Kelley, V. C. and Silver, C., 1952, Geology of the Caballo Mountains, with special reference to regional stratigraphy and structure, and to mineral resources, including oil and gas: University of New Mexico Publications in Geology No. 5, 286 p.

Krier, D. J., 1980, Geology of the southern part of the Gila Primitive Area, Grant County, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 113 p.

Leopodt, W., 1981, Neogene geology of the central Mangas graben, Cliff-Gila area, Grant County, New Mexico [M. S. thesis]: Albuquerque, University of New Mexico, 159 p.

Love, D. W., 1989, Bidahochi Formation: an interpretive summary: New Mexico Geological Society, Guidebook 40, p. 273-280.

Lozinsky, R. P., 1988, Stratigraphy, sedimentology, and sand petrology of the Santa Fe group and pre-Santa Fe Tertiary deposits in the Albuquerque Basin, central New Mexico [Ph.D. dissertation]: Socorro, New Mexico Institute of Mining and Technology, 298 p.

Lucas, S. G. and Williamson, T. E., 1993, Eocene vertebrates and late Laramide stratigraphy of New Mexico: New Mexico Museum of Natural History and Science, Bulletin 2, p. 145-158.

Marr, R. J., 1956, Geology of the Lynch ranches, Catron and Valencia Counties, New Mexico [M.A. thesis]: Austin, The University of Texas, 113 p.

Marvin, R. F., Naeser, C. W., Bikerman, M., Mehnert, H. H. and Ratté, J. C., 1987, Isotopic ages of post-Paleocene igneous rocks within and bordering the Clifton 1°x2° quadrangle, Arizona-New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 118, 63 p.

McDowell, F. W. and Mauger, R. L., 1994, K-Ar and U-Pb zircon chronology of Late Cretaceous and Tertiary magmatism in central Chihuahua State, Mexico: Geological Society of America Bulletin, v. 106, p. 118-132.

McIntosh, W. C., Kedzie, L. L. and Sutter, J. F., 1991, Paleomagnetism and $^{40}Ar/^{39}Ar$ ages of ignimbrites, Mogollon-Datil field, southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 135, 79 p.

McIntosh, W. C., Chapin, C. E., Ratté, J. C. and Sutter, J. F., 1992, Time-stratigraphic framework for the Eocene-Oligocene Mogollon-Datil volcanic field, southwest New Mexico: Geological Society of America Bulletin, v. 104, p. 851-871.

McIntosh, W. C. and Cather, S. M., 1994, $^{40}Ar/^{39}Ar$ geochronology of basaltic rocks and constraints on late Cenozoic stratigraphy and landscape development in the Red Hill-Quemado area, New Mexico: New Mexico Geological Society, Guidebook 45.

McLellan, M., Robinson, L., Haschke, L., Carter, M. D. and Medlin, A., 1982, Fence Lake Formation (Tertiary), west-central New Mexico: New Mexico Geology, v. 4, p. 53-55.

McLemore, V. T., 1993, Geology and geochemistry of the Steeple Rock district, Grant County, New Mexico and Greenlee County, Arizona [Ph.D. dissertation]: El Paso, University of Texas at El Paso, 499 p.

Merrill, R. K. and Péwé, T. L., 1971, The Sheep Crossing Formation: a new late Cenozoic epiclastic formation in east-central Arizona: Arizona Academy of Science Journal, v. 6, p. 226-229.

Merrill, R. K. and Péwé, T. L., 1977, Late Cenozoic geology of the White Mountains, Arizona: Arizona Bureau of Geology and Mineral Technology, Special Paper 1, 65 p.

New Mexico Geological Society, 1982, New Mexico Highway Geologic Map, scale 1:1,000,000, 1 sheet.

North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code: American Association of Petroleum Geologists Bulletin, v. 67, p. 841-875.

Osburn, G. R. and Chapin, C. E., 1983, Nomenclature for Cenozoic rocks of northeast Mogollon-Datil volcanic field, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Stratigraphic Chart 1, 2 sheets.

Peirce, H. W., Damon, P. E. and Shafiqullah, M., 1979, An Oligocene (?) Colorado Plateau edge in Arizona: Tectonophysics, v. 61, p. 1-24.

Potochnik, A. R., 1989, Depositional style and tectonic implications of the Mogollon Rim Formation (Eocene), east-central Arizona: New Mexico Geological Society, Guidebook 40, p. 107-118.

Ratté, J. C., 1981, Geologic map of the Mogollon quadrangle, Catron County, New Mexico: U.S. Geological Survey, Geological Quadrangle Map GQ-1557, scale 1:24,000.

Ratté, J. C., 1989, Geologic map of the Bull Basin quadrangle, Catron County, New Mexico: U.S. Geological Survey, Geological Quadrangle Map GQ-1651, scale 1:24,000.

Ratté, J. C. and Finnell, T. L., 1978, Third day road log from Silver City to Reserve via Glenwood and the Mogollon mining district: New Mexico Geological Society, Special Publication 7, p. 49-63.

Ratté, J. C. and Gaskill, D. L., 1975, Reconnaissance geologic map of the Gila Wilderness study area, southwestern New Mexico: U. S. Geologic Survey, Miscellaneous Investigations Map I-886, scale 1:50,000.

Repenning, C. A. and Irwin, J. H., 1954, Bidahochi Formation of Arizona and New Mexico: American Association of Petroleum Geologists Bulletin, v. 38, p. 1821-1826.

Repenning, C. A., Lance, J. F. and Irwin, J. H., 1958, Tertiary stratigraphy of the Navajo country: New Mexico Geological Society, Guidebook 9, p. 123-129.

Reynolds, S. J., 1988, Geologic map of Arizona: Arizona Geological Survey, Map 26, scale 1:1,000,000.

Richter, D. H., 1987, Geologic map of the O Bar O Canyon East quadrangle, Catron County, New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1976, scale 1:24,000.

Richter, D. H. and Lawrence, V. A., 1989, Geologic map of the O Bar O Canyon West quadrangle, Catron County, New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2075, scale 1:24,000.

Robinson, B. R., 1981, Geology of the D Cross Mountain quadrangle, Socorro and Catron Counties, New Mexico [Ph.D. dissertation]: El Paso, University of Texas at El Paso, 213 p.

Seager, W. R., Hawley, J. W. and Clemons, R. E., 1971, Geology of the San Diego Mountain area, Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 97, 38 p.

Sirrine, G. K., 1956, Geology of the Springerville-St. Johns area, Apache County, Arizona [Ph.D. dissertation]: Austin, University of Texas, 248 p.

Snyder, D. O., 1971, Stratigraphic analysis of the Baca Formation, west-central New Mexico [Ph.D. dissertation]: Albuquerque, University of New Mexico, 160 p.

Tonking, W. H., 1957, Geology of the Puertecito quadrangle, Socorro County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 41, 67 p.

Weber, R. H., 1971, K-Ar ages of Tertiary igneous rocks in central and western New Mexico: Isochron/West, no. 1, p. 33-45.

Willard, M. E., 1959, Tertiary stratigraphy of northern Catron County, New Mexico: New Mexico Geological Society, Guidebook 10, p. 92-99.

Wilpolt, R. H., MacAlpin, A. J., Bates, R. L. and Vorbe, G., 1946, Geologic map and stratigraphic sections of Paleozic rocks of Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro Counties, New Mexico: United States Geological Survey, Oil and Gas Investigations, Preliminary Map 61.

Winchester, D. E., 1920, Geology of Alamosa Creek Valley, Valley, Socorro County, New Mexico; with special reference to the occurrence of oil and gas: U. S. Geological Survey, Bulletin 716-A, p. 1-15.

Woodard, T. W., 1982, Geology of the Lookout Mountain area, northern Black Range, Sierra County, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 95 p.