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POST-LARAMIDE TECTONIC AND VOLCANIC TRANSITION IN WEST-CENTRAL NEW MEXICO

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Abstract—The transition from Laramide crustal shortening to mid-Tertiary extension occurred about 36 my in west-central New Mexico, and was accompanied by a switch from andesitic to bimodal volcanism. The post-Laramide transition occurred during Datil Group volcanism as shown by: (1) cessation of non-volcanic sedimentation, due to foundering of Laramide uplifts that later formed basins of the Rio Grande rift; and (2) displacement reversal across intrabasin fault zones in the eastern Baca basin.

INTRODUCTION

The Tertiary tectonic history of west-central New Mexico can be broadly divided into two periods: a Laramide phase dominated by crustal shortening followed by mid- and late-Tertiary extension. The volcanic and volcaniclastic rocks of the Datil Group in the northern Mogollon-Datil field spanned the tectonic transition between these two periods. The change from Laramide shortening to mid-Tertiary extension marked the regional reorientation of the principal stress directions in the southwestern United States (Rehrig and Heidrick, 1976; Zoback and Zoback, 1980). In the northern Mogollon-Datil field, this reorientation occurred about 36 my, and corresponded to a switch from intermediate-composition volcanism to younger, fundamentally bimodal volcanism that characterized the bulk of post-Eocene volcanism in the region. This paper describes petrologic, stratigraphic and structural data that pertain to the transition from Laramide shortening to mid-Tertiary extension in west-central New Mexico.

STUDY AREA AND METHODS

This report summarizes part of a dissertation (Cather, 1986) on the Datil Group, the oldest volcanic unit (40–32 my) in the northern Mogollon-Datil field. The Datil Group crops out in a broad, west-trending swath of discontinuous exposures in west-central New Mexico (Fig. 1) and ranges in thickness from more than 1 km to about 300 m where it onlaps late Laramide uplifts. The term Datil Formation was coined by

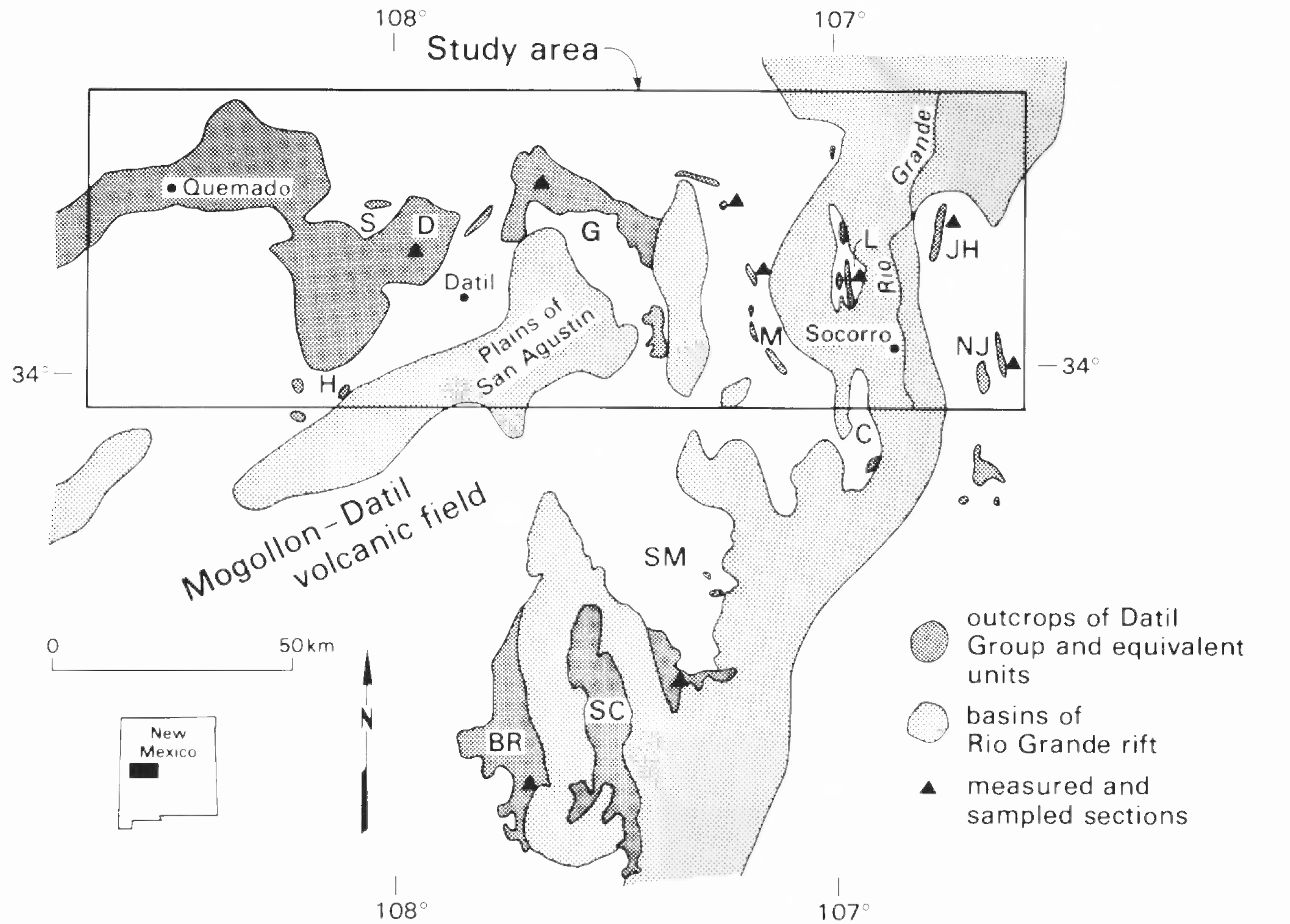

FIGURE 1. Map of west-central New Mexico depicting study area, outcrops of Datil Group, basins of Rio Grande rift, location of measured and sampled sections (Cather, 1986). Selected geomorphic features: JH, Joyita Hills; NJ, northern Jornada del Muerto; L, Lemitar Mountains; C, Chupadera Mountains; M, Magdalena Mountains; G, Gallinas Mountains; D, Datil Mountains; S, Sawtooth Mountains; H, Horse Mountain; SM, San Mateo Mountains; SC, Sierra Cuchillo; BR, Black Range. Base map from New Mexico Geological Society (1982).

Winchester (1920), but its usage has since evolved considerably (for example, Elston, 1976). In this report I employ the nomenclature of Osburn and Chapin (1983), who restrict usage of the Datil Group to the volcanic and volcaniclastic rocks that occur below the Hells Mesa Tuff.

Measurement, description and sampling of nine stratigraphic sections at key localities throughout the Datil outcrop belt provided the primary data base for this study (Fig. 1). The petrologic characteristics of the Datil Group were determined using optical microscopy, scanning-electron microscopy and microprobe analysis. Whole-rock chemical data were provided by wet-chemical analysis by G. K. Hoops of the University of Texas at Austin and by x-ray fluorescence at the New Mexico Institute of Mining and Technology.

The nature of tectonism during Datil time was evaluated by two means: (1) sedimentologic data, which record the initiation of foundering of late Laramide uplifts in the area and (2) comparison of Datil-age displacement on large, intrabasin fault zones to known displacement along these same zones during Laramide crustal shortening and mid- and late-Tertiary extension. The chronostratigraphy of the Datil Group was established by compilation of radiometric ages of ash-flow tuffs and conglomerate clasts (Cather et al., 1987; McIntosh, in press).

CHEMISTRY AND PETROLOGY OF THE DATIL GROUP

Lipman et al. (1972) and Christiansen and Lipman (1972) broadly divide Tertiary volcanism in western North America into an early, intermediate-composition phase and a later, fundamentally basaltic or bimodal phase. In the northern Mogollon-Datil field, the transition between these volcanic phases occurs within the Datil Group. I employ the informal stratigraphic terms "lower Datil Group" and "upper Datil Group" to denote the lower, intermediate-composition part and upper, dominantly bimodal part of the Datil Group, respectively (Fig. 2). The contact between the lower and upper Datil Group is defined as the first up-section occurrence of greater than 50% basaltic andesite detritus in volcaniclastic-dominated parts of the outcrop belt, and by the initial occurrence of mafic lavas in near-vent areas. The contact is stratigraphically abrupt in most parts of the study area. Radiometric dating by $^{40}Ar/^{39}Ar$, K-Ar and fission-track techniques (Fig. 3) indicate the transition from intermediate-composition volcanism to bimodal volcanism in west-central New Mexico occurred at about 36 Ma, near the Eocene-Oligocene boundary (Cather et al., 1987).

Lower Datil Group

Exposures of the lower Datil Group are dominated by a monotonous series of intermediate-composition volcaniclastic rocks and minor lavas that are characterized by phenocrystic plagioclase (An_{20}-An_{60}), amphibole and titanomagnetite (±biotite, clinopyroxene) and groundmass alkali feldspar, silica and plagioclase. Silica content ranges from about 58 to 64 weight percent; K_2O averages about 2.9 weight percent (Cather, 1986). According to the classification method of Ewart (1979, 1982), these rocks are dominantly high-K andesite and high-K dacite. Herein, I will refer to these rocks simply as andesite. Minor amounts (less than about five percent) of rhyolite are also present as conglomerate clasts in the lower Datil Group; mafic lithologies are virtually absent.

Throughout most of the northern Mogollon-Datil field, the lower Datil Group transitionally overlies late Laramide, synorogenic deposits of the Eocene Baca Formation (Cather and Johnson, 1984, 1986). Where deposited on Laramide uplifts, the Datil Group typically overlies strata of Pennsylvanian or Permian age with angular disconformity. Such disconformable contact relations are exposed in the Lemitar Mountains, Chupadera Mountains, southern San Mateo Mountains, Magdalena Mountains, Black Range and at Horse Mountain (Fig. 1).

In nearly all exposures that were examined, non-volcanic detritus identical to that of the Baca Formation is present throughout most or all of the lower Datil Group (Fig. 2). This detritus consists dominantly of fragments of upper Paleozoic limestone, sandstone and siltstone with subordinate amounts of Precambrian lithologies, and is important because it documents the persistence of late Laramide positive areas following the onset of intermediate-composition volcanism in west-central New Mexico. Abundance of non-volcanic detritus in the lower Datil ranges from individual beds of nearly pure Paleozoic and Precambrian detritus to trace amounts of such lithologies present as scattered clasts in volcaniclastic conglomerates.

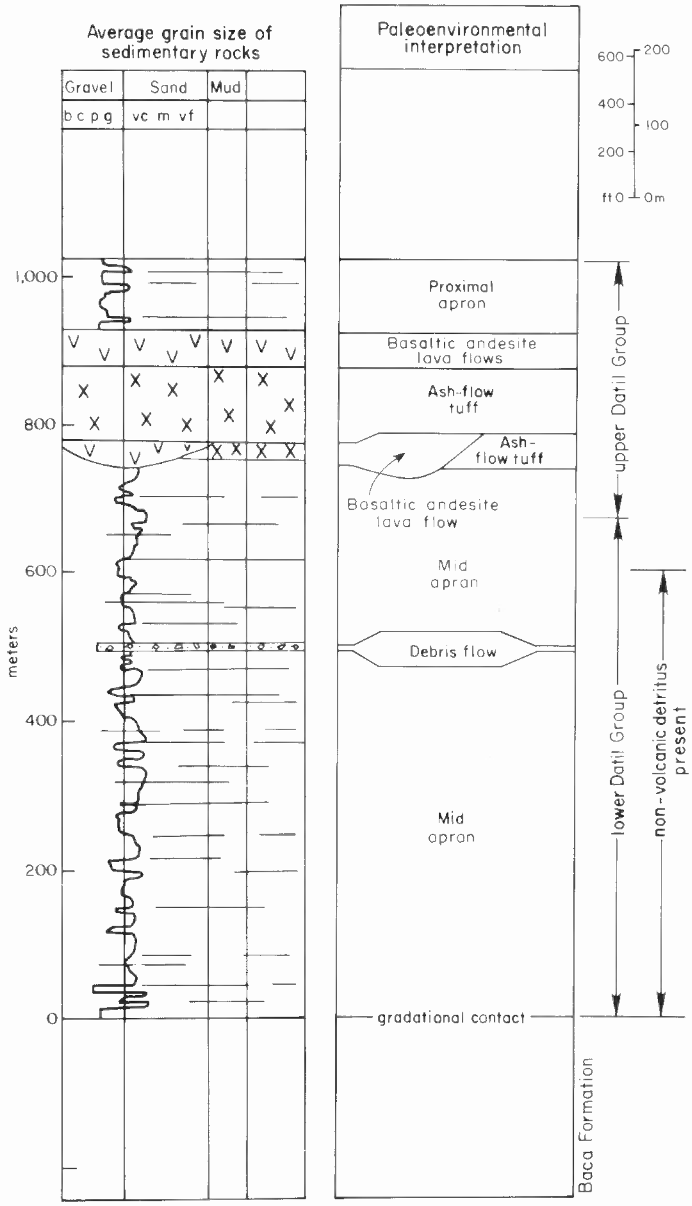

FIGURE 2. Representative stratigraphic section of Datil Group showing informal units and distribution of lithologies. Section measured in northern Jornada del Muerto by S. M. Cather.

Upper Datil Group

The upper Datil Group consists of a fundamentally bimodal suite of mafic lavas, silicic ash-flow tuffs and volcaniclastic rocks derived from these lithologies. Subordinate amounts of intermediate-composition lithologies are also present, as they are in the superjacent, bimodal to basaltic sequences that dominate post-Eocene volcanism in the northern Mogollon-Datil field. Intermediate-composition volcanic products, however, are a relatively minor constituent in the estimated regional abundance of upper Datil and younger lithologies (Cather and Chapin, in press). Unlike lower Datil, the upper Datil does not contain non-volcanic detritus.

Mafic volcanic rocks, herein termed basaltic andesites, are the most abundant lithology in the upper Datil Group (they are dominantly high-

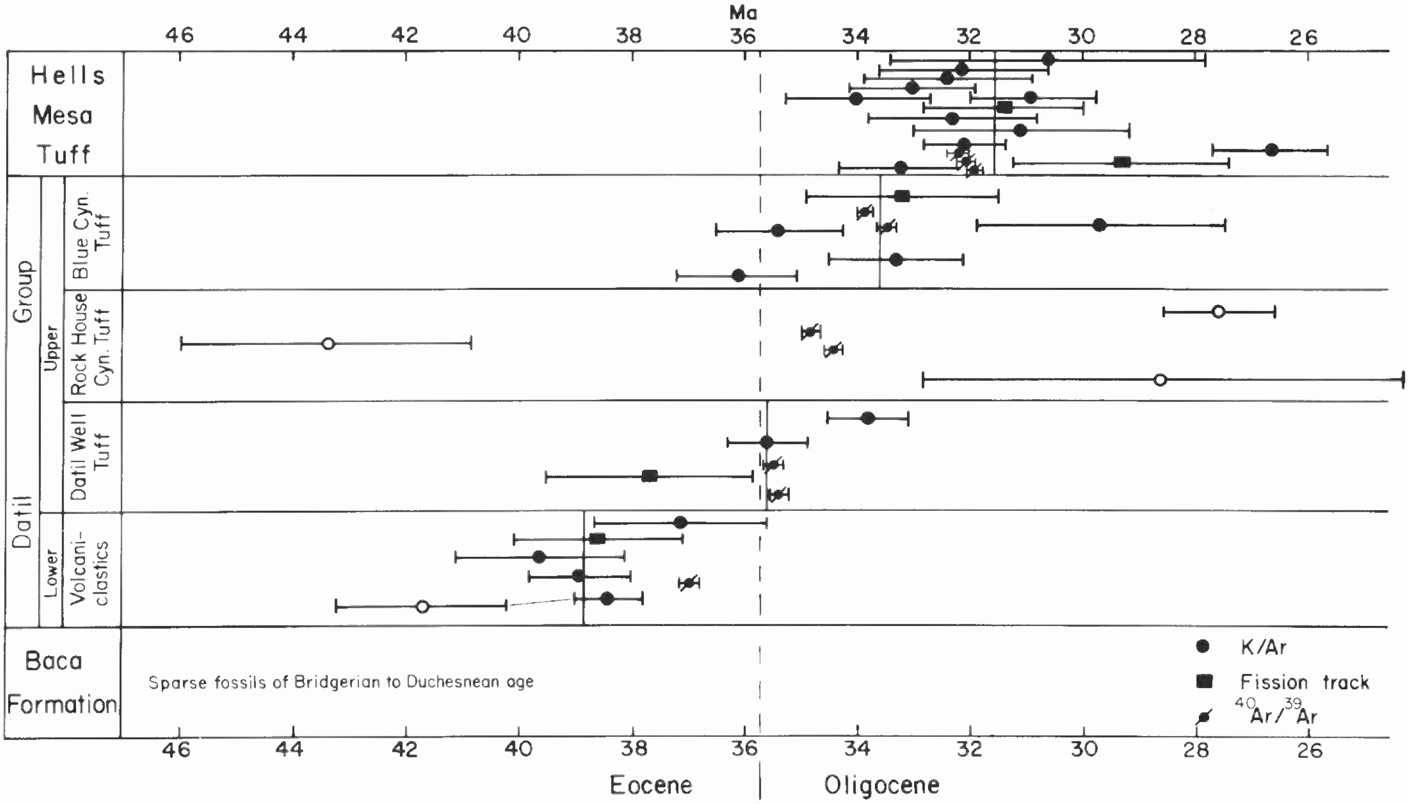

FIGURE 3. Summary of radiometric ages for Datil Group and overlying Hells Mesa Tuff and vertebrate-fossil data for Baca Formation. Brackets indicate one standard deviation about the mean; vertical lines indicate averages for individual units, dashed vertical line is approximate Eocene-Oligocene boundary according to Montanari et al. (1985). Fine line connects analyses from same sample; open symbols represent geologically improbable K-Ar ages. Modified from Cather et al. (1987) and McIntosh (in press).

K basaltic andesites and shoshonites according to Ewart's [1979, 1982] classification). Basaltic andesites range in silica content from about 52 to 56 weight percent, and are characterized by phenocrysts of plagioclase (An_{30}-An_{65}), clinopyroxene and titanomagnetite (±olivine, amphibole) and groundmass plagioclase and alkali feldspar. Basaltic andesite lavas are widespread in the upper Datil; composite thickness for such lava flows locally exceeds 150 m (LaRoche, 1981).

Five ash-flow tuffs of regional extent dominate the silicic mode of upper Datil volcanism. Using the terminology of Osburn and Chapin (1983) and Ratté and McIntosh (in press), these are the Datil Well Tuff, tuff of Farr Ranch, Rock House Canyon Tuff, Blue Canyon Tuff and tuff of Granite Mountain. Silicic detritus derived from domes or lavas is also a locally important component of upper Datil volcaniclastic rocks. Herein, I use the term rhyolite to denote the silicic mode of late Datil volcanism, although rhyodacites are also present. The upper contact of the Datil Group is marked by the base of the Hells Mesa ($^{40}Ar/^{39}Ar$ age 32.0±0.15 my; Kedzie et al., 1985), a thick, regionally extensive ash-flow tuff in the northern Mogollon-Datil field.

SYNOPSIS OF CENOZOIC TECTONISM AND VOLCANISM

During latest Cretaceous(?) to Paleocene time, Laramide uplift of the southern Colorado Plateau margin produced a low-relief erosion surface and weathered zone (Chamberlin, 1981) on Upper Cretaceous rocks in west-central New Mexico. Development of discrete basins in the area, however, did not begin until the Eocene, in response to crustal shortening and right-lateral wrenching along the eastern boundary of the Colorado Plateau (Chapin and Cather, 1981, 1983; Cather and Johnson, 1986; Cather and Chapin, 1988). During deposition of the Eocene Baca Formation, two intermontane basins (the Baca and Carthage-La Joya basins: Fig. 4) and their surrounding uplifts dominated the late Laramide paleogeography of west-central New Mexico. Deposits within these basins represent a broad spectrum of fluvial-lacustrine depositional environments (Johnson, 1978; Cather and Johnson, 1984, 1986).

About 40 my, intermediate-composition volcanism began in the northern Mogollon-Datil field. Andesite stratovolcanoes developed on or near the Laramide Morenci and Sierra uplifts, as shown by the similarity of lower Datil fluvial-lacustrine facies and paleocurrents to those of the underlying Baca Formation (Cather, 1986). Intermediate-composition volcanism and associated sedimentation continued until about 37 my, and were largely supplanted by bimodal volcanism (basaltic andesite/rhyolite) beginning about 36 my (Cather et al., 1987). Mafic lavas, silicic ash-flow tuffs and associated volcaniclastic deposits dominate the upper Datil Group (36–32 my) and comprise the majority of younger rocks in the northern Mogollon-Datil field. Incipient extension began about 36 my (Cather, 1986), and extensional deformation was well underway by 32–28 my (Chapin and Seager, 1975; Chamberlin, 1983; Aldrich et al., 1986). Volcanism waned, and widespread preservation of synrift, bolson-type sediments began about 27–26 my.

POST-LARAMIDE TECTONIC TRANSITION

The timing of the transition from Laramide shortening to mid- and late-Tertiary extension was not synchronous throughout the southwestern United States. The end of the Laramide deformation was regionally diachronous, terminating 34–36 my in Colorado and New Mexico (Dickinson et al., 1988) and about 32 my in Trans-Pecos Texas (Price and Henry, 1984). Timing of inception of mid-Tertiary extension also appears to have varied from place to place and has proven difficult to establish precisely in most areas (Zoback et al., 1981). Strain rates were presumably very low immediately prior to and following the tectonic transition. Nonetheless, deformation in west-central New Mexico was sufficient to produce diagnostic stratigraphic criteria that mark the changeover from Laramide shortening to mid-Tertiary extension.

Many Laramide uplifts in central and southern New Mexico subsided

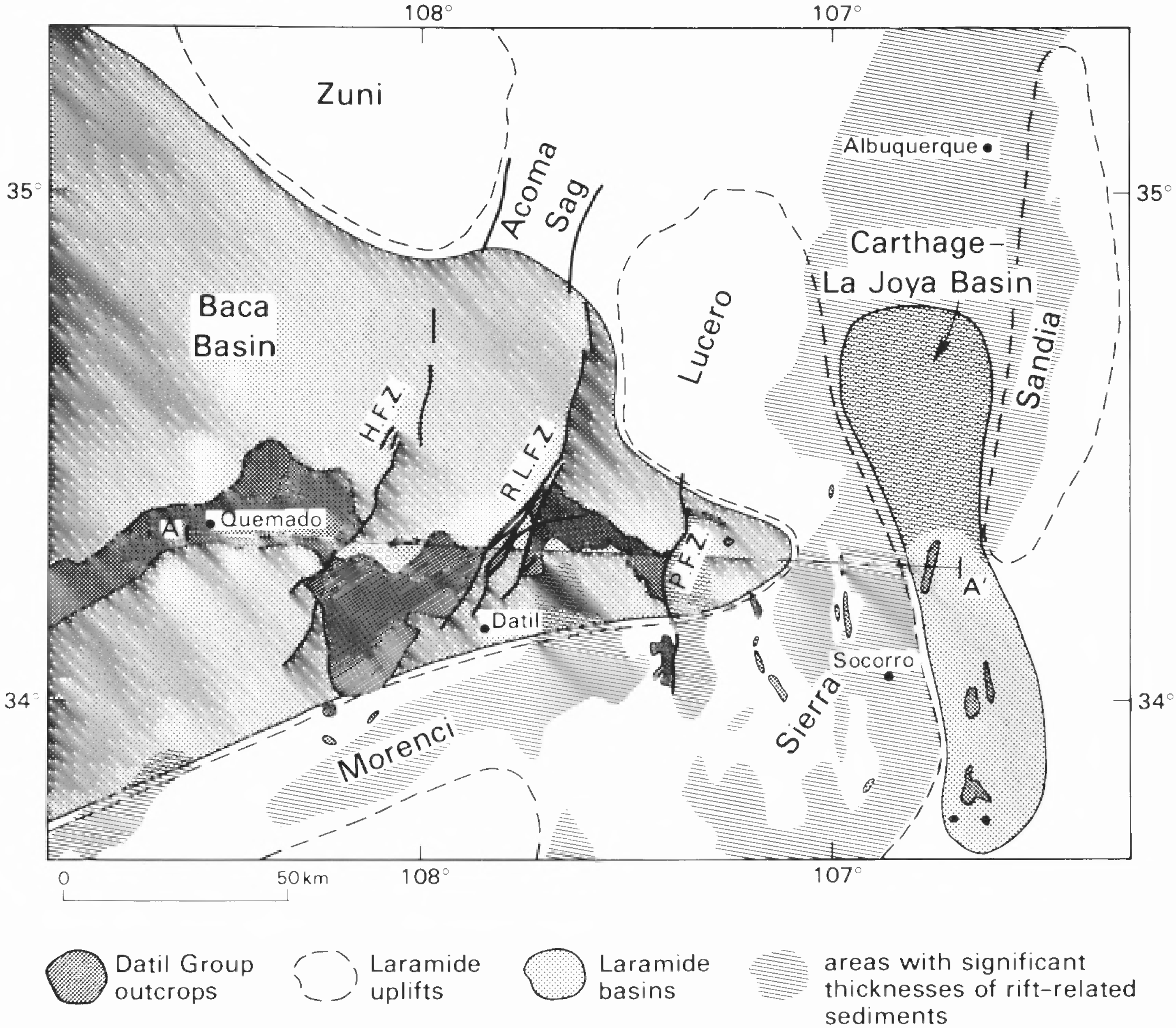

FIGURE 4. Late Laramide (Eocene) paleogeographic map showing basins, uplifts, intrabasin fault zones and modern outcrops of Datil Group. Lined pattern indicates distribution of younger rift basins, which have formed largely by collapse of Laramide uplifts. P.F.Z., Puertecito fault zone; R.L.F.Z., Red Lake fault zone; H.F.Z., Hickman fault zone. A-A' is line of section in Figure 5. Base maps from Cather and Johnson (1984, 1986) and New Mexico Geological Society (1982).

to form basins of the Rio Grande rift (Fig. 4; Cather, 1983; Cather and Johnson, 1984, 1986). Thus, by examining the stratigraphic distribution of sediments derived from these uplifts, the onset of mid-Tertiary extension can be evaluated. The Eocene Baca Formation comprises the major record of late Laramide synorogenic sedimentation in west-central New Mexico. Non-volcanic detritus, including Precambrian lithologies, continued to be shed from the Sierra and Morenci uplifts during the early andesitic phase of Datil volcanism, as shown by the presence of non-volcanic detritus throughout the lower Datil Group in the study area. Laramide-style sedimentation ceased at, or slightly prior to, the onset of bimodal volcanism in west-central New Mexico. No non-volcanic detritus was observed in upper Datil Group exposures anywhere in the study area. Based on this evidence, it appears that Laramide positive areas began to subside and ceased shedding sediment at the onset of bimodal volcanism, about 36 Ma.

No record of a low-relief, late Eocene erosion surface, such as that in central Colorado (Epis and Chapin, 1975), has been documented in west-central New Mexico. Eocene-Oligocene sedimentary sequences in the Baca and Carthage-La Joya basins show no evidence of pronounced lulls in deposition (Cather, 1986). The apparent lack of a late Eocene erosion surface in the study area may be due in part to mid- and late-Tertiary extension which has disrupted most Laramide uplifts in west-central New Mexico (Fig. 4). Such uplifts are largely preserved in Colorado and Wyoming, and are the localities where the late Eocene surface is most readily recognized. Also, volcanism began prior to the end of the Laramide orogeny in west-central New Mexico, producing volcaniclastic sediments which masked any post-orogenic lull in sedimentation that might otherwise have developed.

Intrabasin subsidence patterns in the eastern Baca basin provide additional constraints on the timing of the post-Laramide tectonic transition. The Hickman, Red Lake and Puertecito fault zones (Fig. 4) were active during deposition of the Baca Formation and Datil Group, and were important determinants of basin-fill thickness and of the distribution of sedimentary facies (Cather and Johnson, 1984, 1986; Cather, 1986; Cather and Chapin, in press).

The Red Lake and Puertecito faults were named by Winchester (1920) during his geologic survey of the Alamosa Creek (now Rio Salado) valley in northern Socorro County. Wengerd (1959) was the first to map and describe the Hickman fault system. Subsequent mapping along the Hickman (Maxwell, 1976; Chamberlin, 1981), Red Lake (Givens, 1957; Maxwell, 1976; Harrison, 1980; Robinson, 1981; Chamberlin, 1981) and Puertecito (Tonking, 1957; Chamberlin, 1974; Wilkinson, 1976; Massingill, 1979; Jackson, 1979; Mayerson, 1979; Osburn, 1979; Cather, 1980; LaRoche, 1981) fault zones has documented their structural complexity. Rather than attempt an analysis of the complex structures within these fault zones, I will describe instead the relative displacement histories of the crustal blocks that are *bounded* by these fault zones.

The Hickman and Red Lake fault zones are two north-northeast-trending systems of normal faults and folds that form the western and eastern boundaries, respectively, of a large, late Cenozoic "synclinal horst" (Wengerd, 1959) in the Datil Mountains-Sawtooth Mountains area. Thickness variations in the Baca Formation, however, demonstrate that the area between these two fault zones was *downthrown* during Laramide deformation. The increased thickness of the Baca Formation between these fault zones, as well as the restriction of low-gradient meanderbelt deposits to this same area (Cather and Johnson, 1984, 1986), indicate that the block bounded by the Hickman and Red Lake fault zones was actively subsiding during Baca sedimentation.

The Hickman and Red Lake fault zones represent two north-northeast-trending systems of Laramide reverse faults that have been reactivated as late Cenozoic normal faults. The south-plunging syncline present in the now-uplifted block between these fault zones may be a relict Laramide feature, and appears to merge northward with the Acoma sag (Kelley, 1955; Wengerd, 1959; Chamberlin, 1981). An en echelon series of northwest-trending folds present between the Red Lake and Hickman fault zones (Wengerd, 1959, fig. 4) suggests that right-slip may have accompanied Laramide reverse faulting, although this cannot be confirmed with available data.

The changeover from Laramide reverse slip to mid-Tertiary normal slip along these intrabasin fault zones provides a means by which to evaluate the timing of the stress transition in west-central New Mexico. Because they occur within an area of net sediment accumulation (that is, they behaved as growth faults), variations in thickness of basin-fill can be used to characterize the displacement history along these fault zones (Fig. 5). Stratigraphic thicknesses indicate that reversal in displacement across the Red Lake fault zone occurred about 36 my, approximately coincident with the timing of the lower Datil-upper Datil contact.

Thickness variations indicate the Hickman fault zone was down-to-the-east during Baca and early Datil time, but timing of displacement reversal is hindered by lack of thickness data for upper Datil deposits to the west of the fault zone, where detailed map control is lacking, and the top of the Datil Group is undefined because the superjacent Hells Mesa Tuff has not yet been identified. The Puertecito fault zone (Fig. 5) also has experienced reversal of displacement during the Tertiary. However, timing of displacement reversal can only be constrained between 37 and 26 my because emergence of the hanging-wall block beginning in latest early Datil time violated growth-fault behavior (Fig. 5; Cather, 1986).

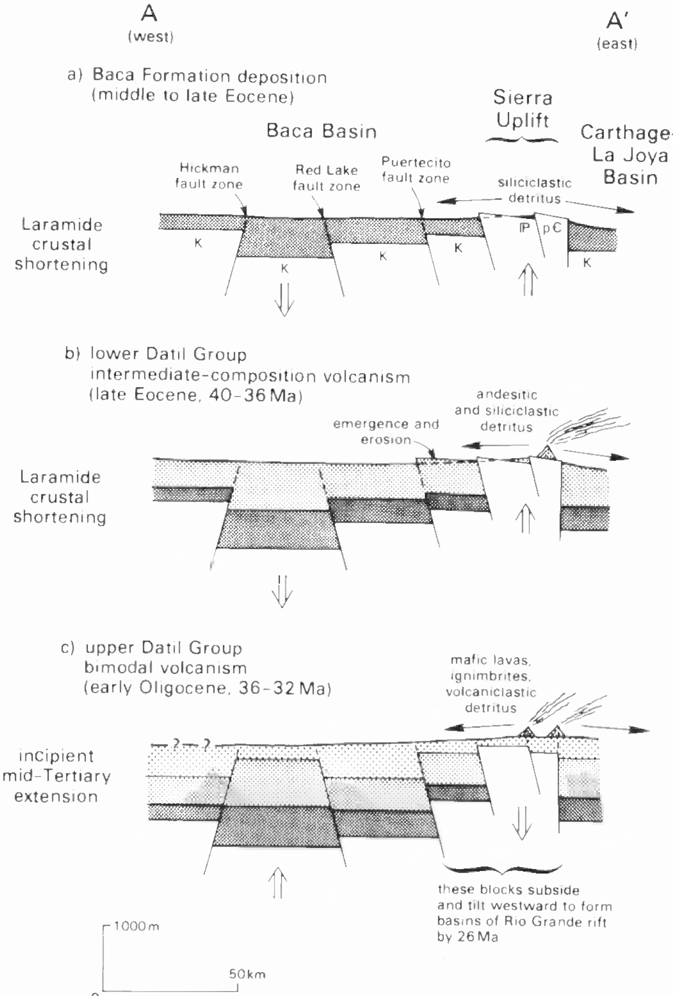

FIGURE 5. Schematic cross sections depicting middle Eocene to early Oligocene uplift and subsidence patterns, sedimentation and volcanism in west-central New Mexico. Note continuation of Laramide-style tectonism (a) during early Datil andesitic volcanism (b). Laramide reverse faults began to be reactivated as normal faults, and the Sierra uplift began to subside about 36 my (c), coincident with the onset of late Datil Group bimodal volcanism. Baca Formation subcrop indicated by symbols in upper cross section. Stratigraphic thickness data from Cather and Johnson (1984, 1986) and Cather (1986).

DISCUSSION

Available data indicate the transition from Laramide shortening to mid-Tertiary extension occurred about 36 my in west-central New Mexico, and was accompanied by a switch from andesitic to bimodal volcanism. The foundation for these interpretations is provided by: (1) detailed knowledge of Cenozoic stratigraphy in the area, largely due to mapping and analysis by C. E. Chapin and his students (Osburn and Chapin, 1983); (2) availability of numerous radiometric ages of volcanic units in the northern Mogollon-Datil field, particularly the high-precision $^{40}Ar/^{39}Ar$ dates by W. C. McIntosh and J. F. Sutter (McIntosh et al., 1986; McIntosh, in press); and (3) knowledge of Laramide basin geometries and intrabasin subsidence patterns in relation to the late Cenozoic tectonic framework (Chapin and Cather, 1981, 1983; Cather, 1983; Cather and Johnson, 1984, 1986). The timing and volcanic signature of the post-Laramide transition in other portions of the Mogollon-Datil field may differ from those of the present study area (W. E. Elston, oral commun., 1989; J. C. Ratté, oral commun., 1989). Further comprehensive studies in other areas are needed.

Lipman (1980, p. 172) described two broad volcano-tectonic assemblages in the western United States, consisting of ". . . an earlier Cenozoic, predominantly andesitic assemblage inferred to result from geometrically complex processes of plate convergence and a later, fundamentally basaltic assemblage associated with extensional tectonic settings. . . ." The early, intermediate-composition assemblage is interpreted by Lipman et al. (1972) and Christiansen and Lipman (1972) to be both syn- and post-orogenic. In the northern Mogollon-Datil field, however, mid-Tertiary extension apparently followed close on the heels of Laramide crustal shortening. Radiometrically constrained stratigraphic sequences adjacent to the Red Lake fault zone suggest that post-Laramide anorogeny was brief, probably less than a few million years in duration. This temporal brevity is perhaps expectable because of the narrow width and dynamic nature of many stress-province boundaries (e.g., Zoback and Zoback, 1980; Aldrich et al., 1986).

With the exception of the apparent brevity of post-Laramide isotropic stress, relations in the northern Mogollon-Datil field are compatible with the volcano-tectonic associations described by Lipman et al. (1972) and Christiansen and Lipman (1972). Late Eocene andesitic volcanism (~40 to 37 my; lower Datil Group and equivalents) occurred during the last stages of Laramide crustal shortening. About 36 my, incipient extensional tectonism began, and volcanism became bimodal. Bimodal volcanism characterized the bulk of post-Eocene volcanism in the northern Mogollon-Datil field, although subordinate amounts of intermediate products were also erupted (Cather and Chapin, in press).

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Looking N at cliff at Red Rock State Park showing contact between medial silty member and upper sandy member of Jurassic Entrada Sandstone (at white line). Photograph 24 February 1989 by Paul L. Sealey.