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The Oligocene Goodsight-Cedar Hills half graben near Las Cruces and its implications to the evolution of the Mogollon-Datil volcanic field and to the southern Rio Grande rift

Greg H. Mack, Alice L. Nightengale, William R. Seager, and Russell E. Clemons, 1994, pp. 135-142

in:
Mogollon Slope (West-Central New Mexico and East-Central Arizona), Chamberlin, R. M.; Kues, B. S.; Cather, S. M.; Barker, J. M.; McIntosh, W. C.; [eds.], New Mexico Geological Society 45th Annual Fall Field Conference Guidebook, 335 p.

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THE OLIGOCENE GOODSIGHT-CEDAR HILLS HALF GRABEN NEAR LAS CRUCES AND ITS IMPLICATIONS TO THE EVOLUTION OF THE MOGOLLON-DATIL VOLCANIC FIELD AND TO THE SOUTHERN RIO GRANDE RIFT

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Abstract—The Goodsight-Cedar Hills (GCH) depression near Las Cruces, New Mexico, was a north-northeast-trending, nonmarine, elliptical basin of Oligocene age that developed along the southeastern margin of the Mogollon-Datil volcanic field. Within the basin were deposited six ash-flow tuff outflow sheets, as well as sedimentary rocks composed of interbedded syneruption and post-eruption lithofacies. The syneruption lithofacies consists of light-colored, medium-grained tuffaceous sandstones that represent reworked fallout tephra. Epiclastic conglomerates and coarse sandstones constitute the post-eruption lithofacies, with clast composition reflecting derivation from adjacent bedrock uplifts. An asymmetrical distribution of post-eruption lithofacies, based on provenance and sediment dispersal data, suggests that the GCH basin was an eastward-tilted half graben, with the Cedar Hills vent zone as the footwall and the Ancestral Goodsight uplift as the hanging wall. The GCH half graben provides important information about the Mogollon-Datil volcanic field, not only because it was a depository for several regional outflow sheets, but also because syneruption sandstones may record explosive eruptions that occurred during or between major ignimbrite-generating events. Furthermore, initial development of the half graben at 35 Ma precedes by 2 to 7 million years previous interpretations of the onset of regional crustal extension in the southern Rio Grande rift.

INTRODUCTION

The Mogollon-Datil volcanic field of west-central New Mexico is characterized by as many as 11 latest Eocene and Oligocene silicic calderas and their associated outflow sheets (McIntosh et al., 1986, 1990, 1991, 1992). The southeastern edge of the volcanic field extends to the vicinity of Las Cruces, where three calderas, Emory, Doña Ana and Organ, were active between 36.2 and 34.9 Ma (Fig. 1; Elston et al., 1975; Seager et al., 1976; Seager, 1981; McIntosh et al., 1990, 1991, 1992). Coeval to and positioned among the active calderas was a subsiding tectonic feature referred to as the Goodsight-Cedar Hills (GCH) volcano-tectonic depression, most of which was subsequently uplifted along late Tertiary normal faults (Fig. 2; Seager, 1973, 1975). The GCH depression contains up to six mappable ash-flow tuffs and interbedded sedimentary rocks of the Bell Top Formation, but was not itself a cauldron (Seager, 1975). It is not clear from earlier studies, which concentrated primarily on the volcanic rocks of the Bell Top Formation, whether subsidence of the GCH depression was driven by volcanic processes or by movement of a basin-bounding fault (Seager, 1973, 1975; Clemons, 1976a). A cauldron origin is unlikely because the basin contains only outflow sheets, most of which are correlated with distant calderas, and there is no evidence for extrusive centers corresponding to the age of the ash-flow tuffs. This study presents sedimentologic and petrographic data from the sedimentary members of the Bell Top Formation that suggest the GCH depression was a half graben, in which were deposited epiclastic conglomerates and sandstones derived from adjacent bedrock uplifts, reworked fallout tephra, and ash-flow tuff outflow sheets. This interpretation provides information about the possible existence of Plinian eruptions between major ash-flow sheets, as well as suggests that regional crustal extension in the southern Rio Grande rift may have begun by 35 Ma.

STRATIGRAPHY OF THE BELL TOP FORMATION

The type section of the Bell Top Formation is in the Sierra de las Uvas, where it consists of six mappable ash-flow tuffs, numbered 2 through 7, and two mappable sedimentary members (Middle and Upper Sedimentary Members), which are the focus of this study (Figs. 2, 3; Kottlowski, 1953; Seager, 1973; Clemons, 1975, 1976a). The upper five tuffs have recently been dated by the ^{40}Ar/^{39}Ar method and range in age from 35.7 to 28.5 Ma (McIntosh et al., 1990, 1991, 1992). Ash-flow tuff 7 is thin and discontinuous in the Sierra de las Uvas and probably is the distal part of the Vicks Peak Tuff of the San Mateo Mountains area (McIntosh et al., 1990, 1991, 1992). Along the southeastern margin of the basin in the Cedar Hills and Rough and Ready Hills is a local map unit, the Coyote Canyon Conglomerate, which is correlative with the Upper Sedimentary Member of the Bell Top Formation (Fig. 2; Clemons, 1976b). The GCH depression is bounded on the east by the Cedar Hills vent zone, a northerly trending series of flow-banded rhyolite domes and related volcanic rocks exposed in the Cedar Hills and Rough and Ready Hills (Figs. 1, 2). The domes appear to be onlapped by ash-flow tuffs 4 and 5 and are roughly the same age or slightly younger than ash-flow tuff 3 (Fig. 3; Seager, 1975; Clemons, 1975).

Ash-flow tuffs 2, 3 and 4 are absent north of the Sierra de las Uvas, although ash-flow tuffs 5, 6 and 7 and the Middle and Upper Sedimentary Members are present in the Rincon Hills and at Point of Rocks (Figs. 2, 3; Seager and Hawley, 1973; Seager et al., 1982).

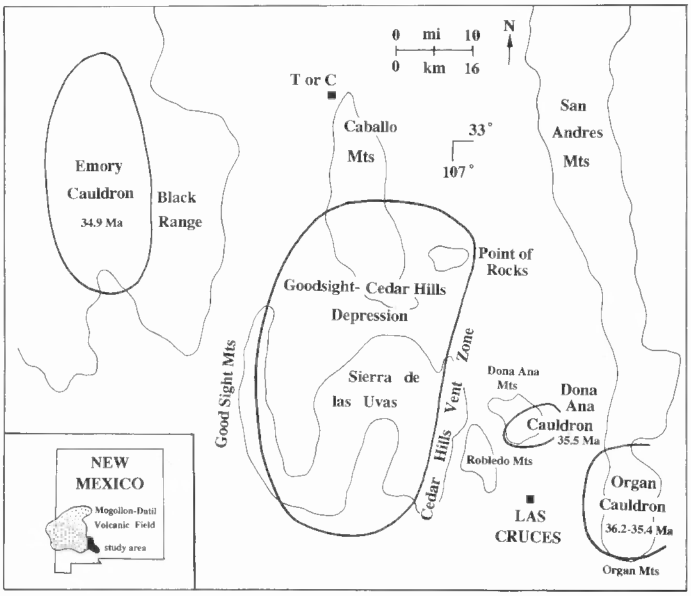

FIGURE 1. Oligocene tectonic elements in south-central New Mexico. Numbers refer to radiometric ages in millions of years (Ma) of tuffs located within calderas, based on McIntosh et al. (1990, 1991, 1992).

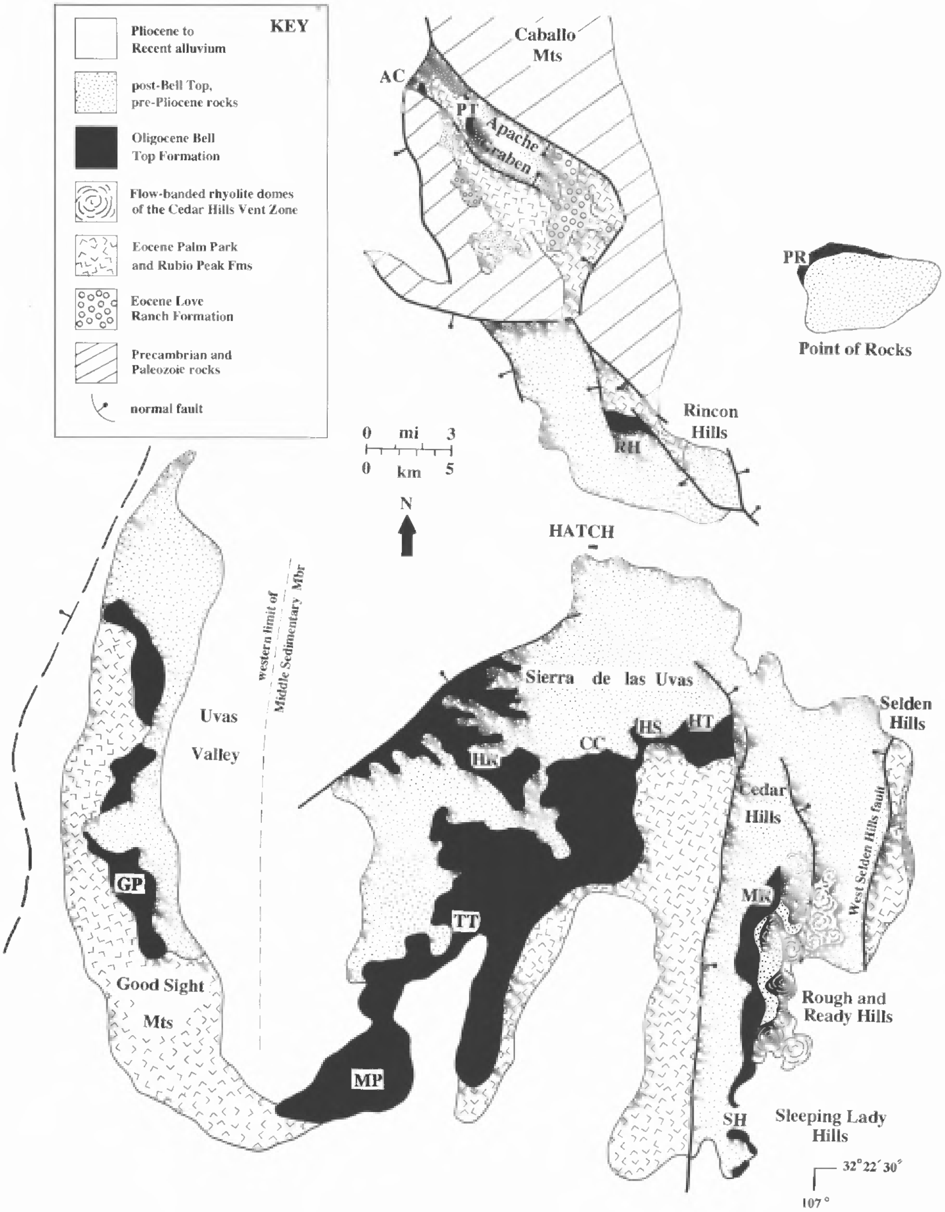

FIGURE 2. Generalized geologic map of south-central New Mexico, adapted from Seager et al., (1982, 1987), and the location of measured sections of the Bell Top Formation. Western limit of the Middle Sedimentary Member is from Clemons (1979). GP=Good Sight Peak, MP= Massacre Peak, TT=Tajanio Pinto Tank, HR= Horse Canyon Ranch, CC= Choases Canyon, HS= Hermantano Springs, HT= Hersey Tank, MR= McCall Reservoir, SH= Sleeping Lady Hills, RH= Rincon Hills, PR= Point of Rocks, AC= Apache Canyon, PT= Pass Tank.

Farther north, in Apache Graben of the Caballo Mountains, ash-flow tuff 6 is absent and Bell Top sedimentary rocks overlie the Kneeling Nun Tuff, which was derived from the Emory cauldron (Figs. 1-3; Elston et al., 1975; Seager and Mack, in press). The Kneeling Nun Tuff is very close in age to ash-flow tuff 5 and the two tuffs may be the same (McIntosh et al., 1990, 1991, 1992).

The Bell Top Formation unconformably overlies andesitic volcanic and volcaniclastic rocks of the Rubio Peak Formation in the Goodsight Mountains and the Palm Park Formation elsewhere (Fig. 3; Seager et al., 1982, 1987). Conformably underlying the Palm Park Formation is the Love Ranch Formation, which is a synorogenic Laramide conglomerate (Fig. 3; Seager, 1983; Seager and Mack, 1986; Seager et al., 1986). The Love Ranch Formation is thickest (up to 600 m) in the southern Caballo Mountains, where it and the lowermost part of the Palm Park Formation are composed of clasts of Paleozoic sedimentary rocks, Precambrian granitic and metamorphic rocks, and Cretaceous(?) andesitic rocks (Seager et al., 1986).

Conformably overlying the Bell Top Formation south of Apache Graben is the Uvas Basaltic Andesite, which has been radiometrically dated (K-Ar) at 27 to 28 Ma (Seager et al., 1984). At the Good Sight Peak, Point of Rocks, and McCall Reservoir measured sections, Uvas-type basalt flows are interbedded within the Upper Sedimentary Member of the Bell Top Formation. In Apache Graben, ash-flow tuff 7 of the Bell Top Formation is conformably(?) overlain by tuffaceous sandstones of the Thurman Formation, the normally intervening Uvas Basaltic Andesite having pinched out to the south (Figs. 2, 3; Seager and Mack, in press).

METHODS

Thirteen stratigraphic sections of the Bell Top Formation between ash- flow tuff 5 or Kneeling Nun Tuff and ash-flow tuff 7 or the Uvas Basaltic Andesite were measured in the study area. Eight of these sections had been measured previously, but were re-examined as part of this study (Fig. 2, SH, MR, RH, HR, HS, CC, TT, MP; Seager and Hawley, 1973; Clemons and Seager, 1973; Seager and Clemons, 1975; Seager et al., 1975; Clemons, 1976b, 1977, 1979). Sedimentologic data collected include thickness of syneruption and post-eruption lithofacies, measurements of the length of the A-axis of the 10 largest clasts within 39 post-eruption conglomerates, and imbrication measurements of 35 post-eruption conglomerates, involving measuring the strike and dip of the AB-plane of 10 to 30 clasts per bed. Compositional data were also collected from post-eruption conglomerates and syneruption sandstones. Three hundred boulder-, cobble- and pebble-sized clasts were counted at each of 39 beds of post-eruption conglomerate, with compositional categories including andesite, basalt, ash-flow tuff, flow-banded rhyolite, granite, foliated metamorphic rocks and sedimentary rocks. In addition, 14 medium-grained, syneruption sandstones were point counted, utilizing 300 points per thin section. Principal grain categories include monocrystalline quartz, polycrystalline quartz, potassium feldspar, plagioclase feldspar, volcanic rock fragments, glass shards and pumice.

LITHOFACIES

The Middle and Upper Sedimentary Members of the Bell Top Formation and the correlative Bell Top Formation in Apache Graben are divided into syneruption and post-eruption lithofacies (Figs. 4-6). Syneruption lithofacies, based on Smith (1991), refers to largely sand-sized fallout tephra that is reworked by sedimentary processes. As a result of Plinian eruptions, large volumes of relatively fine-grained fallout tephra mantles the countryside tens to hundreds of kilometers from the eruptive center. This material is quickly redistributed into local depocenters by gravity flows, running water and/or wind processes. Walton (1979, 1986) called this type of sediment 'active-eruption" or 'active-apron" facies, based on analysis of Oligocene rocks in west Texas. The studies of Walton (1979, 1986) are especially applicable to the Bell Top Formation, because both the volcaniclastic sediment in west Texas and in the present study area were derived from silicic calderas.

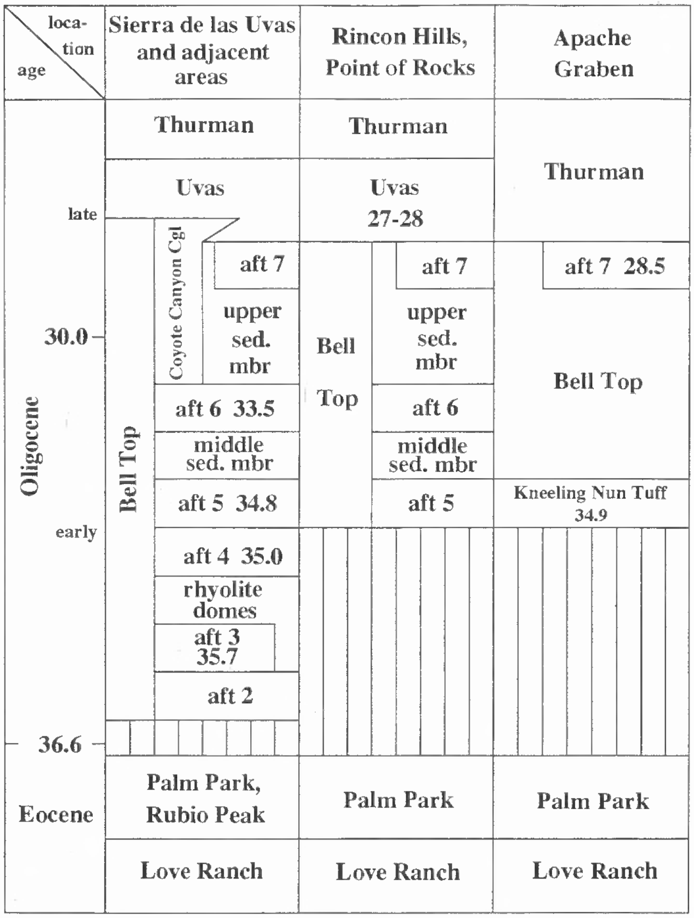

FIGURE 3. Correlation chart of Eocene and Oligocene stratigraphic units in south-central New Mexico. Numbers associated with ash-flow tuffs (aft), Kneeling Nun Tuff, and Uvas Basaltic Andesite are radiometric ages in million of years from Seager and others (1984) and McIntosh and others (1990, 1991, 1992). Age of Eocene-Oligocene boundary is from DNAG time scale (Palmer, 1983).

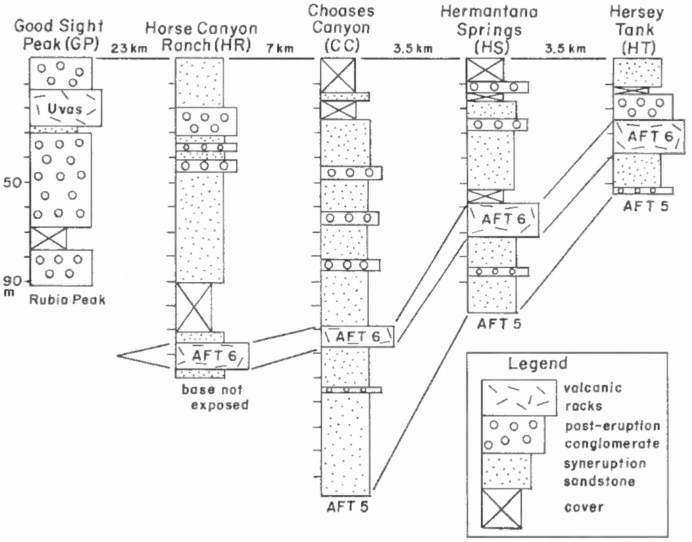

FIGURE 4. Stratigraphic sections of the Middle and Upper Sedimentary Members of the Bell Top Formation in the Good Sight Mountains and northern Sierra de las Uvas. Note differences in scale of Figures 4, 5 and 6.

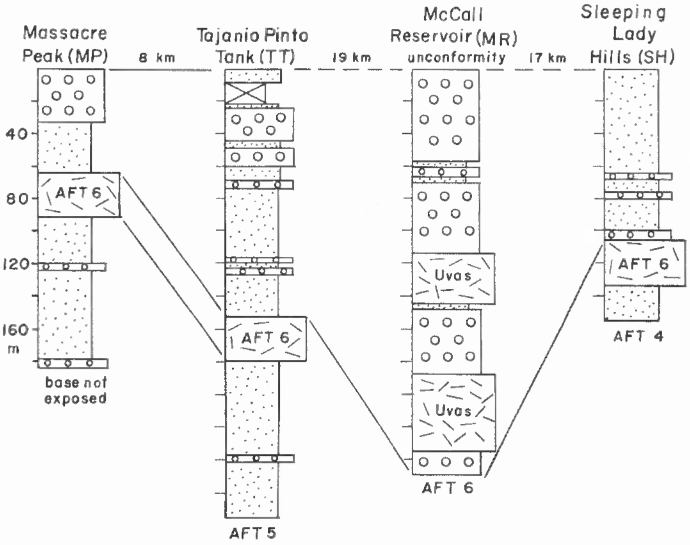

FIGURE 5. Stratigraphic sections of the Middle and Upper Sedimentary Members of the Bell Top Formation in the southern Sierra de las Uvas, Cedar Hills and Sleeping Lady Hills; see Fig. 4 for legend.

Once the fallout tephra is removed from upland regions, bedrock is exposed and supplies epiclastic sediment to adjacent basins. The epiclastic detritus is, in most cases, distinctly different than the syneruption sediment in terms of grain size and composition. Smith (1991) called these deposits "inter-eruption facies", whereas Walton (1979, 1986) used the terms "inactive-apron" or "post-eruption" phase; the term 'post-eruption lithofacies" is used in this study.

Syneruption lithofacies

Syneruption lithofacies of the Bell Top Formation consist of whitish to light gray or tan, fine- and medium-grained sandstone containing scattered granule- and pebble-sized clasts of white pumice. Sandstones generally have in excess of 50% glass shards and pumice, some of which are altered to clay and/or have devitrified to quartz or chert.

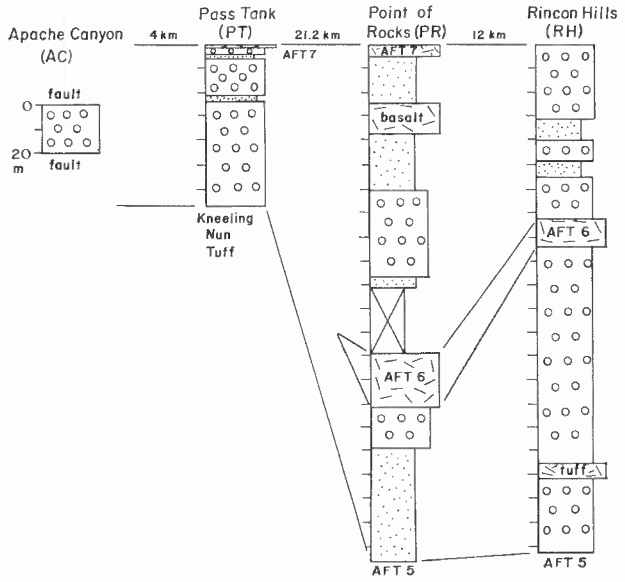

FIGURE 6. Stratigraphic sections of the Middle and Upper Sedimentary Members of the Bell Top Formation at Point of Rocks and in the Rincon Hills and of the Bell Top Formation at Apache Canyon and Pass Tank in the Caballo Mountains; see Fig. 4 for legend.

Shards are typically medium- or fine-sand sized, thin, and curved or Y-shaped, which are common products of rhyolitic or dacitic eruptions (Heiken, 1972). The remainder of the sand grains are primarily sanidine and plagioclase; volcanic rock fragments and quartz are rare (Fig. 7A).

The majority of syneruption sandstones are thin bedded and display horizontal laminae and/or broad (meters), shallow (centimeters) channels. Crossbeds are rare. Locally, pumice granules and pebbles are concentrated along the base of channels or constitute the base of small-scale (<20 cm thick) normally graded beds. The thin-bedded variety of syneruption lithofacies is interpreted to represent deposition by sheetfloods or by low sinuosity streams.

Less commonly, the syneruption lithofacies consists of thick-bedded sandstones that display no internal layering or sedimentary structures. In many cases, gravel-sized pumice clasts are randomly distributed in the sandstone matrix. Thick-bedded, structureless syneruption sandstones are interpreted to be debris-flow deposits.

The syneruption lithofacies is most abundant in the southern and central part of the basin, where it constitutes up to 80% of the sedimentary rocks (Figs. 4, 5). In the northern part of the basin, at Pass Tank and Rincon Hills, the syneruption lithofacies makes up less than 10% of the sedimentary strata (Fig. 6). Geographic variation in abundance of syneruption lithofacies may reflect a southerly source of the fallout tephra or more effective erosion of tephra from the northern part of the basin. The syneruption lithofacies is also less common along the margins of the basin (eg. Apache Canyon, Good Sight Peak, McCall Reservoir) than within the central part of the basin. This trend is most likely related to more effective removal of tephra along the basin margins due to steeper gradients.

Post-eruption lithofacies

The post-eruption lithofacies of the Bell Top Formation consists primarily of conglomerate with minor interbeds of sandstone and mudstone. Gravel-sized clasts are rounded to subrounded and vary in size from granules to boulders up to 1.5 m long dimension.

Conglomerates can be separated into five petrofacies based on composition of the clasts (Fig. 7B). The Coyote Canyon Conglomerate, exposed along the southeastern margin of the basin, constitutes the flow-banded rhyolite-clast petrofacies. The dominant clast type is dark brown to maroon flow-banded rhyolite and rhyolite, but also present are small amounts (<5 %) of basalt. The clasts of flow-banded rhyolite are probably derived from flow-banded rhyolite domes exposed in the Cedar Hills vent zone.

The most widespread petrofacies is the andesite-clast petrofacies, which consists primarily of clasts of purple or green andesite and andesite porphyry and secondarily of ash-flow tuff clasts (15%). The sources of the andesite clasts are the Palm Park and Rubio Peak Formations and the tuff clasts are probably reworked from ash-flow tuffs 5 and 6, based on hand-sample and petrographic comparison. Two stratigraphic sections, Hermantano Springs and Hersey Tank, contain conglomerates composed of subequal amounts of flow-banded rhyolite and andesite clasts and these define the mixed andesite-flow-banded rhyolite-clast petrofacies (Fig. 7B).

In the northern part of the study area, post-eruption conglomerates belong to the mixed igneous-sedimentary-metamorphic-clast petrofacies and consist of a mixture of andesite, andesite-porphyry, ash-flow tuff, granite, gneiss, schist, sandstone and carbonate (Fig. 7B). Andesite and andesite porphyry clasts are most likely derived from the Palm Park Formation and/or from Cretaceous andesitic rocks, whereas the tuff clasts resemble the Kneeling Nun Tuff. The remainder of the clasts are probably second-cycle clasts of Precambrian (granite, gneiss, schist) and Paleozoic (sandstone, carbonate) age derived from the Love Ranch Formation or from the conglomeratic base of the Palm Park Formation. A polycyclic origin for the Precambrian and Paleozoic clasts is supported by excellent rounding of the clasts.

The least common petrofacies, the tuff-clast petrofacies, is exposed in the Sleeping Lady Hills and consists primarily of ash-flow tuff clasts (90%), together with minor amounts of flow-banded rhyolite (5%) and basalt (5%).

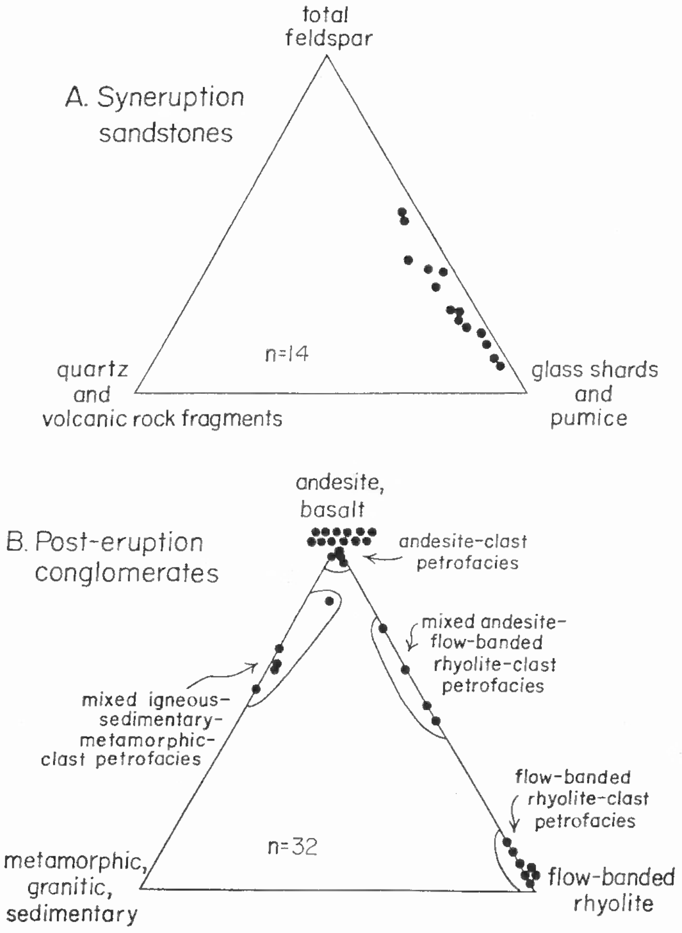

FIGURE 7. Composition of Bell Top sedimentary rocks. A, Triangular plot of the composition of syneruption sandstones, based on 300 points per thin section. B, Triangular plot of principal boulder, cobble and pebble clast types of post-eruption conglomerates, based on 300 counts per bed.

The majority of post-eruption conglomerates are grain supported, moderately well sorted, and locally exhibit imbrication. Meter-scale fining-upward sequences are present, as are thin lenses of coarse sandstone that display horizontal laminae and trough crossbeds. This type of conglomerate is waterlaid and probably represents deposition in high-gradient, low-sinuosity streams. Rare thin (<1 m) beds of red mudstone are interbedded with conglomerates, although a 10-m-thick mudstone, which was probably deposited on an alluvial flat or in a lake, is exposed at the Rincon Hills section.

Less commonly, the post-eruption lithofacies consists of thick-bedded, very poorly sorted conglomerate with no evidence of internal stratification or imbrication. This type of conglomerate, which is interpreted to represent debris flows, is most common along the margins of the basin at Goodsight Peak, McCall Reservoir, and Apache Canyon (Fig. 2).

RECONSTRUCTION OF THE GOODSIGHT-CEDAR HILLS HALF GRABEN

Asymmetrical distribution of lithofacies

The areal distribution of lithofacies in a half graben is markedly asymmetrical, in response to asymmetrical subsidence (Leeder and Gawthorpe, 1987; Blair and Bilodeau, 1988). Footwall-derived alluvial fans are small in area, because they are derived from small, steep drainage basins occupying the footwall scarp. In contrast, hanging wall drainage basins are much larger in area than footwall drainage basins, resulting in large hanging wall-derived alluvial fans that extend far down the hanging wall dip slope. The basin-axis lithofacies, which in a nonmarine depositional setting is commonly a lake or an axial drainage system, occupies a narrow belt above the zone of maximum subsidence near the footwall uplift. The asymmetrical distribution of lithofacies in half grabens has been observed in Neogene sedimentary basins and is a powerful tool in reconstructing the asymmetry of ancient extensional basins (Leeder and Alexander, 1987; Alexander and Leeder, 1987; Frostick and Reid, 1987; Mack and Seager, 1990; Leeder et al., 1991).

Provenance and dispersal directions of post-eruption conglomerates of the Bell Top Formation suggest that the GCH basin was an eastward-tilted half graben, with the Cedar Hills vent zone as the footwall and the Ancestral Goodsight uplift as the hanging wall (Figs. 8, 9). Outcrops of footwall-derived fanglomerate are represented by the Coyote Canyon Conglomerate, exposed in the east-central part of the study area. Extremely coarse grain size, westerly paleocurrents, and the predominance of flow-banded rhyolite clasts (flow-banded rhyolite-clast petrofacies) suggest that the Coyote Canyon Conglomerate is a proximal fan lithofacies derived from flow-banded rhyolite domes in the Cedar Hills vent zone. The flow-banded rhyolite-clast petrofacies cannot be traced westward into the Sierra de las Uvas, supporting the interpretation that this petrofacies was deposited on areally restricted, footwall-derived alluvial fans.

Most of the GCH basin is occupied by the andesite-clast petrofacies, which displays evidence of eastward paleocurrents and an eastward decrease in maximum clast size (Fig. 8). The andesite-clast petrofacies is interpreted to represent hanging wall-derived sediment, from a source of andesitic rocks of the Rubio Peak Formation in the Ancestral Goodsight uplift (Fig. 9). The hanging wall-derived fans extended at least 30 km down the hanging wall dip slope. The mixed igneous-sedimentary-metamorphic-clast petrofacies in the northern part of the basin represents a minor variation in provenance of the hanging wall-derived detritus. Precambrian granitic and metamorphic clasts and Paleozoic sedimentary clasts are of second-cycle origin and were derived from the base of the Palm Park Formation and/or from the Love Ranch Formation, which were not exposed farther south in the Ancestral Goodsight uplift. Thus, the change in provenance of the hanging wall-derived detritus reflects a change in the Eocene source rocks exposed on the hanging wall.

Outcrops at Hersey Tank and Hermantano Springs in the northern Sierra de las Uvas represent a basin-axis lithofacies, because of relatively fine grain size, paleocurrents that indicate northward paleoflow, a direction that roughly parallels the basin axis, and a composition that is a subequal mixture of both flow-banded rhyolite clasts derived from the footwall and andesite clasts derived from the hanging wall (Figs. 8, 9). The fact that the basin-axis lithofacies is not present in the Rincon Hills or at Point of Rocks suggests either that the drainage system changed to a northeasterly course or that the drainage system emptied into a lake located east of the Rincon Hills. No outcrops are available in this area to test these hypotheses.

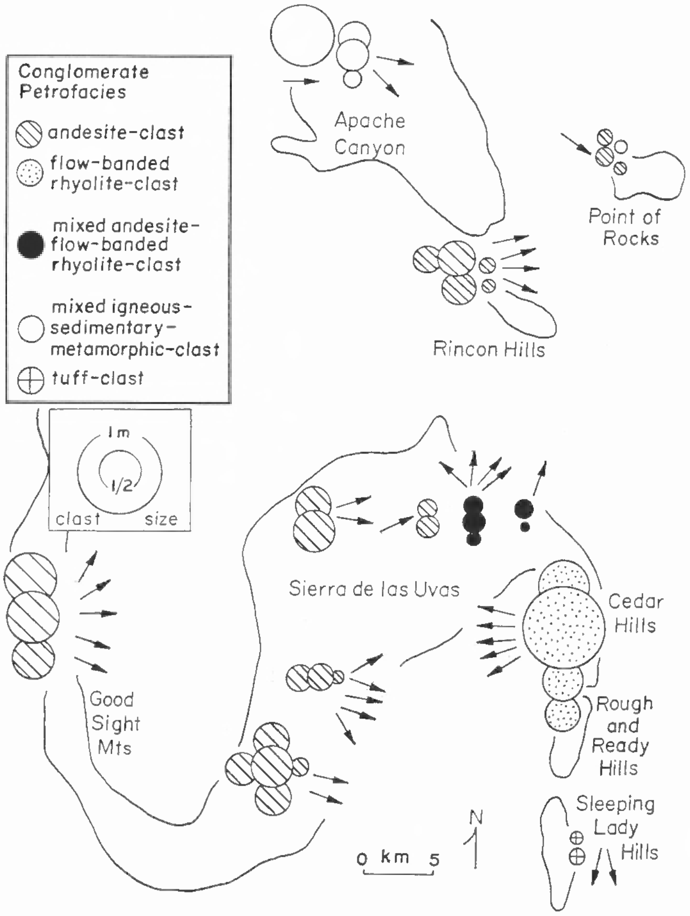

FIGURE 8. Sedimentologic and compositional data of post-eruption conglomerates of the Bell Top Formation. Size of circles represents average maximum clast size and pattern of circles corresponds to conglomerate petrofacies. Arrows represent vector mean paleoflow directions based on imbrication measurements.

The western extent of the Middle and Upper Sedimentary Members also provides evidence in support of a half graben. According to the model of Leeder and Gawthorpe (1987), progressive extension of a half graben causes sedimentary onlap of the hanging wall. This relationship is demonstrated in the Goodsight-Cedar Hills half graben by the fact that the Middle Sedimentary Member exhibits a depositional pinchout in the Uvas Valley, whereas the Upper Sedimentary Member extends at least 8 km farther up the hanging wall into the Good Sight Mountains (Fig. 2; Clemons, 1979).

Post-eruption conglomerates of the Bell Top Formation in the Sleeping Lady Hills do not easily fit the half graben model (Figs. 2, 9). These conglomerates are unique because of relatively fine grain size, paleocurrents indicating southward paleoflow, and a composition primarily of tuff clasts and secondarily of flow-banded rhyolite and basalt clasts. Perhaps the conglomerates in the Sleeping Lady Hills were deposited by axial drainage systems controlled by faults synthetic to the basin-bounding fault, as described in the East African rift by Frostick and Reid (1987).

Nature of faults

The boundary fault along the eastern margin of the GCH half graben is not presently exposed and is thus inferred in Figure 9.

However, the existence of a westward-dipping normal fault or fault zone at this location was suggested previously by Seager (1973, 1975) and Clemons (1976b), in order to account for the coarse grain size and provenance of the Coyote Canyon Conglomerate, for the absence of most ash-flow tuffs east of the inferred fault, and for the northerly alignment of the flow-banded rhyolite domes in the Cedar Hills vent zone.

The fault east of the boundary fault, known as the West Selden Hills fault, is a mappable westward-dipping normal fault (Figs. 2, 9; Seager et al., 1971; Seager and Clemons, 1975). The West Selden Hills fault experienced post-late Miocene movement, because it cuts the Rincon Valley Formation, which contains the 9.6 Ma Selden basalt. The fault is also inferred to have experienced pre-early Miocene movement, because the Eocene Palm Park Formation on the footwall is onlapped by the early Miocene Hayner Ranch Formation. Thus, the Palm Park Formation was uplifted and younger Oligocene volcanic and volcaniclastic rocks either were not deposited above or were eroded off of the Palm Park Formation prior to early Miocene onlap. The age, trend and dip of the West Selden Hills fault suggest that it may be synthetic to the boundary fault of the GCH half graben.

Also shown on Figure 9 is an inferred fault that marks the western boundary of the Ancestral Goodsight uplift. The existence of this fault is based on a linear zone of steep Bouguer gravity gradient displaying a range of up to 200 milligals (Decker and Smithson, 1975; Daggett and Keller, 1982). In its southern part, the gravity gradient corresponds to the margin of the late-rift (post-late Miocene) Good Sight Mountains, but its northern segment cuts across the late-rift Palomas basin. This latter relationship, together with the large magnitude of the gravity anomaly, suggests that the gravity gradient defines the western margin of an early-rift uplift, the Ancestral Goodsight uplift. However, the exact age of the northern part of the gravity gradient cannot be determined at this time and the possibility exists that it postdates development of the GCH half graben.

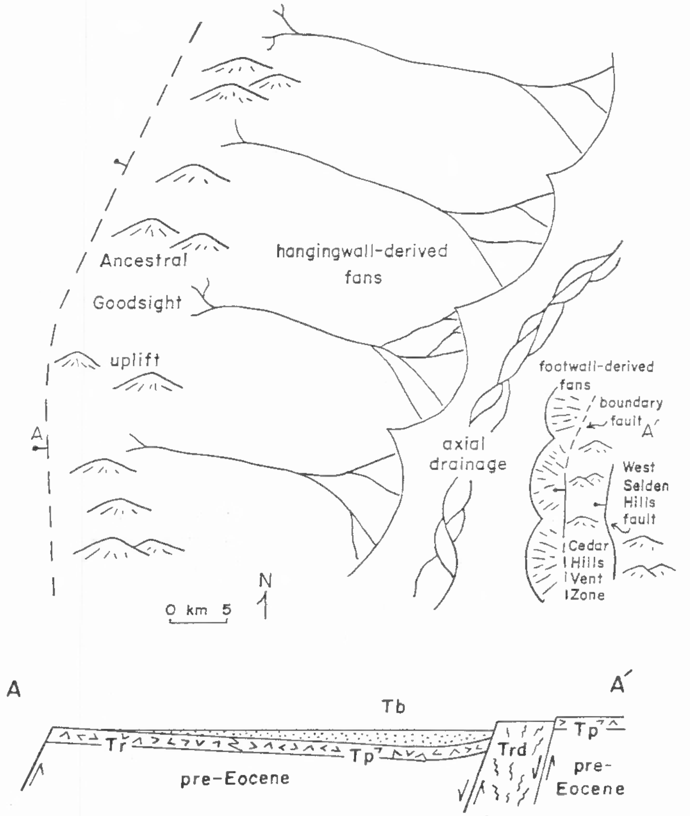

FIGURE 9. Interpretation of the paleogeography and paleotectonics of the Goodsight-Cedar Hills half graben from 35 to 28 Ma. Tp=Palm Park Formation; Trd=flow-banded rhyolite domes; Tr=Rubio Peak Formation; Tb=Bell Top Formation.

Alternative model

We evaluate here an alternative model that does not involve a half graben to explain the distribution of epiclastic conglomerates and sandstones of the Bell Top Formation. In this model, the east-southeastward dispersal system is the distal part of a volcanic apron derived from Palm Park/Rubio Peak andesitic volcanic centers, located approximately 30 km west of the western edge of the GCH basin in the Black Range and Cookes Range. Furthermore, exposure of the rhyolite domes along the eastern margin of the basin represents original relief associated with intrusion, rather than relief created by faulting.

There are several problems with this model that make it less viable than the half graben model. Specific problems related to derivation of Bell Top conglomerates from Palm Park/Rubio Peak volcanic centers are: (1) Bell Top epiclastic conglomerates along the western edge of the GCH basin are too coarse grained to have been derived from the volcanic centers in question; (2) A volcanic source cannot easily account for the Precambrian and Paleozoic clasts reworked from the Love Ranch Formation; (3) There appears to have been a tectonic/topographic reorganization between Palm Park/Rubio Peak time and Bell Top time, as indicated by an unconformity between the units, which in the Good Sight Mountains is angular (Clemons, 1979); and (4) Palm Park/Rubio Peak volcanic aprons contain abundant lahars, which are absent in Bell Top andesite-clast conglomerates.

Unfaulted rhyolite domes along the eastern flank of the GCH basin also present problems. Unfaulted domes should be bordered by a broad, gently-sloping apron of detritus that extends many tens of kilometers into the basin, when in fact the flow-banded rhyolite petrofacies is restricted to a narrow belt adjacent to the domes. Also it would appear to defy normal denudation rates for rhyolite domes to remain topographically high enough to supply coarse gravel to the GCH basin for up to 7 Ma after their intrusion.

IMPLICATIONS TO THE HISTORY OF THE MOGOLLON-DATIL VOLCANIC FIELD

Volcanic and volcaniclastic rocks of the Bell Top Formation in the GCH half graben provide important information about the history of the Mogollon-Datil volcanic field. Because of their position along the southeastern margin of the volcanic field, ash-flow tuffs of the Bell Top Formation in the GCH half graben delimit the maximum lateral extent of regional outflow sheets. Based on $^{40}Ar/^{39}Ar$ ages and paleomagnetism, McIntosh et al., (1990, 1991, 1992) correlated Bell Top tuffs with other ignimbrites and their source cauldrons in the Mogollon-Datil volcanic field. These correlations expand the geographic range of inferred individual outflow sheets by up to 25 percent, particularly in the cases of ash-flow tuffs 5, 6 and 7. Ash-flow tuff 5 is equated to the Kneeling Nun Tuff, which was derived from the Emory cauldron. Ash-flow tuff 6 is correlated with the Box Canyon Tuff, the source of which was probably the Schoolhouse Mountain cauldron, approximately 150 km west-northwest of the GCH basin. Ash-flow tuff 7, which is the distal part of the Vicks Peak Tuff, erupted from the Nogal Canyon cauldron, located about 100 km north of the GCH basin. However, uncertainties remain regarding these correlations, especially with respect to ash-flow tuffs 5 and 6. Mineralogic and geochemical data are needed to test existing correlations.

Syneruption, tuffaceous sandstones of the Bell Top Formation in the GCH half graben also provide potentially important information about the history of the Mogollon-Datil volcanic field. Tuffaceous sandstones, which represent reworked fallout tephra, record Plinian-type eruptions that occurred contemporaneous with or between ignimbrite-generating events. These sandstones may have been related to major ignimbrite events or to eruptions that did not generate major ignimbrite sheets, but rather generated fallout tephra, which was reworked as tuffaceous sandstones in the GCH basin. Systematic radiometric dating and geochemical analyses of the tuffaceous sandstones will probably be required to fully understand their significance to the evolution of the Mogollon-Datil volcanic field.

IMPLICATION TO EVOLUTION OF THE SOUTHERN RIO GRANDE RIFT

The interpretation of the GCH basin as a half graben has important implications to the evolution of the southern Rio Grande rift. The GCH half graben may be an indicator of regional crustal extension, because it does not appear to be spatially or temporally related to caldera development, although the half graben periodically received ash-flow tuffs and fallout tephra from extrabasinal sources. The asymmetrical distribution of lithofacies of the Middle and Upper Sedimentary Members of the Bell Top Formation and their correlatives suggests that the half graben had already developed at the time of or immediately after eruptions of ash-flow tuff 5 / Kneeling Nun Tuff at about 35 Ma. The interpretation of Seager (1973, 1975) that the flow-banded rhyolite domes of the Cedar Hills vent zone, which are roughly coeval with ash-flow tuff 3 (Fig. 3), were emplaced along a fault or fault zone may indicate that extension began about a million years before eruption of ash- flow tuff 5 / Kneeling Nun Tuff. This idea cannot easily be tested by sedimentologic data, however, because Bell Top sedimentary rocks older than ash-flow tuff 5 are poorly exposed and restricted to the southern part of the study area.

Interpretation of the initiation of regional extension at approximately 35 Ma is 2 to 7 million years older than previous interpretations of the onset of extension in the southern and central Rio Grande rift (Chapin and Seager, 1975; Seager et al., 1984; Newcomer and Giordano, 1986). However, the interpretation presented here corresponds closely to the recent model of Cather (1986, 1990) and Cather and Chapin (1989), who suggested that the change from regional Laramide compression to extension in the central Rio Grande rift occurred at about 36 Ma, based on displacement reversals across relict Laramide fault zones and the change from intermediate to bimodal volcanism.

Interpretation of paleostress orientation during development of the GCH half graben is not possible because the boundary fault is not exposed. It does seem safe to say, however, that the GCH half graben does not represent reactivation of Laramide structures. The axis of GCH half graben is almost perpendicular to the west-northwest-trending late Laramide Rio Grande uplift and complementary Love Ranch basin in the same region (Seager, 1983; Seager and Mack, 1986; Seager et al., 1986). It also appears clear, based on the lack of exposure of pre-Eocene rocks in the hanging wall and footwall uplifts and relatively slow sediment accumulation rates (maximum, uncompacted rate of 40 m/Ma), that extension rates were probably not rapid during development of the half graben.

CONCLUSIONS

The Oligocene Goodsight-Cedar Hills basin in south-central New Mexico is interpreted to have been an eastward-tilted half graben, in which several hundred meters of ash-flow tuffs, syneruption tuffaceous sandstones and post-eruption conglomerates of the Bell Top Formation were deposited. Exposed in the footwall of the half graben were flow-banded rhyolite domes of the Cedar Hills vent zone, whereas exposures in the hanging wall, referred to as the Ancestral Goodsight uplift, consisted primarily of Eocene andesitic rocks and locally in its northern part of Eocene synorogenic conglomerates.

The GCH half graben is an important component of the Mogollon-Datil volcanic field, not only because regional ignimbrite outflow sheets accumulated within it, but because syneruption, tuffaceous sandstones, which represent reworked fallout tephra, may provide a record of explosive volcanism that occurred during or between other major ignimbrite-generating events. Regional crustal extension responsible for development of the half graben began about 35 Ma, 2 to 7 Ma earlier than previous interpretations of the onset of crustal extension in the southern Rio Grande rift.

ACKNOWLEDGMENTS

W.C. James, E. Timothy Wallin, Steven M. Cather and Richard M. Chamberlin read an earlier version of this manuscript and made helpful suggestions for its improvement.

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