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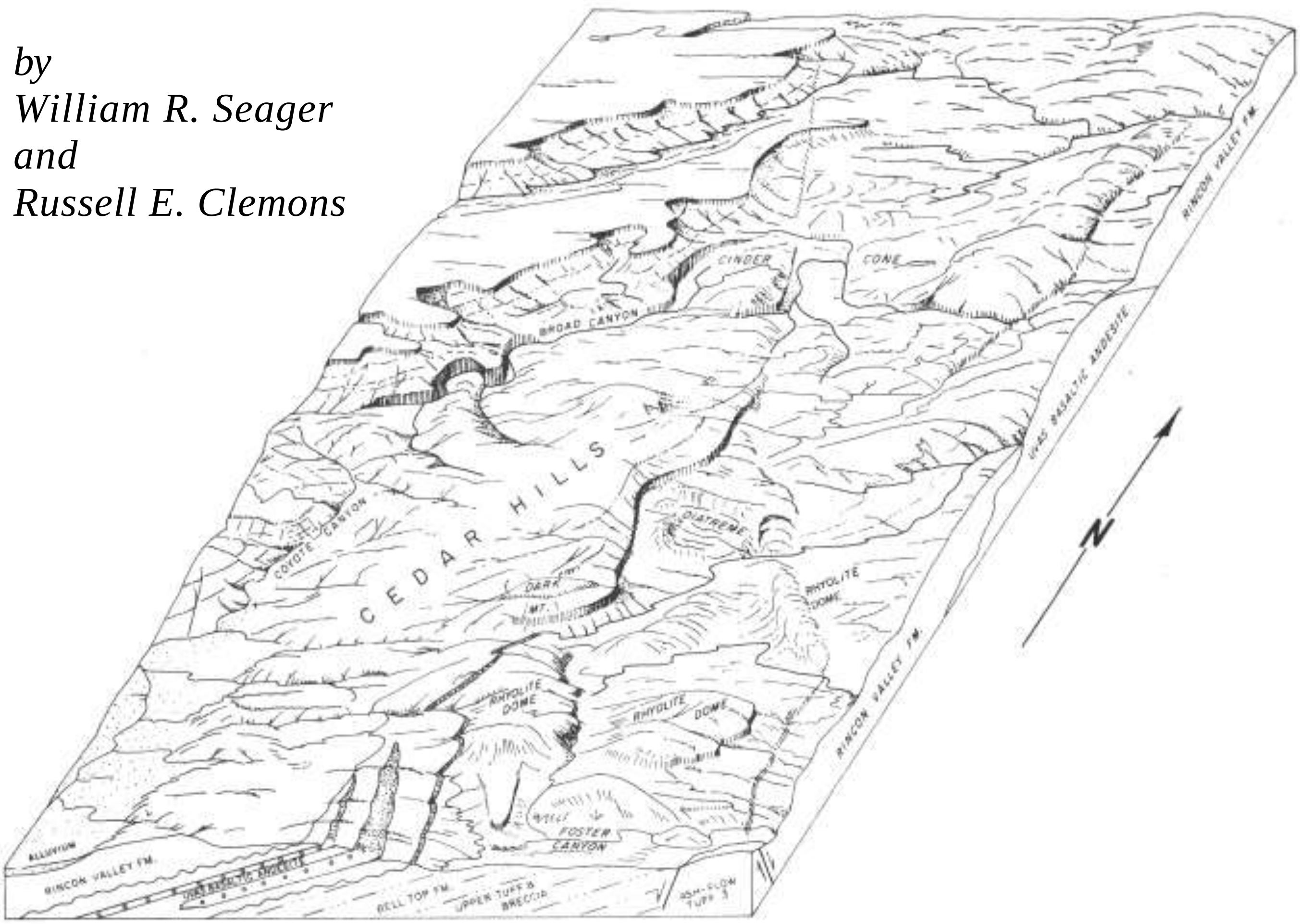
MIDDLE TO LATE TERTIARY GEOLOGY OF CEDAR HILLS-SELDEN HILLS AREA, NEW MEXICO

by
William R. Seager
and
Russell E. Clemons



New Mexico Bureau of Mines & Mineral Resources

A DIVISION OF
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Preface

Our investigation of the geology of the Cedar Hills-Selden Hills area had three objectives. The first was to interpret the geology of the Oligocene-Miocene Cedar Hills vent zone. A variety of volcanic and subvolcanic features in various stages of erosion are well exposed. These include rhyolite domes, cinder and tuff cones, probable ignimbrite dikes, collapsed areas, and a possible diatreme—all formed along the eastern border of a broad volcano-tectonic depression. The internal structure of these features, their relationship to surface flows, and the magmatic evolution depicted can be interpreted from structural, stratigraphic, and chemical relationships. These features may be of value in recognizing similar vent zones in other ancient volcanic complexes in the Southwest or elsewhere.

The second objective was to point out evidence (from the vent zone area) that helps in dating the beginning of Rio Grande rifting in southern New Mexico. We suggest that certain middle Oligocene volcano-tectonic features were precursors of the rift, and will discuss the possibility that the change from Oligocene volcanism to late Tertiary rifting was entirely transitional, culminating in active block faulting during the Miocene, and especially the Pliocene. These data will relate importantly to timing of rifting in models of Tertiary plate tectonics of the western United States.

The third objective was to summarize evidence (from the Cedar Hills-Selden Hills and adjacent areas) relating to evolution of the Rio Grande rift during the Miocene-Pliocene. This phase involves interpretation of Santa Fe strata and their relation to paleobasins and paleouplifts, as well as to modern uplifts and basins of the rift zone.

The importance of this area in terms of Tertiary tectonics was recognized following detailed mapping of several 7 1/2- and 15-minute quadrangles from 1967 to 1974; most of that work is published, in press or in open-file (Seager, Hawley and Clemons, 1971; Clemons and Seager, 1973; Seager and Clemons, 1975; Seager, Clemons and Hawley, in press; Seager, in press; Clemons, in press; and Kottlowski, Seager and Hawley, in preparation). These reports are part of a broader project involving systematic mapping from Hatch to Las Cruces (fig. 1, following page).

The New Mexico Bureau of Mines & Mineral Resources supported our mapping efforts between Las Cruces and Hatch. The Bureau also provided numerous thin sections, K-Ar dates, and chemical analyses. We particularly wish to thank Frank E. Kottlowski, Director of the Bureau for his interest and help in the project. Special thanks are due John W. Hawley of the Soil Conservation Service, and C. E. Chapin of the Bureau for valued counsel on late Tertiary geology. We also thank 0. W. Preece of Radium Springs for allowing access to his mining claims in the Cedar Hills. The illustration on cover is by Neila Pearson after a sketch done by C. B. Hunt.

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January, 1975

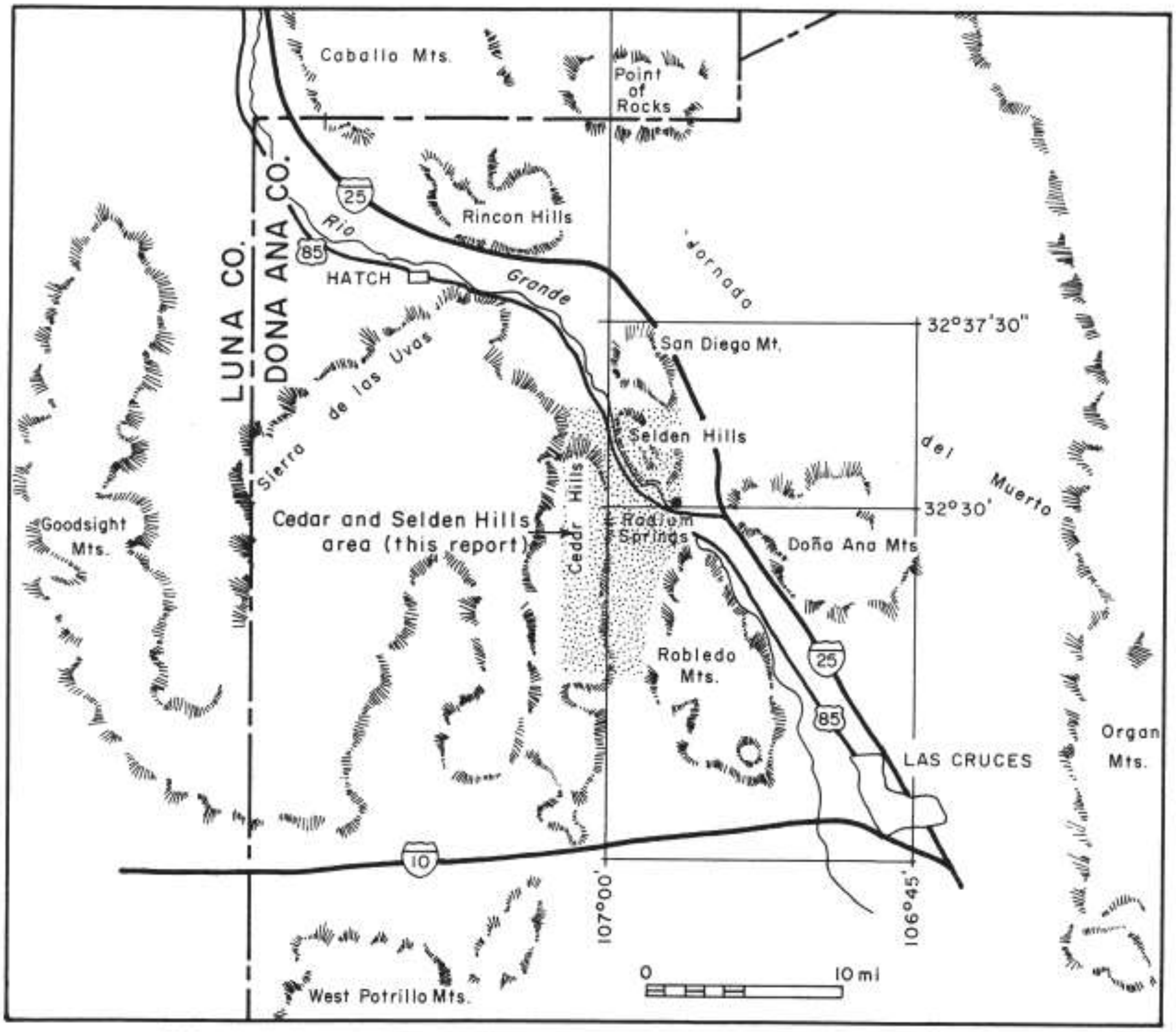

FIGURE 1—MAP SHOWING PROGRESS IN MAPPING, NORTHERN DOÑA ANA COUNTY, NEW MEXICO.

Contents

ABSTRACT **7**

INTRODUCTION **7**

TECTONIC SETTING **7**

CEDAR HILLS VENT ZONE **9**
- GENERAL **9**
- PRE-OLIGOCENE ROCKS **9**
- BELL TOP FORMATION **9**
  - Basalt Member **9**
  - Lower Tuff and Breccia **11**
  - Tuff 3 **12**
  - Upper Tuff, Breccia, and Andesite **12**
  - Flow-banded Rhyolite and Rhyolite Porphyry **12**
  - Bell Top Rocks Younger Than Vent Zone **13**
- STRUCTURAL FEATURES **13**
  - Intrusive Tuff 3 **13**
  - Diatreme at Porcupine Tank **14**
  - Collapsed Area at Foster Canyon **14**
  - Rhyolite Domes **14**
  - Oligocene (?) Faults **15**
- SUMMARY AND CONCLUSIONS **15**

ANDESITE INTRUSIONS OF FAULKNER CANYON **16**

RIO GRANDE RIFT **16**
- UVAS BASALTIC ANDESITE **16**
- SANTA FE GROUP **17**
- SUMMARY AND CONCLUSIONS **18**

REFERENCES CITED **20**

APPENDIX A—Petrographic Summaries **21**

APPENDIX B—Cedar Hills Section **22**

FIGURES

1—Progress map iv
2—Index map vi
3—Structure map **8**
4—Cross section of Cedar Hills vent zone area **9**
5—Stratigraphic section near Foster Canyon **11**
6—Distribution and thickness of ash-flow tuff 3 **12**
7—Diagrammatic section of Bell Top vents **13**
8—View of rhyolite dome, Dark Mountain **14**
9—View of rhyolite dome, south of Foster Canyon **14**
10—Structure map and section, rhyolite dome **15**
11—View of Broad Canyon area **16**
12—View of Coyote Canyon fanglomerate member **16**
13—Early to middle Miocene intrarift basin **17**
14—Late Miocene-early Pliocene intrarift basins **19**

TABLES

1—Rocks in Cedar Hills-Selden Hills area **10**
2—Chemical analyses of Tertiary rocks **11**

REAR POCKET

Tectonic map
Cross sections

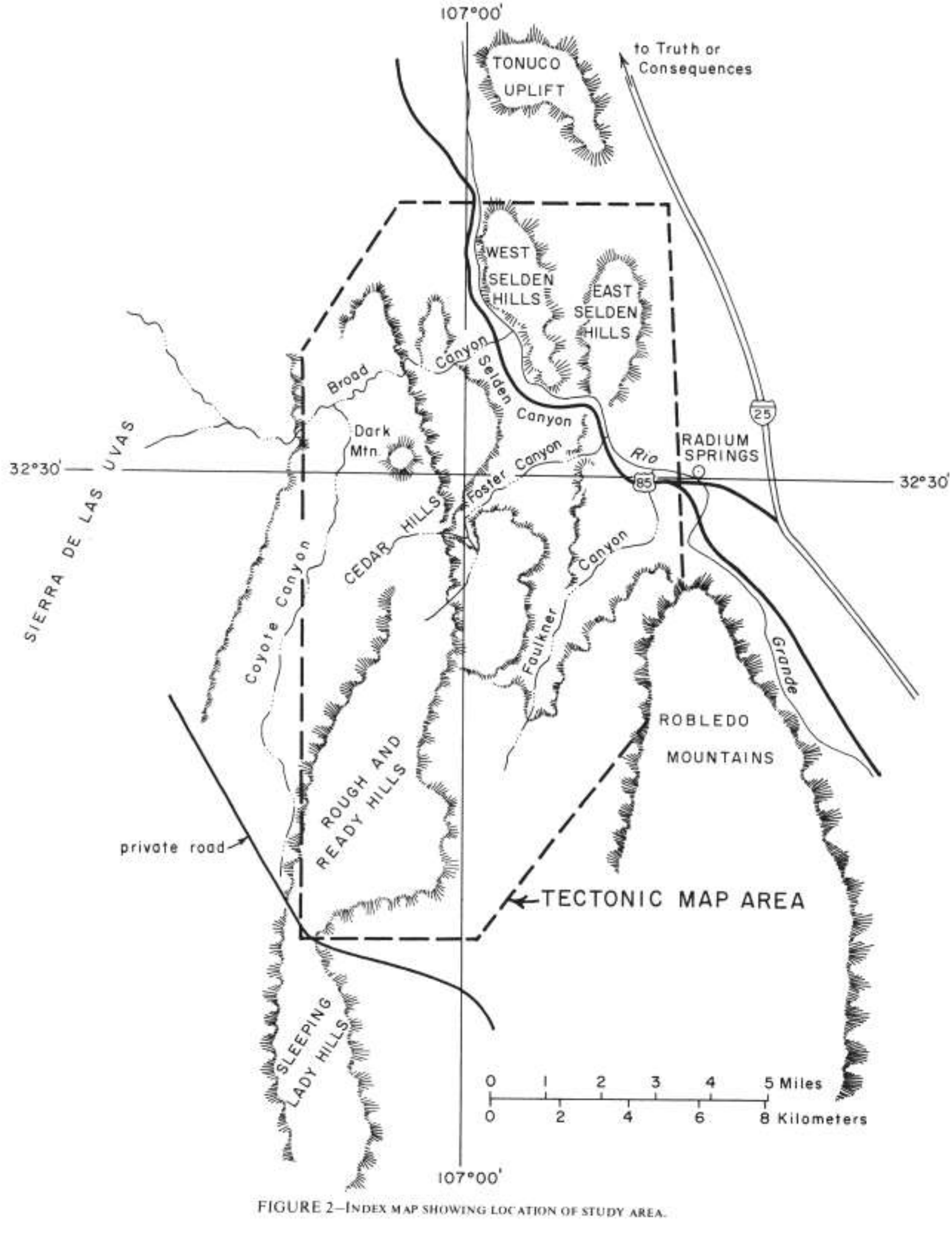

FIGURE 2—Index map showing location of study area.

Abstract

Rocks in the Cedar Hills and Selden Hills provide an excellent record of 1) Oligocene volcanism in the Cedar Hills vent zone, 2) the timing of initial rifting in the Rio Grande rift, and 3) the Miocene-Pliocene evolution of the rift. Volcanic activity in the Cedar Hills vent zone about 35 m.y. ago was concentrated along a north-trending zone at least 20 miles long and as much as 4 miles wide. Initial rhyolitic tephra eruptions were closely followed by emplacement of an ash-flow tuff sheet from fissures within the vent zone, and by the formation of tuff cones, diatremes, and collapsed areas. Volcanic activity in the zone was climaxed by the intrusion of at least 21 flow-banded rhyolite intrusions. The vent zone, together with other north-trending Oligocene faults and basins, all generally parallel to the Rio Grande rift, suggest that these features may be precursors of the rift.

The transition into active faulting within the Rio Grande rift is marked by outpouring of Uvas Basaltic Andesite (26 m.y.). Initial rifting is indicated by eruption of basaltic andesite from a cinder cone constructed across the Cedar Hills fault, one of the large, through-going rift faults of the region. The interfingering of basaltic andesite flows with fanglomerate derived from the uplifted block suggests rifting was in progress at least 26 m.y. ago.

Late Tertiary evolution of the rift is characterized by the development of deep, broad downwarps in Miocene time that were filled with bolson deposits, and then segmented into smaller intrabasin uplifts and grabens in Pliocene time. Many of the uplifts of the region appear to have formed initially in Pliocene time, while others originated as early as earliest Miocene or latest Oligocene.

Introduction

The Cedar Hills vent zone is located within the Cedar Hills and the Rough and Ready Hills in west-central Dona Ana County, New Mexico (fig. 2). The area shown on the tectonic map (in pocket) is about 20 miles northwest of Las Cruces, and encompasses about 100 square miles of canyon, badland, and hill country west of Radium Springs (comprising parts of the Corralitos Ranch, Las Cruces, and San Diego Mountain 15-minute quadrangles, and Sierra Alta 7 1/2-minute quadrangle).

Access through the northeastern part of the area is provided by US-85, which follows the Rio Grande through Selden Canyon. Jeep trails are scattered throughout the Cedar Hills and are accessible from Faulkner or Selden Canyon. Access north of the Rio Grande is limited to a few jeep trails starting at the resort in Radium Springs on the east side of the river.

Tectonic Setting

The Cedar Hills vent zone is located along the eastern margin of the Goodsight-Cedar Hills depression (fig. 3), a broad, shallow volcano-tectonic sag of Oligocene age (Seager, 1973). The depression is filled with ash-flow tuff and epiclastic sediments of the Bell Top Formation and basaltic flows of the Uvas Basaltic Andesite (Kottlowski, 1953; Clemons and Seager, 1973). The regional stratigraphic and structural relations between the depression and the Cedar Hills vent zone are shown in fig. 4 on page 9. At least one of the Bell Top ash flows and several of the Uvas flows were erupted from the vent zone.

Superimposed across the Goodsight-Cedar Hills depression are late Tertiary high-angle normal faults of the Rio Grande rift (Kelley and Silver, 1952; Kelley, 1955; Chapin, 1971). Uplift and erosion along these faults exposed the volcanic fill of the depression, together with vent rocks and structures of the Cedar Hills vent zone. Bolson sediments, derived from the fault blocks, form the bulk of the Santa Fe Group (Miocene to Pleistocene) that filled the intrarift grabens.

The Goodsight-Cedar Hills depression, and the Cedar Hills vent zone and associated faults all trend northerly, parallel to the younger Rio Grande rift. These volcano-tectonic features may be precursors of the Rio Grande rift in this area, and reflect a local or regional east-west extension already present during the Oligocene. On the other hand, the northerly trend may be inherited from an older Laramide structural grain. Normal faulting associated with earliest stages of rifting appears to have begun about 26 m.y. ago in the region as suggested by fanglomerate interbedded in Uvas Basaltic Andesite.

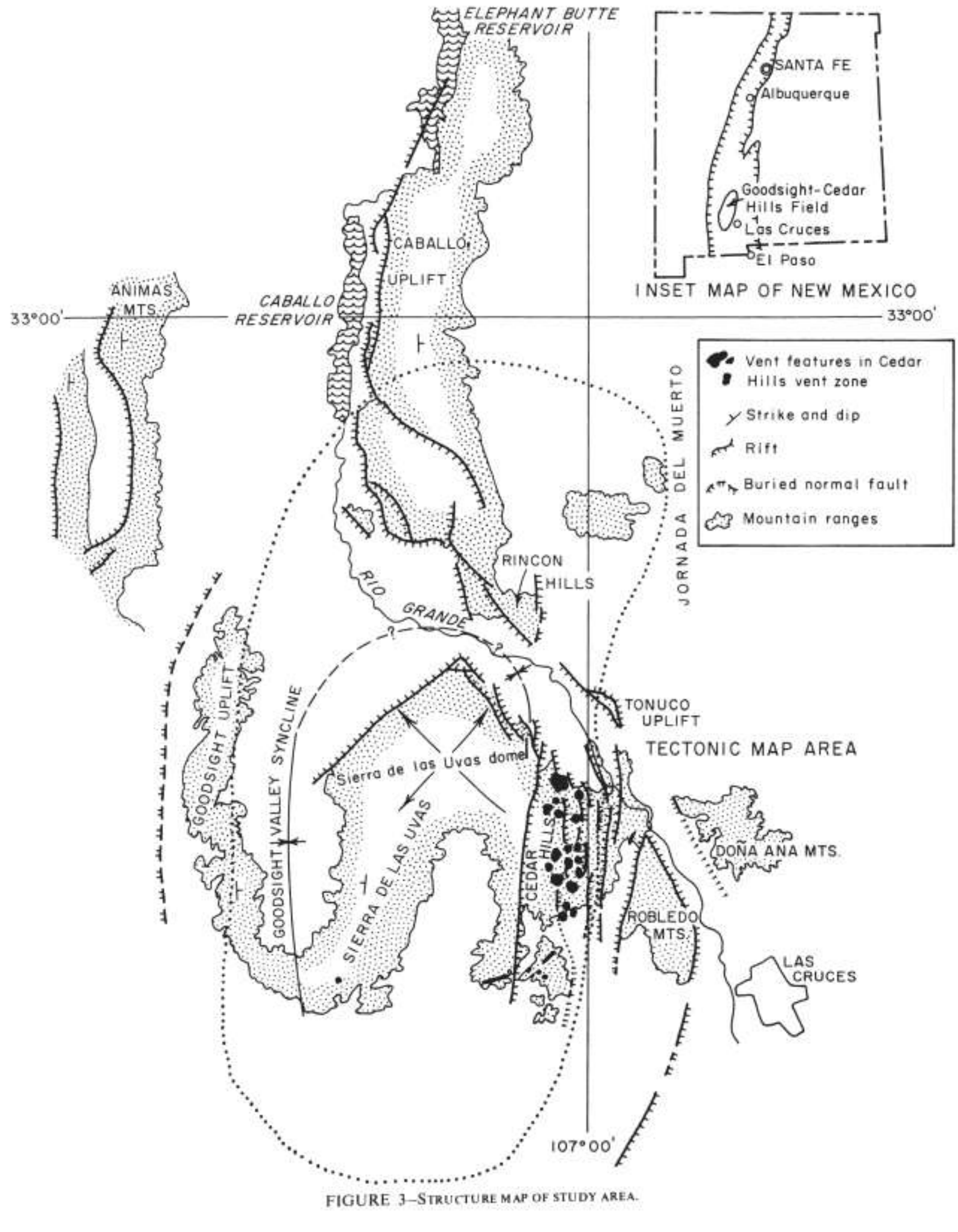

FIGURE 3—Structure map of study area.

Cedar Hills Vent Zone

GENERAL

Rock units exposed in the map area range in age from Silurian to Holocene, approximately 4,000 ft in total thickness. Emphasis will be given to Oligocene and earliest Miocene rock units and structures, particularly those genetically related to the Cedar Hills vent zone, or critical to interpretation of the evolution of late Tertiary rifting. More detailed accounts of pre-Oligocene, late Tertiary (Santa Fe), and Quaternary units can be found elsewhere (Clemons and Seager, 1973; Seager and Hawley, 1973; Seager, Clemons, and Hawley, in press). Table 1 emphasizes Tertiary stratigraphy in the area; lithologic and petrographic descriptions of volcanic rock units are presented in Appendix A.

PRE-OLIGOCENE ROCKS

In the map area, Precambrian rocks are not exposed and Paleozoic strata are represented only by a small slide block of Fusselman Dolomite and Oñate Formation in the East Selden Hills. Paleozoic rocks crop out in the Robledo Mountains outside the map area. El Paso, Montoya, Fusselman, Percha, Caballero, Magdalena Group, Bursum, Hueco, and Abo strata are well exposed. Presumably these units with the Bliss, are generally present in the subsurface of north-central Doña Ana County. In the Cedar Hills-Selden Canyon area, however, the Pennsylvanian and Permian systems are probably missing due to Laramide uplift and erosion (Seager, in press).

In uplifts adjacent to the map area, early Tertiary (?) strata are represented by the Love Ranch Formation (Kottlowski and others, 1956; Seager and others, 1971), a fanglomerate to basin sequence probably derived from Laramide uplifts. The unit is probably discontinuously present in the subsurface of the Cedar HillsSelden Hills area.

Eocene rocks of the Palm Park Formation (Kelley and Silver, 1952) overlie the Love Ranch and crop out widely in Faulkner Canyon, Selden Canyon, and Cedar Hills. These rocks have been described by Seager, Hawley, and Clemons (1971); Seager, Clemons and Hawley (in press); and Seager (in press). Typical Palm Park includes epiclastic andesitic rocks, mainly of laharic origin, but including fluvial, basin-floor, and piedmont toe-slope facies as well as small subvolcanic sills, dikes, and minor flows. Ash, crystals, and several varieties of andesite porphyry clasts comprise the bulk of the epiclastic facies. Sources of the epiclastic or igneous rocks are not known. Thicknesses are generally about 2,000 ft, although varying appreciably due to pre-Palm Park topography. Potassium-argon dates from several plutons and flows range from 42 to 51 m.y. and are summarized in table 1. The Palm Park Formation and its correlative Rubio Peak Formation (Elston, 1953 and 1957) form the floor of the Goodsight-Cedar Hills depression.

BELL TOP FORMATION

Stratigraphic relationships among Bell Top units are shown in fig. 4. Figure 5 is a larger scale diagram illustrating Bell Top units in the Cedar Hills. Bell Top strata originating in the Cedar Hills vent zone include: 1) lower tuffs and breccia, 2) ash-flow tuff 3, 3) upper air-fall and epiclastic deposits, 4) flow-banded rhyolite domes and flows. Collectively the four units comprise a westward-tapering wedge underlain by older Bell Top flows and overlapped unconformably by younger Bell Top ash-flow tuffs or Uvas Basaltic Andesite. The sources of the rocks above or below the wedge are not known, but apparently they are not related to the Cedar Hills vent zone. A measured section of Bell Top and Uvas units is presented in Appendix B.

BASALT MEMBER

Basaltic flows and interbedded sandstone discontinuously overlie the Palm Park Formation in the Cedar

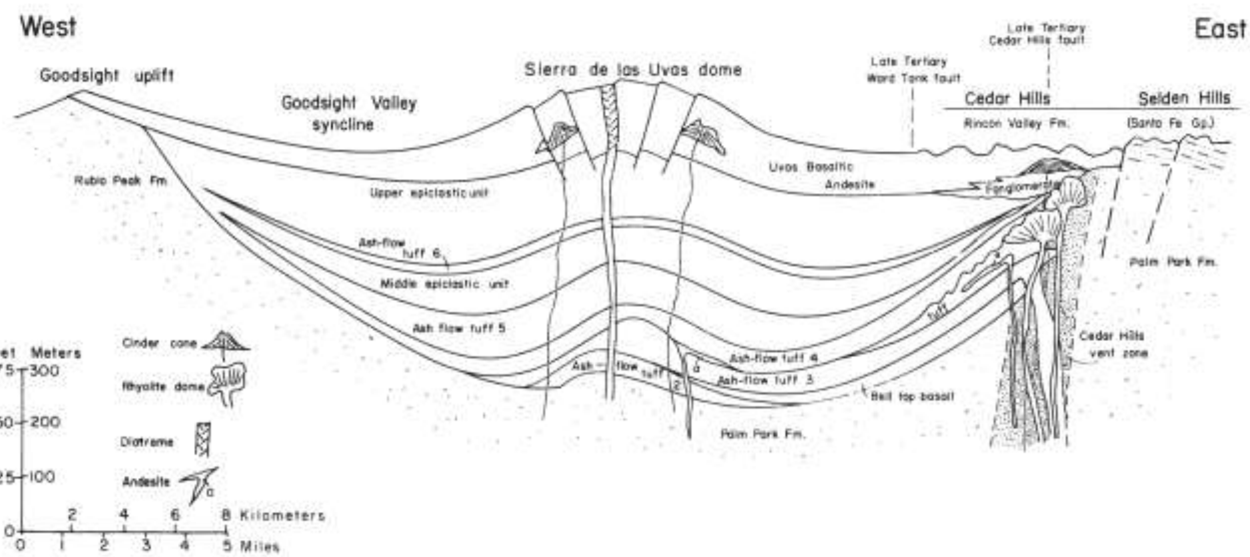

FIGURE 4—West-east diagrammatic cross section of Goodsight-Cedar Hills depression; effects of late Tertiary faulting removed. Reprinted by permission from Geological Society of America Bulletin, v. 84, p. 3614.

TABLE 1—Rocks in the Cedar Hills-Selden Hills area

Age	Radiometric dates	Rock units	Maximum thickness (ft)	Characteristics
QUATERNARY		Alluvium	10	Stream, flood plain, alluvial fan gravels, wind-blown sand, and colluvium
QUATERNARY		SANTA FE GROUP: Camp Rice Formation	100	Fluvial sandstone and gravel, and caliche-cemented piedmont-slope gravels
LATE MIOCENE	9 m.y.[1]	SANTA FE GROUP: Rincon Valley Formation	500	Fanglomerate, sandstone, conglomeratic sandstone, claystone and gypsiferous siltstone. Contains an olivine basalt flow (Selden Basalt) in Selden Canyon
		LOCAL ANGULAR UNCONFORMITY		
MIOCENE		SANTA FE GROUP: Hayner Ranch Formation	1900	Red sandstone, conglomeratic sandstone, and conglomerate
MIOCENE		SANTA FE GROUP: Transitional unit	1650	Bright red siltstone, conglomeratic sandstone, and shale in lower half; brown to purple conglomerate, conglomeratic sandstone and mudstone in upper half
OLIGOCENE	26 m.y.[2]	Uvas Basaltic Andesite and Coyote Canyon fanglomerate member	800±	Gray to black, platy, vesicular to amygdaloidal basaltic andesite flows, tuff and agglomerate; interbedded with brown conglomerate, sandstone, and mudstone derived from flow-banded rhyolite domes
OLIGOCENE	31.5 m.y.[5]	Andesite of Faulkner Canyon		Dark gray to black andesite dikes and plugs
OLIGOCENE	35 m.y.[2] 34 m.y.[3]	BELL TOP FORMATION: Ash-flow tuff 5		Tan to light gray crystal-vitric ash-flow tuff containing abundant pumice lumps
OLIGOCENE		BELL TOP FORMATION: Ash-flow tuff 4		Grayish-purple to brown welded vitric-crystal ash-flow tuff with dark, devitrified, flattened pumice fragments to 1 ft in diameter
OLIGOCENE		BELL TOP FORMATION, Cedar Hills Rhyolite Complex: Flow-banded rhyolite and rhyolite porphyry		Pink to gray flow-banded rhyolite and associated vitrophyre. Cream-colored to pink rhyolite porphyry is present in Faulkner Canyon, Selden Hills, and Robledo Mountains
OLIGOCENE		BELL TOP FORMATION, Cedar Hills Rhyolite Complex: Upper tuff and breccia	800	White to tan rhyolitic air-fall tuff and breccia, with epiclastic sandstone; locally opalized
OLIGOCENE	33 m.y.[4]	BELL TOP FORMATION, Cedar Hills Rhyolite Complex: Vesicular andesite	50±	Dark-gray to black vesicular andesite flows and dikes
OLIGOCENE	33 m.y.[4]	BELL TOP FORMATION, Cedar Hills Rhyolite Complex: Ash-flow tuff 3	300	Pink to orange, porous, vitric ash-flow tuff containing 20 percent pumice. Widespread as a flow in Sierra de las Uvas, but almost entirely intrusive in northern Cedar Hills
OLIGOCENE	33 m.y.[4]	BELL TOP FORMATION, Cedar Hills Rhyolite Complex: Lower tuff and breccia	200	White to tan, purple or red rhyolitic air-fall breccia and tuff, locally opalized. Restricted to Cedar Hills
OLIGOCENE	33 m.y.[4]	BELL TOP FORMATION: Basalt	130	Black olivine-bearing basalt flows
EOCENE	39 m.y.[4]	BELL TOP FORMATION: Ash-flow tuff 2	100	Pale-purple to tan welded vitric ash-flow tuff with well-developed microscopic eutaxitic texture; known only from Sierra de las Uvas
EOCENE	51 m.y.[4] 43 m.y.[3] 42 m.y.[4]	Palm Park Formation	100-3000	Purple, red, tan, gray andesitic sandstone, mudstone, breccia and conglomerate. Minor andesite porphyry flows, and subvolcanic plutons
EOCENE		Love Ranch Formation	200	Boulder conglomerate, and red sandstone, and siltstone derived from Paleozoic or Precambrian rocks; locally grades up into Palm Park Formation.
		ANGULAR UNCONFORMITY		
PALEOZOIC		Not exposed except for small slide block of Silurian and Devonian in East Selden Hills		

1. Gile, and others, 1970; F. E. Kottlowski, letter, 1970
2. F. E. Kottlowski, letter, 1970
3. Kottlowski and others, 1969
4. Kottlowski, letter, 1972
5. Kottlowski, letter, 1974

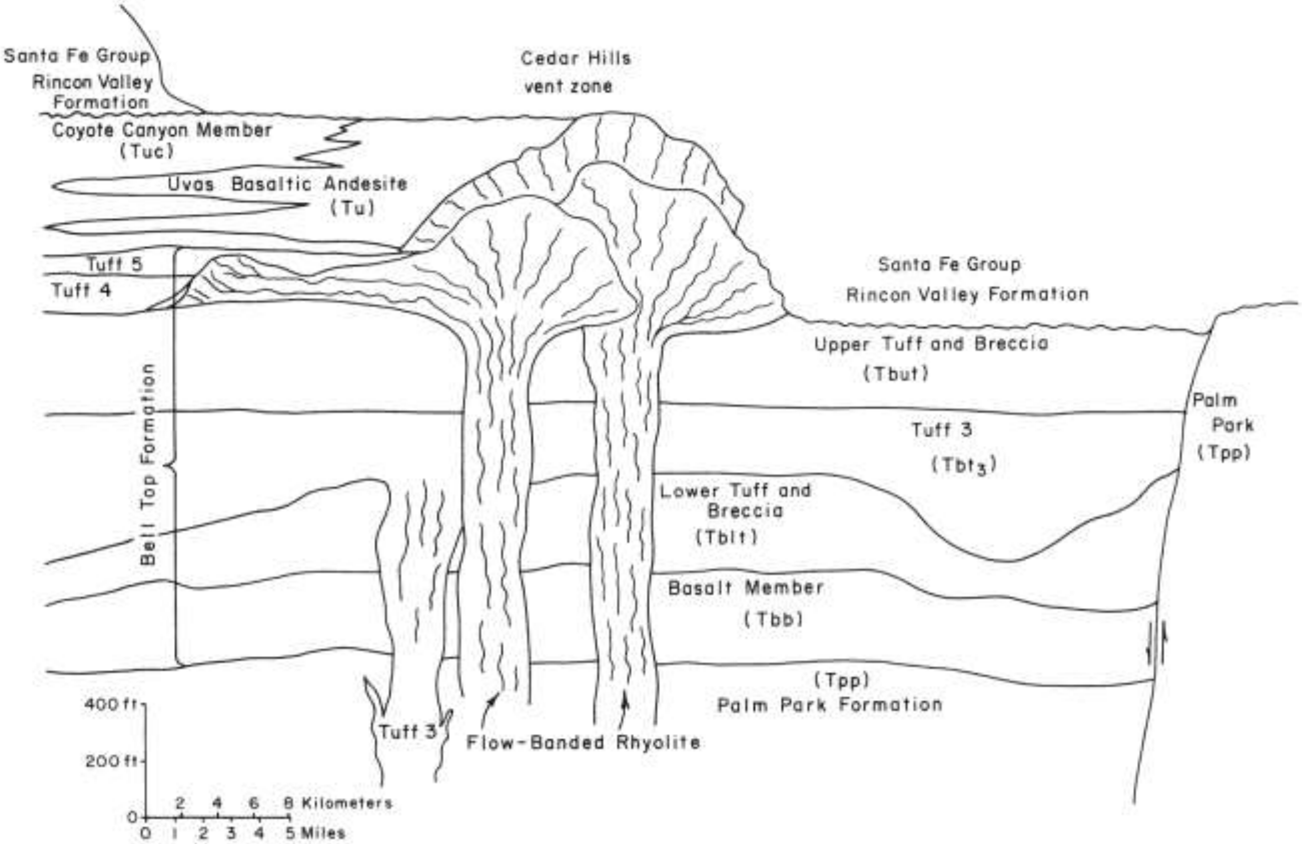

FIGURE 5—West-east stratigraphic section near Foster Canyon, Cedar Hills.

Hills area. In the Sierra de las Uvas the flows are interbedded between tuff 2 and tuff 3, hence part of the Bell Top Formation. Thickness ranges up to 150 ft; individual flows are from 10 to 50 ft thick, scoriaceous, dark gray, and dense. The basalt is between 39 and 35 m.y. old (table 1), apparently the oldest known Tertiary basalt in New Mexico (W. E. Elston, personal communication, 1973). Their source is unknown. A chemical analysis is shown in table 2; petrographic description is given in Appendix A.

Lower Tuff and Breccia

The lower tuffs represent initial volcanic activity in the Cedar Hills vent zone about 35 to 36 m.y. ago, and heralded eruption of ash-flow tuff 3. Throughout most of the Cedar Hills region the tuffs are only 50 to 70 ft thick and consist mainly of white air-fall ash overlying the basalt member or the Palm Park Formation. Locally, the tuffs contain large quantities of pumice and grade into overlying tuff 3 deposits. Coarsest accumula-

TABLE 2—Chemical analyses of Tertiary rocks, Cedar Hills-Selden Hills area

	Location	Rock unit	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Loss	Total
	Bell Top Mtn., C. sec. 11, T. 21 S., R. 3 W.	Bell Top Basalt	48.5	2.54	15.9	12.3	1.76	6.23	7.84	2.9	1.0	.95	1.90	101.82
Cedar Hills type	SW¼ sec. 13, T. 21 S., R. 2 W.	Flow-banded rhyolite	73.4	.16	13.2	.57	.021	.03	.17	4.0	5.5	1.05	.49	97.591
Cedar Hills type	NE¼ sec. 21, T. 22 S., R. 2 W.	Flow-banded rhyolite	70.8	.272	13.6	.86	.028	.13	.28	4.2	5.2	1.05	.43	95.850
Cedar Hills type	NE¼ sec. 21, T. 22 S., R. 2 W.	Flow-banded rhyolite	72.9	.276	14.3	.86	.023	.20	.14	4.8	5.4	1.05	.37	99.919
Robledo type	Sec. 27, T. 22 S., R. 1 W.	Rhyolite porphyry	73.37	.35	13.39	1.27	.02	.57	.21	.68	7.04	.07	—	96.970
	NW¼ sec. 8 T. 20 S., R. 3 W.	Uvas Basaltic Andesite (base)	53.1	1.14	16.4	7.0	.083	2.59	5.60	3.1	1.5	.95	1.57	93.033
	SW¼ sec. 17, T. 20 S., R. 3 W.	Uvas Basaltic Andesite (top)	57.5	.94	16.7	6.0	.09	2.62	4.81	3.7	2.4	.70	1.02	96.48

tions of the lower tuff is present along the northern rim of the diatreme at Porcupine Tank. Here bedded rhyolite pebble breccia and tuff, containing many Palm Park clasts, is variably opalized and perhaps 200 ft thick. The unit appears to be intruded by tuff 3 at this locality.

TUFF 3

Overlying or locally intruding the lower tuff is ash-flow tuff 3. In both the Sierra de las Uvas, where the unit is as much as 300 ft thick, and in the Cedar Hills, the tuff appears to be a single flow. Generally, the pink to orange ash-flow tuff is poorly to moderately welded and contains as much as 90 percent devitrified glass, including abundant uncollapsed pumice. A single K-Ar date from the tuff yielded an age of 33.4 m.y., an anomalously young date. Radiometric dating of stratigraphically younger tuffs and intrusives suggest that tuff 3 more likely is approximately 35 to 38 m.y. old (table 1). On the basis of chemical and petrographic similarities with overlying flow-banded rhyolite, dated 35 m.y., we consider the tuff and rhyolite to be comagmatic, approximately 35 m.y. old.

The source of the ash-flow tuff is probably the Cedar Hills vent zone. Accidental and essential lithic fragments, 1 to 5 cm in diameter, are abundant in the tuff of the vent zone area, together with variable, but locally intense welding and alteration. The tuff is typically fine grained in the vent zone area. Intrusive masses of tuff 3 appear to be present in the Porcupine Tank and Foster Canyon areas. Other tuff 3 vents may be occupied by the rhyolite domes. The distribution and thickness of the tuff with respect to the Cedar Hills vent zone is shown in fig. 6. The southern limit of the tuff is unknown. The comparatively thin deposits of tuff 3 over the vent zone compared to adjacent areas in the Sierra de las Uvas is attributed to greater subsidence along the axis of the Goodsight-Cedar Hills depression.

UPPER TUFF, BRECCIA, AND ANDESITE

Continuing tephra eruptions in the vent zone resulted in deposition of 200 to 800 ft of rhyolitic air-fall tuff, breccia and associated epiclastic sediments above ash-flow tuff 3. These deposits appear to represent vent-clearing explosive activity preceding emplacement of rhyolite domes. Angular blocks of vesicular andesite, flow-banded rhyolite, ash-flow tuff 3, Palm Park clasts, and Paleozoic limestone comprise much of the breccia in the lower parts of the deposits, while ash, cross-bedded epiclastic sediment, and pumiceous vitrophyre tuff beds are widespread in the upper parts.

Locally the upper breccia and tuff beds are clearly related to vent features. Near Porcupine Tank the air-fall strata form a tuff and breccia cone centered on a circular collapsed area 0.4 mile in diameter. The feature has many of the aspects of a diatreme, including a ring dike of brown vesicular andesite, and is further described under structural features. Stratigraphic relations within the diatreme are shown in fig. 7. In Foster Canyon unusually thick (800 ft ±) tuff and breccia beds form the floor of a sunken block, and contain welded, brecciated slabs of the basalt and tuff 3 members of the

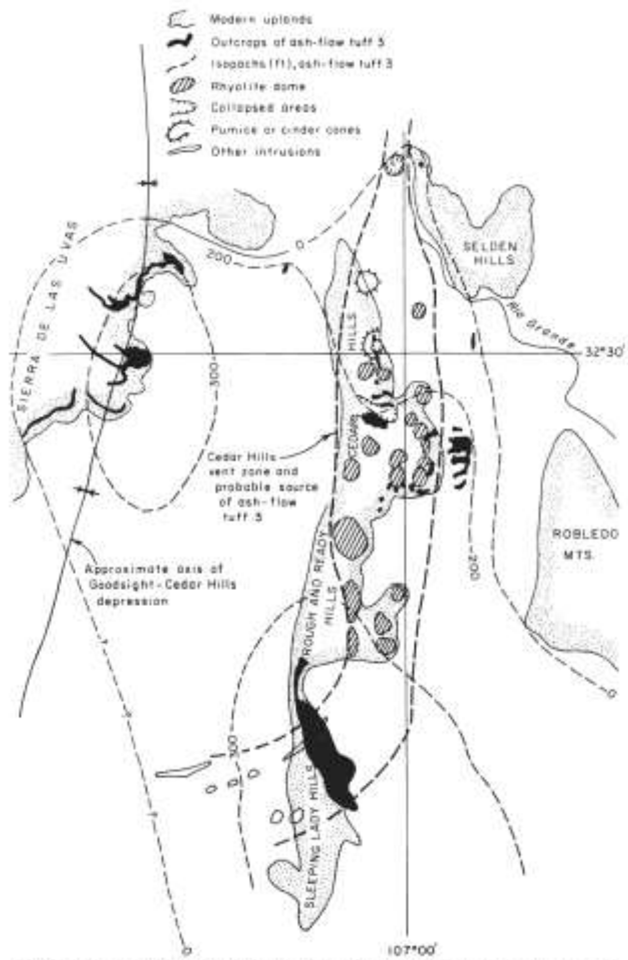

FIGURE 6—Distribution and thickness of ash-flow tuff 3.

Bell Top Formation. The slabs are 10 to 100 ft long and are concordant with bedding in air-fall breccia. They are thought to be slide blocks derived from adjacent rims or walls of the sunken area. Large quantities of Paleozoic limestone clasts in the breccia in this area, as well as the great thickness of air-fall deposits, suggest explosive eruption of tephra and accidental blocks concurrent with subsidence of the block.

Outcrops between Foster Canyon and Dark Mountain show that eruption of the upper tuff and breccia beds was closely followed by emplacement of gray flow-banded vitrophyre and stoney, pink to gray rhyolite in the form of domes and flows.

FLOW-BANDED RHYOLITE AND RHYOLITE PORPHYRY

Culmination of Oligocene volcanic activity in the Cedar Hills vent zone resulted in emplacement of two lithologically and chemically distinctive types of rhyolite. The Cedar Hills type occurs throughout the Cedar Hills vent zone in the form of domes and flows that intrude or overlie the upper air-fall deposits just described. The Robledo type occurs only as intrusions east of Faulkner Canyon in a belt extending southward from the East Selden Hills through the Robledo Mountains.

Rhyolites of the Cedar Hills type are flow-banded, gray, yellow or pink varieties, locally spherulitic, becom-

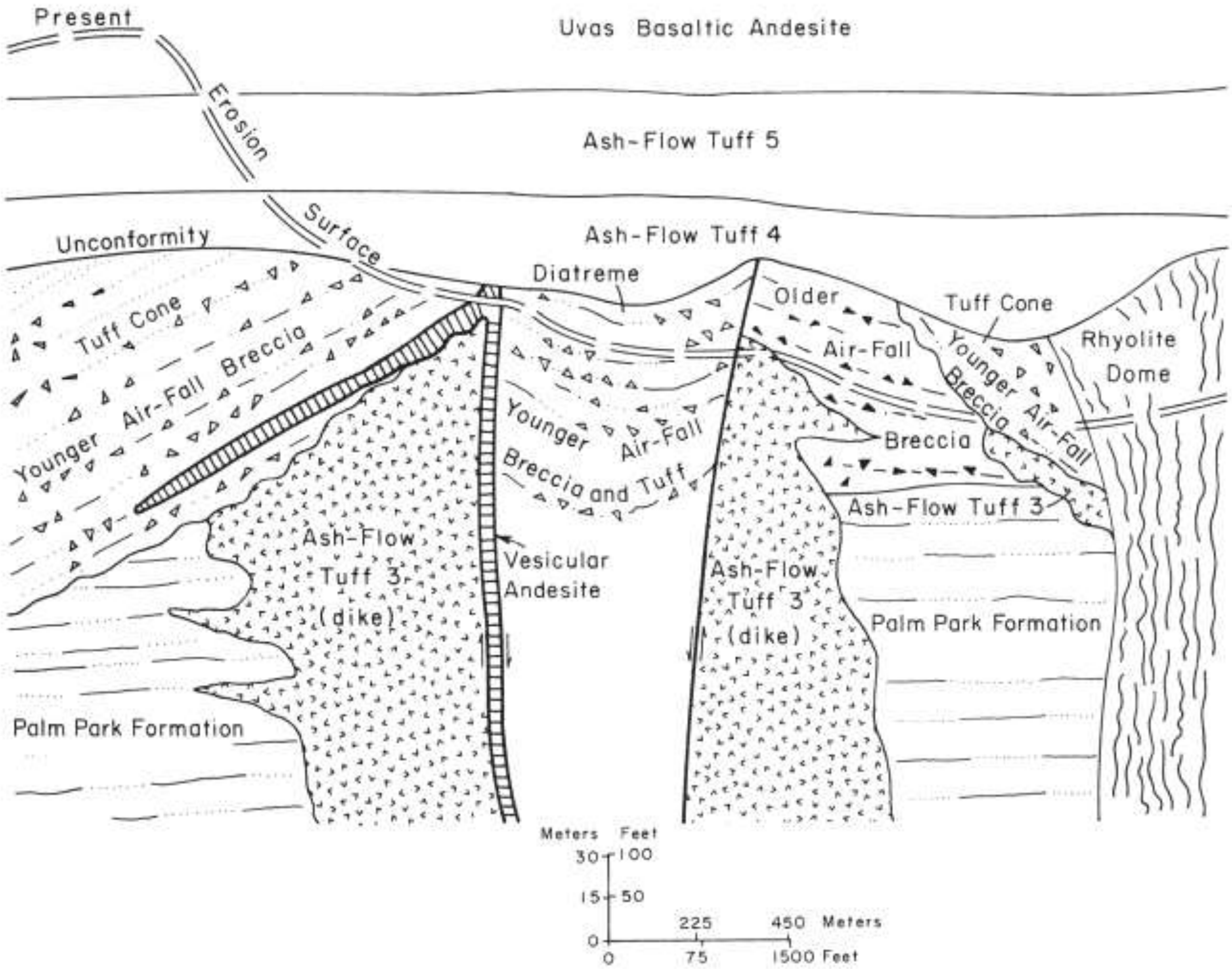

FIGURE 7—West-east diagrammatic section of Bell Top vents near Porcupine Tank, Cedar Hills.

ing more porphyritic southward. They are usually associated with black, green, or gray vitrophyre, best developed at the base of flows or at the edges of intrusions. Autobrecciation is common, both internally and at the edges of flows or intrusives. Talus or crumble megabreccias are locally preserved. In contrast, rhyolite of the Robledo type is creamy-yellow to white, massive, porphyritic rock, seldom showing flow banding and never associated with vitrophyre, but altered to red or pink in many places. Phenocrysts are white feldspar 2 to 4 mm in diameter, usually altered to clay.

Chemically the two rhyolites are also distinctive, as shown by table 2. Cedar Hills rhyolite is potassic-sodic, while rhyolite of the Robledo type is potassic. In addition, the Robledo type contains considerably more Mg, Fe, and Ti than does the Cedar Hills type.

The two rhyolites probably are nearly contemporaneous. A K-Ar date from the Robledo type in the Robledo Mountains gave an age of 35 m.y. (Kottlowski and others, 1969). In the Cedar Hills area flow-banded rhyolite intrudes rocks younger than 39 m.y. old and is overlain by tuff 5, dated 35 m.y. (see table 1).

BELL TOP ROCKS YOUNGER THAN VENT ZONE

Unconformably inset against the western edge of the Cedar Hills vent complex are ash-flow tuffs 4, 5, and 6 of the Bell Top Formation (figs. 4 and 5). These flows are well developed in the Sierra de las Uvas (Clemons and Seager, 1973), but their source is unknown. The rhyolite dome complex of the Cedar Hills apparently blocked the eastward spread of the ash flows, resulting in the inset relations on the western side of the vent zone. Remnants of the flows have not been found east of the vent zone.

STRUCTURAL FEATURES

Structural features associated with the Cedar Hills vent zone include: 1) intrusive masses of tuff 3, 2) diatreme at Porcupine Tank, 3) collapsed area at Foster Canyon, 4) rhyolite domes, and 5) faults of possible Oligocene age at the margin of the Goodsight-Cedar Hills depression. Areal relationships among these features are shown on the tectonic map.

INTRUSIVE TUFF 3

In the vicinity of Porcupine Tank tuff 3 appears to be in the form of a north-northwest-trending dike about 1 mile long and as much as 300 yards wide. Relations between the tuff and adjacent rocks are shown in fig. 7. The intrusive nature of the tuffs is indicated primarily by several apophyses that project from the dike-like mass into adjacent air-fall breccia or Palm Park beds. The tuff is variably bleached to yellow or white over large irregular areas. Welding is characteristic of some contacts, all apophyses, and of irregular patches within the tuff. Near edges of the dike, foliation, formed by flattened pumice, is either largely obliterated by welding, or dips steeply parallel to the contacts (fig. 7). However, interior portions of the dike at deeper levels of erosion exhibit gently west-dipping foliation, an attitude resulting from late Tertiary tilting of the Cedar Hills fault block; original foliation was near horizontal. This attitude suggests compaction of the tuff within the dike following emplacement. Other workers have observed near vertical foliation in ignimbrite intrusive bodies (Cook, 1968; Walker, 1969; Almond, 1971; Reynolds, 1954; Branch, 1967) but horizontal foliation in compacted ignimbrite intrusives should not be unexpected.

DIATREME AT PORCUPINE TANK

A nearly circular diatreme transects the tuff 3 dike west of Porcupine Tank (fig. 7 and tectonic map). The diatreme vent, about 0.4 mile in diameter, is central to a tuff cone about 1.5 miles in diameter, constructed of upper tuff and breccia beds. Tuff and breccia beds in the central vent are enclosed by a ring fault and have centroclinal dips, while similar strata in the cone dip radially away from the central vent at initial dips of up to 30 degrees (section *B-B'*, in pocket). An andesite flow interbedded in the cone breccia was fed by a ring dike occupying the western half of the ring fault.

The diatreme probably formed through a series of explosions that drilled a cylindrical pipe upward through underlying volcanics. Abundant accidental fragments of tuff 3 and Palm Park are present in the tuff cone, together with flow-banded rhyolite, vitrophyre and pumice. Collapse of the vent filling, or upper cone, resulted in the formation of the ring dike, subsequently invaded by andesite. Ejection of tephra and subsidence continued until the emplacement of flow-banded rhyolite domes and flows. The upper tuff and breccia beds are widespread and locally thick elsewhere along the Cedar Hills vent zone, suggesting explosive activity at more than one vent. Some of these may now be occupied by rhyolite domes, while others probably are buried by younger deposits.

COLLAPSED AREA AT FOSTER CANYON

Upper tuff and breccia beds form an east-trending sunken block in the upper Foster Canyon area. The block is about 0.5 to 1 mile wide and at least 1.2 miles long. The eastern third of the block is a graben but the western part forms a structural basin partly buried by younger rocks (tectonic map and section *C-C'*). The footwall blocks of the graben are formed of Palm Park and the basalt and Tuff 3 members of the Bell Top structurally several hundred feet higher than the same rocks in the graben. The walls of the graben apparently were sources of landslide blocks, now found interbedded in tuffs and breccias of the graben floor as brecciated slabs 10 to 100 ft long. Numerous curved fractures and associated alteration, together with possible rhyolite dikes cut various parts of the graben-basin couplet.

The sunken block is interpreted to have resulted from episodic collapse accompanying eruption of tephra from the graben-basin area. This is indicated primarily by the unusually thick upper breccia sequence within the sunken block, by alteration of the breccias, by the interbedded landslide blocks, and by the abundance of accidental limestone clasts in the breccias of the sunken block area. Limestone clasts are rare in other parts of the Cedar Hills vent zone. The tephra eruptions and collapse were clearly contemporaneous with eruptions at the diatreme 2 miles to the north.

RHYOLITE DOMES

Culmination of volcanic activity in the Cedar Hills vent zone during Bell Top time resulted in emplacement of at least 21 flow-banded rhyolite intrusions, probably in the form of dome-flow complexes (figs. 8 and 9). The presence of a buried rhyolite dome near the northern edge of the map (tectonic map) is inferred from the presence of very coarse flow-banded rhyolite detritus in Miocene Santa Fe fanglomerates across the river in the West Selden Hills. At the present level of erosion the exposed domes range from about ^{1}/3 to ^{2}A mile in diameter and are circular to oval in plan. Some of the intrusives are composite, formed of more than one variety of rhyolite, emplaced at slightly different times. Some are entirely isolated, while others are connected by comparatively thin dikes of rhyolite. Rhyolite flows

FIGURE 8—Rhyolite dome southeast of Dark Mountain, Cedar Hills. View to southeast.

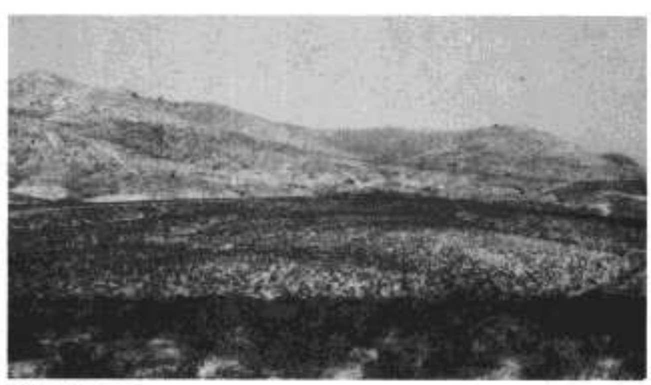

FIGURE 9—Rhyolite dome south of Foster Canyon. See fig. 10 for structure of this dome. View to west.

extend from the base of several intrusives suggesting that the erosional beveling of the domes has not been deep, perhaps a few hundred feet. Talus or crumble breccia are preserved locally beneath younger rocks at the margins of flows or domes.

Foliation and lineation are well developed in all domes and flows. Foliation measurements show the intrusions to be primarily funnel shaped, although some are nearly vertical cylinders (tectonic map). The structure of an exemplary funnel-shaped intrusion is shown in fig. 10.

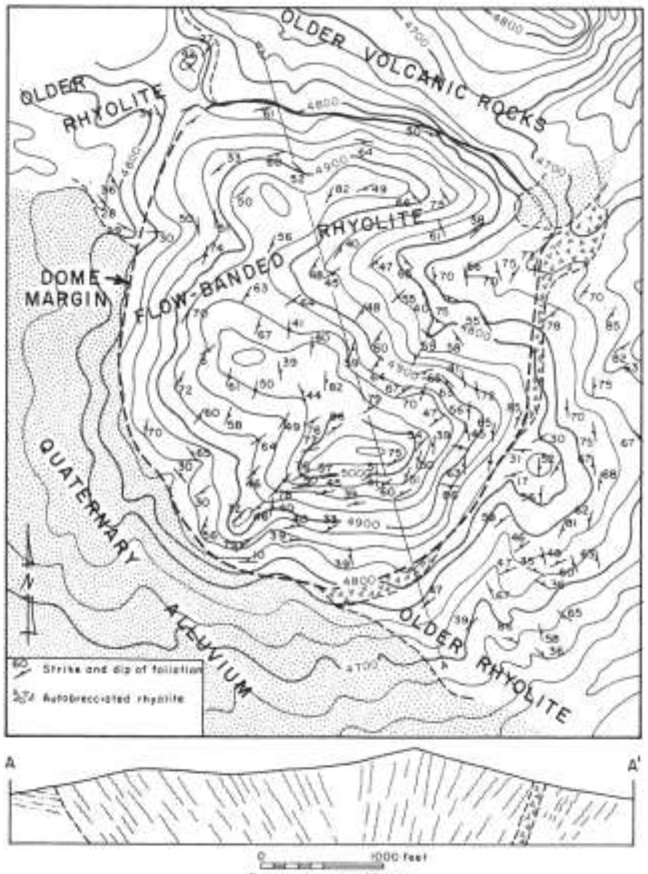

FIGURE 10—STRUCTURE MAP AND CROSS SECTION OF RHYOLITE DOME SHOWN IN FIG. 9.

OLIGOCENE (?) FAULTS

Just east of the Cedar Hills vent zone numerous north-trending faults, generally downthrown to the west, occur in a **4-** to 5-mile-wide belt. This zone of block-faulted terrain is probably the eastern margin of the Goodsight-Cedar Hills depression. The existence of some of the faults during Oligocene time is inferred by small rhyolite intrusions in some of the fault zones and by local inset relations of Uvas and Bell Top units against the West Selden Hills fault-line scarp. From the Tonuco uplift (fig. 2) southward to Faulkner Canyon, Uvas and Bell Top units are either thin and discontinuous or missing altogether; Santa Fe deposits generally overlie the Palm Park Formation. Those occurrences contrast with the region west of the fault belt and Cedar Hills vent zone where all Bell Top and Uvas units are well developed and thicken westward (sections *A-A', B-B', C-C')*. These relations indicate a structurally high, faulted margin of the Goodsight-Cedar Hills depression existed during emplacement of Bell Top and Uvas units. The Cedar Hills vent zone occupies the inner border of this margin. Pliocene or younger displacement on most of the faults in the zone is proved by offset of late Miocene Santa Fe strata.

SUMMARY AND CONCLUSIONS

Rock units originating in the Cedar Hills vent zone indicate the following sequence of events about 35 m.y. ago: 1) explosive rhyolitic tephra eruptions followed closely by emplacement of tuff 3 along north-trending fissures, 2) a short erosional interval, 3) renewed rhyolitic tephra eruptions, particularly from the Foster Canyon area and the diatreme at Porcupine Tank, but also elsewhere along the vent zone; collapse in the Foster Canyon area was contemporaneous with this activity, as was emplacement of minor andesite, 4) tephra eruptions culminated in intrusion of at least 21 rhyolite domes in the vent zone, and smaller, more potassic rhyolite plutons along faults to the east.

The volcanic activity and sequence of rock types suggests one cycle of eruption from a single magma chamber. The gas-rich cap of the magma chamber was tapped first resulting in explosive tephra eruptions and emplacement of the pumiceous ash-flow tuff 3. This was followed shortly by emplacement of the lower gas-poor part of the rhyolitic magma as numerous rhyolite domes and flows. This conclusion is supported by chemical data in table 2; tuff 3 and flow-banded rhyolites are virtually identical in chemical composition. A potassic differentiate of the magma was tapped in areas to the east of the vent zone.

The Oligocene structures are possible precursors of the Rio Grande rift in southern New Mexico. The northerly alignment of vents and associated faults, and the northerly elongation of the Goodsight-Cedar Hills depression suggest an east-west extensional stress field already existed in south-central New Mexico during the Oligocene. This stress field may have been a precursor to the more active extension that developed in early Miocene time, culminating in the Rio Grande rift. If so, middle Oligocene extension was apparently unique to south-central New Mexico, inasmuch as evidence of it elsewhere along the rift is lacking. Alternatively, the northerly trend of Oligocene volcano-tectonic features may be strictly local, related to cauldron subsidence of the Goodsight-Cedar Hills depression; or the northerly trend may be inherited from an older Laramide structural grain.

Basaltic andesite volcanism is characteristic of the transition from predominantly rhyolitic volcanism 39 to 33 m.y. ago to active block faulting about 26 m.y. ago.

Andesite Intrusions of Faulkner Canyon

Numerous east trending basaltic andesite dikes crop out in the Faulkner Canyon area. The andesites are dark-gray to black rocks containing as much as 95 percent plagioclase and pyroxene microphenocrysts. Many of the dikes are associated with two plugs of fine-grained biotite andesite located a short distance southwest of McCall Ranch (tectonic map). The dikes cut the upper tuff and breccia unit of the Cedar Hills vent zone sequence (35 m.y.), and are overlain uncon formably by late Miocene and Pliocene (?) Rincon Valley fanglomerate. These relations are computable with a K-Ar date of 31.5 m.y. obtained from one of the dikes (F. E. Kottlowski, written communication, 1974).

North of McCall ranch the dike swarms are associated with an east-trending anticline in Palm Park beds (tectonic map). Apparently the dikes are connected at shallow depth with a stock of andesite above which Eocene rocks are arched.

Rio Grande Rift

Geologic evidence from the Cedar Hills vent zone bears directly on the problem of timing of initial late Tertiary rifting in southern New Mexico. This data comes primarily from relationships between the Uvas Basaltic Andesite, the Coyote Canyon fanglomerate member of the Uvas, and the late Tertiary Cedar Hills fault. Rocks of the Santa Fe Group provide some insight into later evolution of the Rio Grande rift.

UVAS BASALTIC ANDESITE

The Uvas Basaltic Andesite was the last series of volcanic rocks to be deposited in the Goodsight-Cedar Hills depression; the Uvas also is the first rock sequence directly related to the Rio Grande rift. The formation is thickest in the Sierra de las Uvas near the axis of the depression. Here, the Uvas contains the largest number of flows, is associated with several vents, and appears to interfinger downward into volcaniclastic strata of the Bell Top Formation. Adjacent to the Cedar Hills vent zone, however, the Uvas overlies Bell Top rocks disconformably, and comprises two laterally intertonguing facies: 1) a series of basaltic andesite flows, including an exhumed cinder cone, and 2) fanglomerate derived from the Oligocene flow-banded rhyolite domes described earlier.

The Uvas flow sequence comprises about 400 ft of light- to dark-gray vesicular flows averaging 25 to 75 ft thick. Chemical analysis of a flow from the Sierra de las Uvas is presented in table 2. A K-Ar date of 26 m.y. was obtained from one of the Uvas flows in the Sierra de las Uvas.

The source of most of the Uvas flows in the Cedar Hills area is a cinder cone located in the northern part of the Cedar Hills vent zone. The cone, partially exhumed by Broad Canyon and its tributaries, is about 1 mile in diameter. Flanks are cut by several dikes, some of which merge into flows. Locally, flows undercut the edges of the cone and eventually buried the flanks. The cinder cone lies across, and is offset by movement on, the Cedar Hills fault (fig. 11 and tectonic map)—indicating the fault was present 26 m.y. ago, and provided an avenue for magma movement to the surface. Because the Cedar Hills fault is clearly a component of the Rio Grande rift in this area, active extension accompanied by block faulting was apparently in progress as early as 26 m.y. ago. Fanglomerate interbedded in the Uvas also supports this interpretation.

Uvas flows become thinner and intertongue with fanglomerate south of the cinder cone (fig. 12). The fanglomerate is considered to be a member of the Uvas Basaltic Andesite, and is named Coyote Canyon mem-

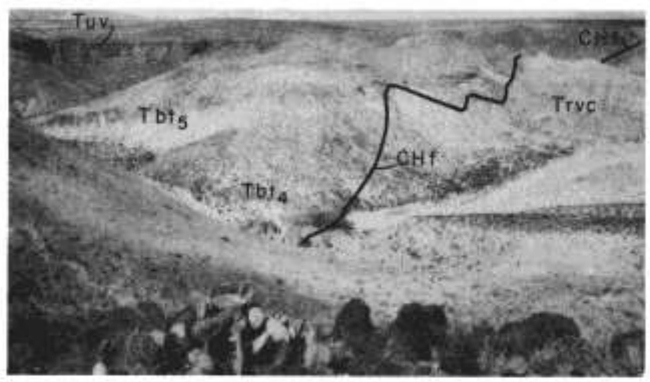

FIGURE 11—UVAS CINDER CONE AND CEDAR HILLS FAULT IN BROAD CANYON AREA. CHf = CEDAR HILLS FAULT; Tuv = CINDER BEDS IN UVAS BASALTIC ANDESITE (WEST FLANK OF UVAS CINDER CONE); Trvc = RINCON VALLEY FORMATION (CONGLOMERATE FACIES); Tbt_4 = TUFF 4 MEMBER OF BELL TOP FORMATION; Tbt_5 = TUFF 5 OF BELL TOP FORMATION. VIEW TO NORTHWEST.

FIGURE 12—COYOTE CANYON FANGLOMERATE MEMBER OF UVAS BASALTIC ANDESITE EXPOSED IN WEST-FLOWING TRIBUTARY TO COYOTE CANYON.

ber for exposures in tributaries to Coyote Canyon. A type section is given in Appendix B.

Judging from the present outcrop (tectonic map), the fanglomerate formed as coalescing fans adjacent to the flow-banded rhyolite domes and flows of the Cedar Hills vent zone. Composition of clasts indicate the dome-flow complexes were the principal source. Fluvial, high-gradient deposition is indicated by large mean grain size, poor sorting, low-angle cross bedding and lenticular character of the deposits. Gradation from boulder deposits at the base of the fanglomerate upward to conglomeratic sandstone and fine-grained sediment is typical and probably reflects burial of the source area in its own debris.

The fan, like the Uvas Cinder cone, resulted from movement along the Cedar Hills fault about 26 m.y. ago. Erosion accompanying uplift provided detritus for the fan, while contemporaneous basalt eruptions along the fault resulted in mutual intertonguing of flows and fanglomerate.

SANTA FE GROUP

Although initial development of the Rio Grande rift apparently is marked by the Uvas Basaltic Andesite, younger evolution of the rift is recorded by the overlying Santa Fe Group (Miocene to Pleistocene). Intraformational unconformities and fanglomerate wedges at different levels in the sequence testify to repeated uplift, erosion, and deposition within the rift (Seager and Hawley, 1973).

Earliest among the post-Uvas intrarift basins in northern Dona Ana County is a broad downwarp that extended from the Jornada del Muerto northwestward along the northern edge of the Selden Hills and Cedar Hills and Sierra de las Uvas to the vicinity of Hatch (fig. 13). The basin is no longer obvious because in Pliocene time it was segmented into smaller intrabasin grabens and horsts, such as the Tonuco uplift, Rincon Hills uplift, and Rincon Valley graben. These relatively young uplifts resulted in exposures of the paleobasin fill.

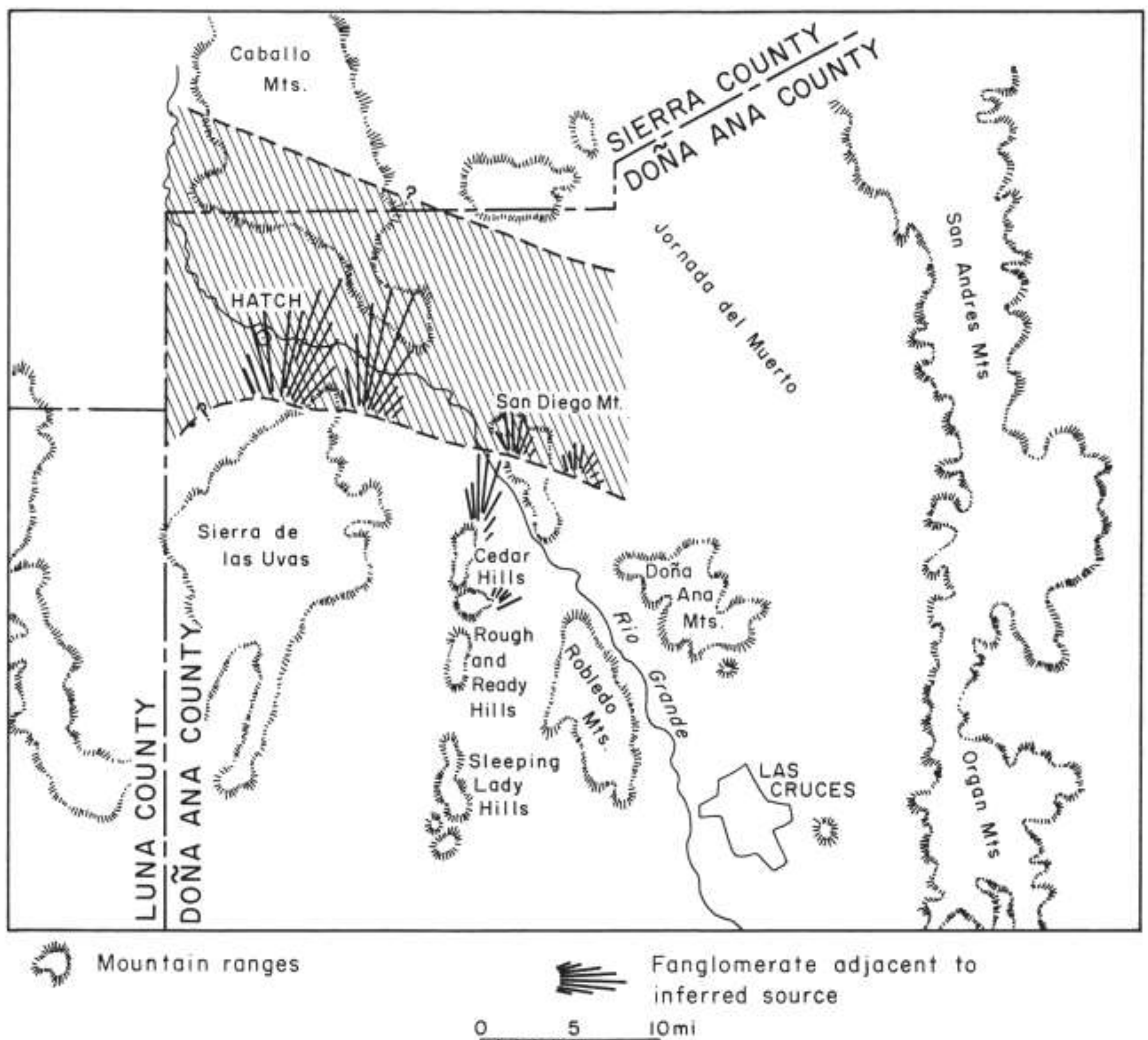

FIGURE 13—Early to middle Miocene intrarift basin, containing transitional beds and Hayner Ranch Formation.

More than 3,500 ft of red, brown, and purple, locally derived, volcanic sandstone and conglomeratic sandstone comprises the earliest rift deposits (Santa Fe Group) in the Tonuco uplift and Rincon Hills uplift. These sandstones are subdivided into an older transitional unit and younger Hayner Ranch Formation. The two units overlie Uvas and associated volcaniclastic strata and were probably deposited near the axis of the paleobasin. Coarse fanglomerate wedges derived from the Sierra de las Uvas dome (Seager, 1973), or from the eastern raised rim of the Goodsight-Cedar Hills depression, locally constitute an important part of the Hayner Ranch Formation, especially along the western margin of the basin. Fan facies along the southwestern basin margin is also accompanied by overlap as illustrated in the northern part of the West Selden Hills; at this locality Hayner Ranch boulder beds overlap onto Palm Park strata.

The age of the two basal Santa Fe units is uncertain. In the Rincon Hills the transitional unit and Hayner Ranch Formation are stratigraphically about 1,400 ft above the Uvas Basaltic Andesite (26 m.y.); in the Tonuco uplift they are at least 1,000 ft beneath the Selden Basalt (9 m.y.). Apparently the early Santa Fe strata are between about 25 m.y. and 12 m.y. old.

Pre-Pleistocene Santa Fe strata above the Hayner Ranch Formation are included in the Rincon Valley Formation. This formation is distinguished from older Santa Fe units by its brown or tan color, locally abundant clasts of limestone, granite or chert, and by the widespread development in the upper part of the formation of a pale-red siltstone-claystone-gypsum facies. The Rincon Valley formation locally overlies faulted and altered older Santa Fe beds with angular unconformity, although conformable relations are present near the center of the paleobasin described above.

In the Tonuco uplift the Rincon Valley Formation is more than 1,350 ft thick, conformable with underlying Hayner Ranch strata, and represents culmination of the uninterrupted filling of the paleobasin described above. Upper parts of the Rincon Valley Formation near the basin center are deposits of alluvial flats and playa lakes. To the south, the formation overlaps older Santa Fe strata at the southern edge of the paleobasin and was deposited in a broad, north-trending trough adjacent to the Cedar Hills (fig. 14). This trough truncates the eastern margin of the Goodsight-Cedar Hills depression, so that the Rincon Valley Formation was deposited across a wide variety of older rocks and structures. The formation generally overlies Palm Park Formation east of the West Selden Hills fault, and Uvas or Bell Top rocks to the west. Within this trough the Rincon Valley Formation comprises a westward-thickening and coarsening wedge of fanglomerate and sandstone, derived primarily from the Cedar Hills and Sierra de las Uvas. Two olivine basalt flows, named Selden Basalt, are interbedded in the fanglomerate near Selden Canyon, and are interpreted to have erupted from fissures or faults along the toe slope of fans draining eastward into the trough from the Cedar Hills fault block. A K-Ar date of 9 m.y. from the Selden Basalt also dates the fanglomerate, and indicates continuing uplift of the Cedar Hills block in late Miocene time. The total absence of Paleozoic or Palm Park detritus in outcrops of Rincon Valley Formation within yards of the Robledo Mountains suggests that uplift of this range was a Pliocene-Pleistocene event.

The Cedar Hills fault block probably was buried in middle to late Miocene time by Rincon Valley fanglomerate spreading eastward from the Sierra de las Uvas and by bajada development around both sides of the Cedar Hills. The thickness and composition of Rincon Valley Formation exposed on the western dip slope of the range support this interpretation. These strata contain a mixture of volcanic clasts derived from both east and west; when projected to the summit of the range these units would entirely bury pre-Santa Fe rocks.

Probably the most active period of block faulting in south-central New Mexico was in Pliocene time. Uplifts like the Tonuco, Rincon Hills, Selden Hills, and Robledo apparently owe most of their structural relief to faulting at this time. Evidence is twofold: 1) absence of earlier (Miocene) deposits derived from these uplifts, and 2) post-Rincon Valley Formation offset along range boundary faults of hundreds to thousands of feet. On the other hand, the Cedar Hills, Sierra de las Uvas, and Caballo Mountains are somewhat older judging from the volume of pre-Pliocene Santa Fe deposits derived from them (Seager and Hawley, 1973; Seager, Clemons and Hawley, in press). Probably 70 to 90 percent of the total uplift of the Cedar Hills is Pliocene, however, as suggested by the stratigraphic separation of the Rincon Valley Formation across the Cedar Hills fault, nearly equaling the total separation measured on older rocks. The amount of Pliocene uplift of the Sierra de las Uvas or Caballo Mountains cannot be estimated at present.

SUMMARY AND CONCLUSIONS

Uplift of the Cedar Hills fault block was initiated about 26 m.y. ago. Concurrent basaltic volcanism along the Cedar Hills fault and erosion of the Cedar Hills fault block produced interfingering fanglomerate and flows dated 26 m.y. This faulting and volcanic activity is interpreted as marking initial active faulting in the Rio Grande rift of south-central New Mexico. Similar evidence from the Socorro-Magdalena area and eastern San Juan Mountains also indicates initial rifting 26 to 24 m.y. ago (Chapin, 1974; Lipman, Steven and Mehnert, 1970), but faulting beginning about 20 m.y. ago is indicated from the Mimbres area within the Basin and Range Province (Elston, 1973). The pre-existing Oligocene extension in south-central New Mexico, whether of regional significance or not, produced comparatively minor faulting, but did influence formation of north-trending volcanic features.

The transition from east-west extension during the Oligocene to active rifting in early Miocene time was accompanied by a change from predominantly rhyolitic to basaltic andesite volcanism as elsewhere (Lipman, and others, 1972; Christiansen and Lipman, 1972; Chapin, 1974; Bruning and Chapin, 1974). In northern Doña Ana County andesite dikes and plugs, dated 31.5 m.y., and voluminous Uvas Basaltic Andesite flows, 26 m.y., represent this transition.

Evolution of the rift during the Miocene is characterized by accumulation of thick Santa Fe bolson strata

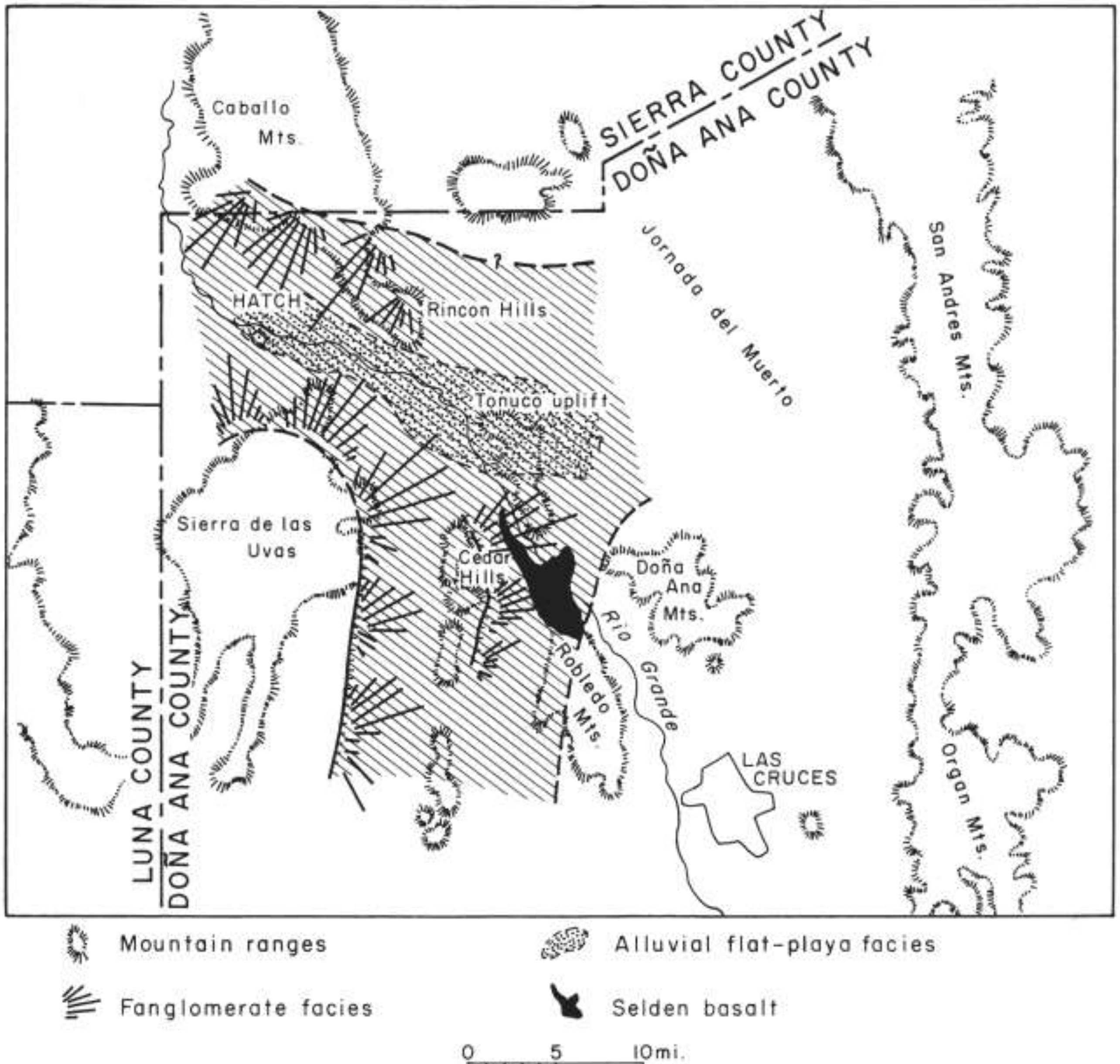

FIGURE 14—LATE MIOCENE-EARLY PLIOCENE INTRARIFT BASIN, CONTAINING RINCON VALLEY FORMATION.

in local broad basins. The earliest of these intrarift basins extended northwestward from the Jornada del Muerto to Hatch. At least 4,500 ft of early to middle Miocene elastics derived from the Sierra de las Uvas, Cedar Hills, and eastern margin of the GoodsightCedar Hills depression as well as middle to late Miocene fanglomerates from the Caballo Mountains fill this basin. A second series of shallower, north-trending basins developed on the east side of the Sierra de las Uvas and Cedar Hills in middle to late Miocene time. Basaltic flows in this basin fill are dated 9 m.y. None of these early basins exist now as topographic or structural features, having been segmented into smaller intrabasin horsts and grabens during the latest Miocene or Pliocene.

Probably most of the structural relief of uplifts such as the Robledo, Tonuco, Cedar Hills, East and West Selden Hills, and Rincon Hills is the result of Pliocene faulting. Thus, the general conclusion is that rifting progressed from local faulting and formation of broad basins throughout the Miocene, culminating in extreme segmentation of the crust into narrow, closely spaced uplifts and basins in Pliocene time. The shape of the Pliocene uplifts and grabens remains unchanged today, but movement along some boundary faults continued through Pleistocene into Holocene time. Bruning (1973) and Bruning and Chapin (1974) have documented a virtually identical Miocene-Pliocene evolution of the Rio Grande rift in the Socorro-Magdalena area.

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Appendix A— Petrographic Summaries

PALM PARK FORMATION

The Palm Park Formation is a heterogeneous unit containing muddy, conglomeratic, tuffaceous volcanic arenites; flows; and intrusives.

Laharic breccia and conglomerate clasts: The predominant types are light-gray, pale-brown, pale-grayish-red, grayish-red, and light-greenish-gray biotite-hornblende andesite porphyries. Phenocrysts of dark-red biotite and red basaltic hornblende (0.1 to 5.0 mm) comprise from 1 to 15 percent of the rocks. Oxidation of the biotite and hornblende ranges from a stage where they are surrounded by a thin dark rim to one where only magnetite grains and hematitic zones mark their former presence. Normal and oscillatory zoned plagioclase phenocrysts (0.5 to 5.0 mm) comprise 25 to 40 percent of the rocks. Their composition generally ranges from An_{30} to An_{46} but a few cores are as calcic as An_{70} Saussuritization of the more calcic parts is common. Pilotaxitic or intersertal matrices consist of andesine (An_{28-36}) laths, hornblende, pyroxene, and biotite microlites with magnetite dust.

Andesite flow: Grayish-red-purple slightly porphyritic hornblende andesite. Phenocrysts of basaltic hornblende (0.5 to 3.0 mm) make up about 10 percent of the rock. They are partly to completely replaced by biotite, and granular magnetite-augite. Phenocrysts of zoned plagioclase (An_{36}-6_0) add another 5 percent. The pilotaxitic matrix consists of about 65 percent andesine (An_{10}) laths, 0.05 to 0.12 mm long; 20 percent pyroxene granules, magnetite, crystalites, and cryptocrystalline material.

Andesite intrusives: The Palm Park intrusives are medium-gray, brownish-gray, light-olive-gray, pale-grayish-red-purple, and dusky-red hornblende andesites and hornblende andesite porphyries. Normal and oscillatory zoned plagioclase phenocrysts, ranging in size from 0.5 to 8 mm, comprise up to about 30 percent of the rocks. Their composition ranges from oligoclase (An_{24}) to labradorite (An_{60}) in the more strongly zoned phenocrysts, averaging about An_{36-40}. Euhedral to subhedral basaltic hornblende phenocrysts, ranging in size from 0.5 to 5.0 mm, make up another 2 to 12 percent of the rocks. The hornblende is strongly oxidized and largely replaced by biotite, magnetite, and augite. Dark-red hematite rims are common. Pilotaxitic to intersertal matrices are predominantly plagioclase (An_{28-34}) laths and stubby microphenocrysts with pyroxene grains, magnetite, brown glass and cryptofelsic material. One specimen, from East Selden Hills, contained a trace of sanidine and quartz, and may be a trachyandesite or latite porphyry.

BELL TOP BASALT

Dense, grayish-black, very fine crystalline, olivine-bearing basalt. Olivine phenocrysts 0.5 to 2.0 mm across make up less than 4 percent of the rock. They are embedded in an intersertal matrix of labradorite (An_{64-70}) laths, as much as 0.15 mm long, smaller pyroxene and magnetite grains, and brownish glass. Red material (iddingsite?) forms rims around the olivine phenocrysts and fills some of the fractures. Small (1.5 mm) zones of ophitic texture were noted in a specimen from Bell Top Mountain.

ASH-FLOW TUFF 3

Grayish-orange-pink to pale-red, poorly to highly welded, vitric ash-flow tuff containing as much as 20 percent pale-red pumice fragments. The pumice fragments are typically equant and about 5 to 20 mm across; larger, flattened fragments up to 10 cm long and 3 cm thick are common locally. Small (less than 1.5 mm) crystal fragments of sanidine, quartz and biotite comprise up to 7 percent of the tuff but average about 4 percent. Biotite is least abundant, forming only a trace to 0.4 percent of the rock. Abundant, large, devitrified shards show axiolitic structure. The tripartite nature of this unit (a cliff-former between two slope-formers), characteristic in the Sierra de las Uvas, is not as well developed in the Cedar Hills.

Intrusive (?) Ash-Flow Tuff 3: Grayish-orange-pink to moderate-red, very dense, highly welded vitric ash-flow tuff. Petrographically indistinguishable from the typical flow rock.

BELL TOP VESICULAR ANDESITE DIKE AND FLOW

Grayish-orange to yellowish-brown, vesicular andesite. Blocky microphenocrysts, up to 1.0 mm across, of andesine (An_{44-50}) are enclosed in an intersertal matrix of andesine (An_{30-40}) laths, magnetite grains, and brownish, cryptocrystalline to glassy material. The cores of the larger plagioclase crystals have been saussuritized. Vesicles, which comprise about 10 percent of the rock, have thick, brown, glassy inner rims.

FLOW-BANDED RHYOLITES

Cedar Hills Type: Include pale-red, pale-grayish-red, pale-brown, pale-yellowish-brown, and grayish-red flow-banded rhyolites. The phenocryst content ranges from only a trace to about 18 percent, with the higher percentages being typical of the rhyolites in the Rough and Ready Hills. Phenocrysts (ranging from 0.3 to 2.0 mm) are predominantly sanidine, with oligoclase and biotite generally in lesser amounts. Plagioclase exceeds sanidine in a few of the rocks along the western edge of the Cedar Hills. The matrices typically show a fluidal texture; composed of blocky and elongated feldspar laths, and microlites in a light-brownish cryptocrystalline to glassy groundmass. A couple of the flows have very dusky red to black vitrophyre bases; and a pale-yellowish-brown microvitrophyre is associated with several flow-banded rhyolites in the Cedar Hills. Microvesicular to vesicular, lithophysal, and spherulitic textures are present in some of the rocks.

Robledo Mountains Type.' Pale-red to yellowish-gray rhyolite. Phenocrysts of sanidine, quartz, and plagioclase (An_{20-26}) comprise about 10 percent of the rock. The sanidine is generally altered to sericite and kaolin, especially the larger (I to 2 mm) phenocrysts. The plagioclase contains abundant inclusions and has altered cores consisting of sericite, carbonate, and clay. The matrices are an anhedral mosaic of feldspar and quartz (?), with magnetite, clay, and cryptocrystalline material.

ASH-FLOW TUFF 4

Grayish-red-purple, highly welded, dense, vitric-crystal ash-flow tuff containing abundant pale-red, devitrified, flattened pumice fragments. Some of the pumice fragments are as much as 1 ft long, but average about I inch. Crystal fragments, less than 1.5 mm, of sanidine, plagioclase, An_{10-20}, biotite, and quartz comprise 6 to 22 percent of the rock, averaging about 10 percent. Abundant glass shards show a well-developed eutaxitic texture. Upper two-thirds of the unit is a very dense cliff-former, grading downward into a crumbly, porous slope-former.

ASH-FLOW TUFF 5

Pale-red-purple to grayish-pink, moderately to highly welded, crystal-vitric ash-flow tuff with abundant soft, white, pumice fragments. Pumice fragments are generally less than one inch in diameter but a few are up to 3 inches long, and more abundant near the top of the unit. Crystal fragments up to 5 mm across, of sanidine, quartz, plagioclase (An_{20-25}), and biotite comprise 18 to 30 percent of the rock, averaging about 28 percent. Only a few glass shards are present in the devitrified groundmass. Upper one-fourth of the unit is porous, crumbly, and poorly welded, gradational downward into a denser, highly welded tuff cliff-former with poorly developed columnar joints.

ASH-FLOW TUFF 6

Pale-red to grayish-red-purple, highly welded, vitric-crystal ash-flow tuff containing abundant light-gray, flattened pumice fragments up to 4 inches long. Crystal fragments, up to 3 mm across, of sanidine, plagioclase (An,,,,,), quartz, and biotite comprise 12 to 32 percent of the rock, averaging about 20 percent. Abundant, large, devitrified shards distinguish this unit from ash-flow tuff 5. Locally, upper 5 to 10 ft are darker colored and possess subconchoidal fractures. This zone grades downward into a less dense, slightly porous, cliff-forming zone. The basal 2 to 6 ft are poorly welded to nonwelded, porous, crumbly ash.

FAULKNER CANYON ANDESITE PLUGS AND DIKES

Dark-gray, dense, fine-crystalline rock ranging from a slightly porphyritic biotite andesite to a porphyritic pyroxene andesite. The biotite andesite contains about 2 percent plagioclase (An_{30-35}) phenocrysts and 1 percent biotite phenocrysts, up to 2.0 mm long, in a pilotaxitic matrix. The biotite is reddened by oxidation and partly replaced by magnetite and hematite; some appears to have replaced hornblende. The matrix consists of tiny (.005 to .05 mm) plagioclase laths in a cloudy, cryptocrystalline to glassy groundmass with magnetite, dark-gray microliter, and secondary epidote and chlorite. The pyroxene andesite contains up to 25 percent plagioclase (An,,,,,), hypersthene, and augite phenocrysts, up to 1.5 mm long but averaging about 0.5 mm. The plagioclase is normal and oscillatory zoned. The pilotaxtic matrix consists of plagioclase (An_{28-44}) laths, augite, and magnetite.

UVAS BASALTIC ANDESITE

Uvas flows are mostly basaltic andesite, but a few are olivine-bearing and at least one is hypersthene andesite. They range in color from medium gray to dark brownish black. Basaltic hornblende phenocrysts up to 1.5 mm long are embedded in an intergranular felted matrix of andesine laths (averaging 0.3 mm long), pyroxene, and magnetite grains. The rock is mostly microvesicular to vesicular, with some of the basal flows containing abundant calcite and chalcedony amygdules. Olivine phenocrysts, up to 4.0 mm across, are present in some of the darker-gray flows, but without significant change in plagioclase composition (An_{45-50}). The hypersthene andesite contains reddish-bronze bastite phenocrysts, I to 2 mm across, in a matrix of blocky andesine laths, hypersthene, augite, and tiny magnetite grains. Most of the flows have brecciated, vesicular basal parts; dense, platy-jointed central parts; and vesicular to scoriaceous, reddish-brown upper parts.

Appendix B— Cedar Hills Section

Westward from NE 1/4 NE 1/4 sec. 23, T. 21 S., R. 2 W. to western edge of section 23; offset 0.7 mile N. 10 E., then westward for 0.5 mile; offset 1.0 mile S. 5 W., then west-northwestward down tributary arroyo to Coyote Canyon.

Measured by R. E. Clemons April 25 and May 2, 1974.

Unit	Description	Thickness (ft)
	Base of Rincon Valley Formation	
	Uvas Basaltic Andesite (total thickness)	818
	Upper tongue of Coyote Canyon member (total thickness)	367
34	Coarse sandy pebble conglomerate and muddy sandstone; 5- to 10-ft units of each interbedded in about equal amounts; some cobbles and a few boulders in the conglomerate; angular to subrounded clasts of flow-banded rhyolite and Uvas Basaltic Andesite; increasing amounts of ash-flow tuff 3 clasts upward; sandstone is grayish-orange-pink (5YR7/2) to very pale orange (10YR8/2)	64
33	Muddy sandstone; very poorly sorted with few pebbles and cobbles; poorly cemented; very pale orange (10YR8/2); interbedded coarse sandy pebble conglomerate lens 3 ft thick; slope-former	23
32	Coarse sandy conglomerate; fewer boulders than in lower units; several interbedded muddy sandstone units 6 to 10 ft thick; 3- to 18-inch thick beds; pale-yellow-brown (10YR7/2); tuffaceous; friable; massive-bedded; slope- and ledge-former	41
31	Coarse sandy cobble conglomerate; some boulders up to 2-ft in diameter; poorly sorted, angular to subrounded clasts of flow-banded rhyolite and Uvas Basaltic Andesite; moderately well cemented with chalcedony; 6-inch to 3-ft beds; cross-bedded; channels; few muddy sandstone lenses; grayish-orange-pink (5YR7/2); poorly bedded, 2- to 6-ft lenses; friable	110
	Fault, down to west, dips 78 degrees west; cuts out approximately 50 to 100 ft of section	
30	Coarse sandy cobble conglomerate; 1- to 6-ft beds; otherwise same as unit 31	104
29	Coarse sandy cobble conglomerate; 2- to 6-ft beds with boulders up to 3-ft diameter; less sandstone, but otherwise same as unit 30	25
	Upper tongue of Uvas Basaltic Andesite	104
28	Basaltic andesite flow; dark-gray (N3) to brownish-black (5YR2/1); scoriaceous top	16
27	Basaltic andesite; dense portion of same flow; ½- to 2-inch thick platy joints with horizontal, vertical, and contorted attitudes	60
26	Basaltic andesite; basal portion of same flow; brecciated; vesicular	28
	Middle tongue of Coyote Canyon member	143
25	Coarse sandy pebble conglomerate; some cobbles; angular to subangular clasts of flow-banded rhyolite and Uvas Basaltic Andesite; poorly indurated; poorly bedded; upper 4 ft is a muddy tuffaceous sandstone	33
24	Cobble breccia; abundant boulders up to 2 ft in diameter; angular to subangular clasts of flow-banded rhyolite, Uvas Basaltic Andesite, and tan microvitrophyre; poorly bedded with indistinct imbrication of cobbles dipping east	110
	Lower tongue of Uvas Basaltic Andesite	154
23	Basaltic andesite; medium-dark-gray (N4); dense; large vesicles; scoriaceous top	50
22	Mostly covered; basaltic andesite; dark-gray (N3); dense, platy joints; vesicular, scoriaceous top	49
21	Basaltic andesite; medium-dark-gray (N4); dense; platy joints; slightly vesicular; abundant amygdules of calcite and chalcedony; scoriaceous top; abundant white chalcedony on ground surface	55
	Lower tongue of Coyote Canyon member	50
20	Cobble-boulder breccia; angular to subangular clasts of flow-banded rhyolite 4 ft in diameter; poorly consolidated; poorly exposed	50
	Bell Top Formation	949
	Tuff 5 member	123
19	Vitric-crystal ash-flow tuff; grayish-orange-pink (5YR 7/2); abundant white pumice fragments; upper 5 ft is more porous and weathers into flaggy layers	60
	Fault, down to east, dip 80° E.; repeats upper 55 ft of unit 18	
18	Vitric-crystal ash-flow tuff; grayish-orange-pink (5YR 7/2); densely welded; sanidine, quartz, plagioclase, and biotite crystals; light-colored pumice fragments abundant near top; cliff-former; poorly welded base rests on either remnants of a flow-banded rhyolite breccia or the upper tuffaceous sediment member	118
	Flow-banded rhyolite flow	125
17	Flow-banded rhyolite; mottled and streaked grayish-pink (5R8/2) and grayish-red (5R4/2); few, small phenocrysts of sanidine, plagioclase, and biotite; cliff-former	91
16	Flow-banded microvitrophyre; pale-yellowish-brown (10YR7/2); brecciated lower part; slope-former	34
	Upper tuffaceous sedimentary member	296
	(Not the same as the upper sedimentary member	

Unit	Description	Thickness (ft)
	described in New Mexico Bureau Mines & Mineral Resources Bulls. 100 and 102.)	
15	Slightly granular, sandy, mudstone; grayish-pink (5R8/2); tuffaceous, with abundant pumice fragments; 1- to 10-ft beds poorly developed; bentonitic; friable; slope-former	63
14	Same as unit 15 except more pumice, and 3- to 8-inch crossbeds dip 30° E.	57
13	Slightly conglomeratic, muddy, sandstone; grayish-orange-pink (10R8/2); pumiceous; massive, poorly bedded; subangular to subrounded basalt and ash-flow tuff 3 clasts; some rounded Palm Park cobbles; slope-former	28
12	Slabs of basalt and ash-flow tuff 3 members of Bell Top Formation	29
11	Conglomeratic, muddy sandstone; grayish-orange-pink (10R8/2); pumiceous; subangular to subrounded clasts of basalt and ash-flow tuff 3 up to 2-ft diameter; slope-former	12
10	Slightly granular, muddy sandstone; grayish-orange-pink (10R8/2); pumiceous; 2- to 10-inch beds with shaly partings; slope-former	28
9	Same as unit 8; less pumiceous; massive, poorly developed bedding; slope-former	13
8	Same as unit 7; 2- to 6-inch beds; slope-former	9
7	Slightly granular, sandy mudstone; grayish-pink (5R8/2); tuffaceous; massive, poorly developed bedding; angular to subrounded clasts of basalt and ash-flow tuff; bentonitic, friable; slope-former	29
6	Mostly covered; appears similar to unit 7	28
	Tuff 3 member	200
5	Vitric ash-flow tuff; predominantly pale-red (10R6/2) with local zones of moderate-red (5R5/4), and upper 2 to 4 ft white (N9); medium welded; porous; abundant darkened pumice fragments generally less than 1-inch across; minor sanidine, quartz, and plagioclase crystals; cliff-former	200
	Lower tuffaceous sedimentary member	74
	(Not the same as the lower sedimentary member described in New Mexico Bureau Mines & Mineral Resources Bulls. 100 and 102.)	
4	Slightly granular, sandy mudstone; grayish-orange-pink (10R8/2); pumiceous, bentonitic; minor amounts of basalt and Palm Park-derived pebbles and small cobbles; poorly bedded; slope-former	74
	Basalt member	131
3	Basalt; medium-gray (N5); dense; horizontal platy joints; brecciated base, scoriaceous top; ledge-former	51
2	Muddy boulder conglomerate; very pale orange (10YR8/2); well-rounded, Palm Park-derived clasts; poorly bedded; slope-former	46
1	Basalt; dark gray (N3); olivine-bearing; horizontal platy joints; brecciated base, scoriaceous top; ledge-former	34
	Palm Park Formation	

POCKET INSERTS

Tectonic map.
Cross sections.

Type faces: Text in 10 pt. Times Roman, leaded one-point
References 8 pt. Times Roman, leaded one-point
Display heads in 24 pt. Times Roman, letterspaced

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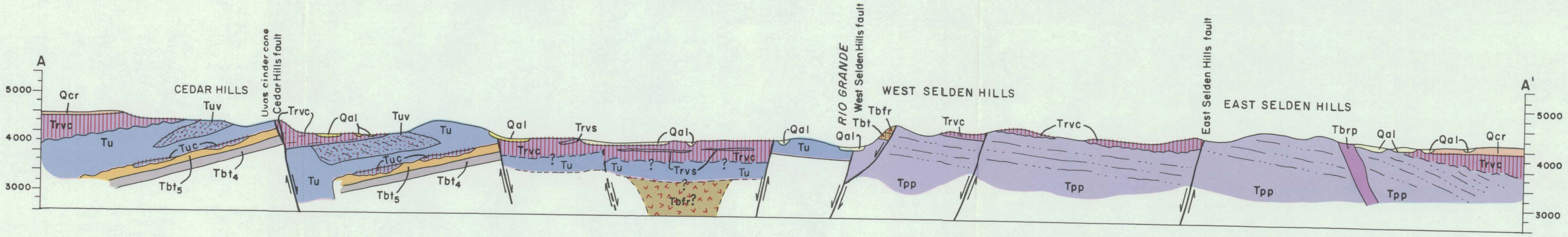
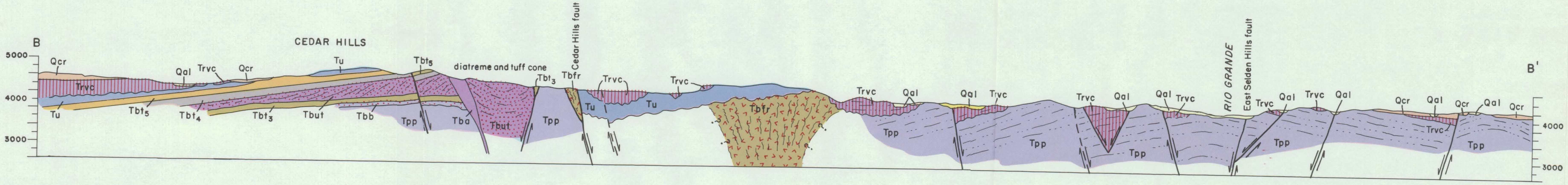
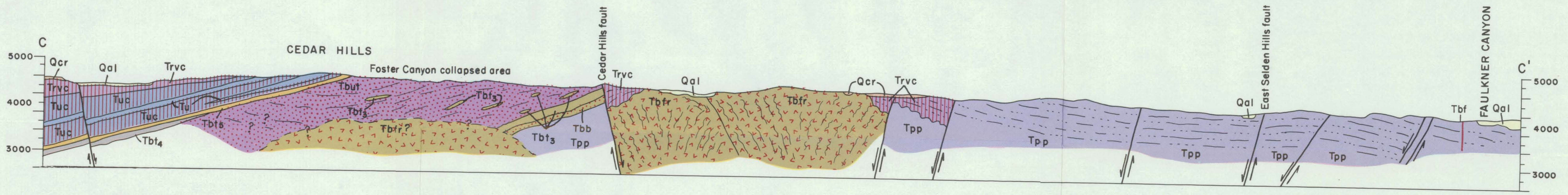
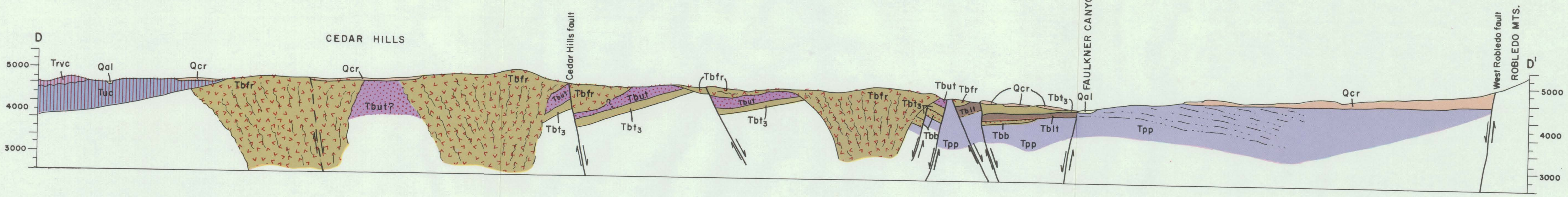
Saddlestitch

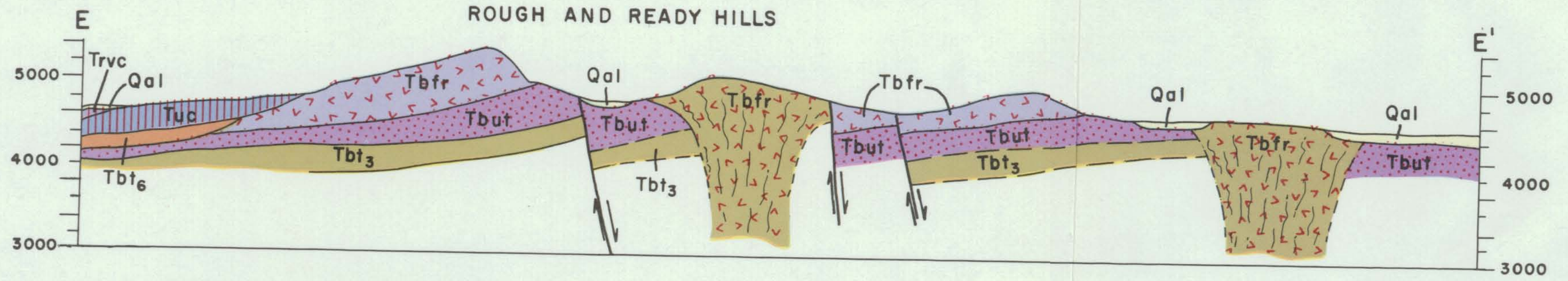
Paper: Cover on 65 lb. Cover Stock
Text on 60 lb. White Offset











0 1/2 1 2 Miles

Horizontal and vertical scale
1:24,000

CROSS SECTIONS OF CEDAR HILLS-SELDEN HILLS AREA, NEW MEXICO

by William R. Seager and Russell E. Clemons, 1975

MIDDLE PLEISTOCENE TO HOLOCENE

Qal — **Post-Camp Rice Alluvium**
Arroyo, fan and fluvial deposits related to entrenchment of the modern Rio Grande

UNCONFORMITY

LATE PLIOCENE TO MIDDLE PLEISTOCENE — Upper Santa Fe Group

Qcr — **Camp Rice Formation**
Intertonguing fanglomerate and fluvial deposits formed prior to valley entrenchment; to 300 ft thick

ANGULAR UNCONFORMITY

MIDDLE TO LATE MIOCENE — Lower Santa Fe Group

Trvs, Trvc — **Rincon Valley Formation**
Fanglomerate (Trvc) with local Selden Basalt Member (Trvs); 50 to 500 ft thick

ANGULAR UNCONFORMITY

OLIGOCENE-MIOCENE

Tuv, Tu, Tuc — **Uvas Basaltic Andesite**
Basaltic andesite flows (Tu) and agglomerate to cinder beds (Tuv); intertongues with fanglomerate and sandstone of Coyote Canyon member (Tuc); about 820 ft thick

OLIGOCENE

Tbf — **Andesite of Faulkner Canyon**
Fine-grained andesite dikes and plugs

UNCONFORMITY

Bell Top Formation

Tbt_6 — **Tuff 6 Member**
Porous to dense, pale-grayish-red, vitric-crystal ash-flow tuff; to 50 ft thick

UNCONFORMITY

Tbt_5 — **Tuff 5 Member**
Porous to dense, grayish-pink, crystal-vitric ash-flow tuff; abundant pumice fragments; to 125 ft thick

UNCONFORMITY

Tbt_4 — **Tuff 4 Member**
Porous to dense, pale-grayish-red-purple vitric-crystal ash-flow tuff; abundant dark, devitrified pumice fragments to 1 ft in diameter; to 100 ft thick

UNCONFORMITY

Tbfr, Tbut, Tbt_3, Tblt, Tba, Tbt — **Rocks of Cedar Hills Vent Zone**
Tbfr — flow-banded rhyolite flows and domes (Cedar Hills type); Tbut — air-fall breccia and tuff and epiclastic rocks, to 800 ft thick. mapped as Tbt where ash-flow tuff 3 is missing; Tba — vesicular andesite dikes and flows near Porcupine Tank diatreme; Tbt_3 — ash-flow tuff 3, intrusive (?) in part; about 200 ft thick. Tbtl — White to tan air-fall tuff and breccia, locally opalized, containing interbedded epiclastic sediments; about 80 to 150 ft thick; shown as Tbt where Tbt_3 is absent.

Tbrp — **"Robledo Type" Rhyolite Porphyry**
Cream to pink rhyolite porphyry dikes, plugs and sills

Tbb — **Basalt Member**
Olivine-bearing basalt flows and interbedded sandstone and conglomerate; about 150 ft thick in Foster Canyon

UNCONFORMITY

EOCENE

Tpp — **Palm Park Formation**
Tpp — volcaniclastic sediments, mainly lahars; minor andesite flows

foliation — bedding

TECTONIC MAP OF CEDAR HILLS - SELDEN HILLS AREA