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New Mexico Geology, v. 3, n. 2 pp. 22-24, Print ISSN: 0196-948X, Online ISSN: 2837-6420.
https://doi.org/10.58799/NMG-v3n2.22

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Cenozoic stratigraphy and structure of the Socorro Peak volcanic center, central New Mexico: a summary

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The purpose of this article is to review highlights of recent work on the Socorro Peak volcanic center and to summarize a lengthy dissertation (Chamberlin, 1980). The geologic framework of the Socorro geothermal area, which includes all of the Socorro Peak volcanic center, has been described by Chapin and others (1978). Geologic mapping in the Molino Peak quadrangle (Osburn and Petty, in preparation) and ongoing mapping in the southern Chupadera Mountains (Eggleston, in progress) has shown that the Socorro cauldron is a segment of a very large cauldron from which the Hells Mesa Tuff was erupted about 33 m.y. ago. These new data require some revisions of the stratigraphic sequence and cauldron relationships in the Socorro Peak area as previously described (Chapin and others, 1978; Chamberlin, 1980). New stratigraphic units described by Chamberlin (1980) appear in italics; these names are being formalized by Osburn and Chapin (in preparation).

Geologic setting

In central New Mexico, the Rio Grande rift has broken a northeast-trending chain of Oligocene cauldrons and surrounding volcanic plateau (part of the Datil–Mogollon volcanic field) into a series of north-trending, tilted, fault-block ranges and alluvial basins. The cauldrons lie along the ancient crustal flaw of the Morenci lineament, which has been reactivated within the rift as a deep-seated zone of lateral shearing (Chapin and others, 1978). This transverse shear zone is a diffuse domain boundary at the surface, where it separates fields of tilted fault blocks that are stepped down and rotated in opposing directions. In cross section, the closely spaced fault blocks look similar to a train of fallen dominoes (Chamberlin, 1978).

The Socorro Peak volcanic center (fig. 1) lies within the rift at the east end of the cauldron complex. The three mountain ranges and two flanking basins of the map area expose strata that range in age from Precambrian to Holocene (fig. 2).

Oligocene cauldrons

Strongly tilted (35–60 degrees) Oligocene volcanic strata exposed in ranges of the Socorro Peak volcanic center represent remnants of the northeastern part of the resurgent Socorro cauldron that is now correlated with eruption of the Hells Mesa Tuff. Approximately 0.9 km of densely welded cauldron-facies Hells Mesa Tuff is exposed in an east-dipping section on the resurgent dome in the northern Chupadera Mountains. Previously, this cauldron-facies tuff was correlated with the 28-m.y.-old *Lemitar Tuff* (Chapin and others, 1978; Chamberlin, 1980).

The great thickness of the intracaldera Hells Mesa Tuff and the presence of welded-tuff mesobreccias (rich in fragments of Precambrian rocks) are indicative of subsidence contemporaneous with the ash-flow eruptions. The mesobreccias were most likely derived from caving of an oversteepened wall on the southeast rim of the caldera (Eggleston, in progress). Bedded lag-fall breccias at the top of the cauldron-facies section contain fragments of semicongealed magma blown out of a nearby ignimbrite vent.

The northeastern structural-topographic margin of the Socorro cauldron is exposed in west-tilted strata on the east face of Socorro Peak. Here, landslide deposits derived from precaldera strata (Madera Limestone and Spears Formation) are banked against the topographic wall of the caldera. During resurgence, a moatlike area between the resurgent dome and caldera wall was filled to overflowing by alternating eruptions of andesite-to-rhyodacite lavas and lithic-rich, rhyolitic ash-flow tuffs. High-silica rhyolite domes and tuffs then capped the moat sequence. Assigned to the *Luis Lopez Formation,* these moat deposits range from 800 m, near the moat axis, to less than 200 m thick at the buried caldera wall. During filling, minor subsidence of the moat area occurred along faults

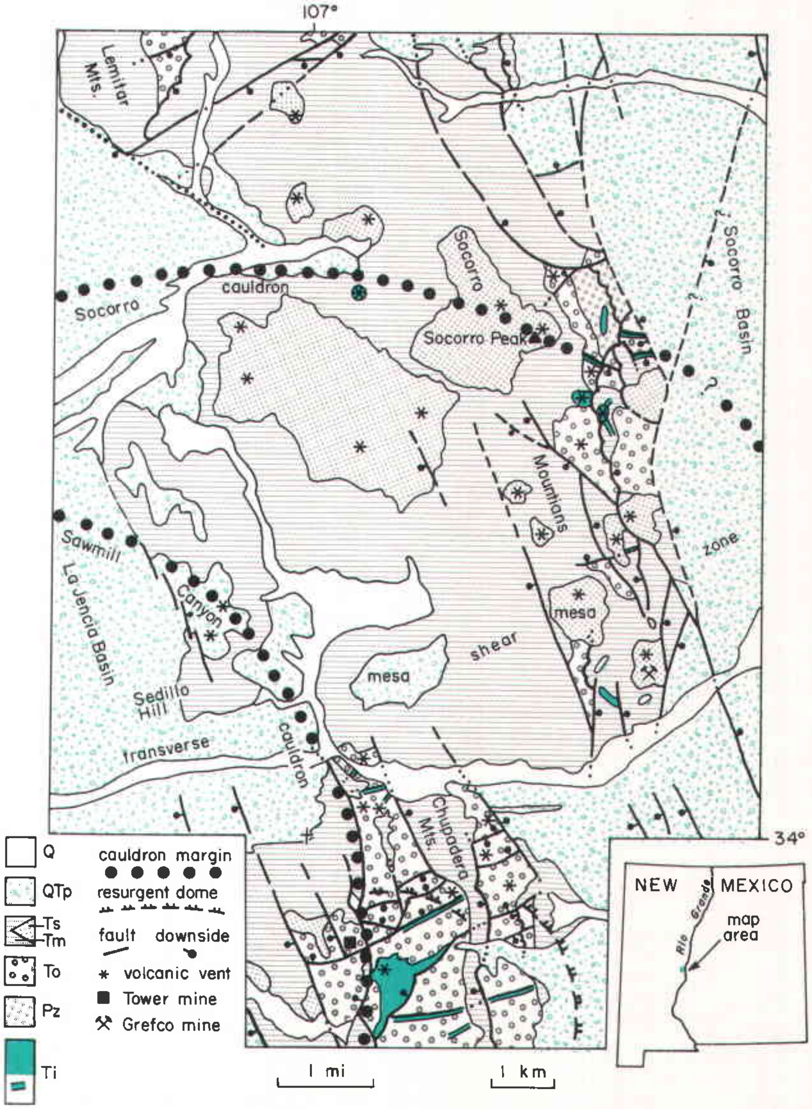

FIGURE 1—GENERALIZED GEOLOGIC MAP OF THE SOCORRO PEAK VOLCANIC CENTER; Paleozoic and Precambrian rocks (**Pz**), Oligocene volcanic rocks (**To**), Miocene Popotosa Formation (**Tm**), late Miocene *Socorro Peak Rhyolite* (**Ts**), Oligocene and Miocene intrusive rocks (**Ti**), Pliocene to Pleistocene Sierra Ladrones Formation and older piedmont gravels (**QTp**), and late Quaternary alluvium (**Q**).

Stratigraphic units

approximate age in m.y.		
	Surficial deposits (middle to late Quaternary)	
	Santa Fe Group: (Miocene to Pleistocene)	
4	basalt of Sedillo Hill >	Sierra Ladrones Formation
12-7	basalt of Bear Canyon > *Socorro Peak Rhyolite* > basalt of Kelly Ranch >	upper Popotosa Formation
	lower Popotosa Formation	
	rocks of the Datil-Mogollon volcanic field (Oligocene)	
26	tuff of South Canyon	
	upper La Jara Peak Basaltic Andesite	
28	*Lemitar Tuff*	
	middle La Jara Peak Basaltic Andesite	*unit of Sixmile Canyon (caldera fill)
	A-L Peak Tuff: pinnacles member	
	lower La Jara Peak Basaltic Andesite	
30	A-L Peak Tuff: flow-banded member	
33-29	*Luis Lopez Formation* (caldera fill)	
33 37	Hells Mesa Tuff *Spears Formation	erosional truncation at caldera wall near Socorro Peak
	Madera Limestone (Pennsylvanian) Sandia Formation (Pennsylvanian)	
	Precambrian rocks	

FIGURE 2—REVISED STRATIGRAPHY OF THE SOCORRO PEAK VOLCANIC CENTER (modified after Chamberlin, 1980); asterisk indicates unit present in subsurface only.

partly outlining the resurgent dome and along ring fractures at the margin; many of these faults acted as feeder dikes.

About 30 m.y. ago, the A-L Peak Tuff was erupted from the dumbbell-shaped Sawmill Canyon and Magdalena cauldrons (Chapin and others, 1978), which overlap the very large Socorro cauldron as redefined. Near the Tower mine (fig. 1), the resurgent dome of the Socorro cauldron is truncated by an arcuate fault zone that marks the eastern edge of the Sawmill Canyon cauldron. The eastern half of the Sawmill Canyon cauldron is filled with an anomalously thick section (0.5 km) of *Lemitar Tuff* that may have flowed into the preexisting Sawmill Canyon depression from a source to the west.

Development of rift structures

In the southern Lemitar Mountains, rhyolite to high-silica rhyolite ash-flow sheets of the A-L Peak Tuff, *Lemitar Tuff,* and tuff of South Canyon are separated by three northward-thickening tongues of the La Jara Peak Basaltic Andesite (redefined). This bimodal magmatic association marks the onset of rifting about 30 m.y. ago (Chapin, 1979). The compositionally zoned (64–77 percent SiO_2) Lemitar outflow sheet covered early rift blocks that were tilted 5–15 degrees. However, the distribution of the "synrift" (synchronous with rifting) tuff was not significantly affected because 100–200 m of potential fault-block topography was filled in by wedge-shaped prisms of basaltic-andesite lavas (Chamberlin, 1978).

In the Socorro area, near the axis of the rift, crustal extension has been accommodated mostly by progressive slipping and rotation of closely spaced, originally high-angle normal faults (referred to here as domino-style normal faulting). After 20–30 degrees of rotation the original set of domino faults is abandoned and the process continues on a second (and third and so on) set of domino blocks (Morton and Black, 1975). Thus, steeply tilted Oligocene strata are typically repeated by low-angle normal faults (fig. 1, cuspate fault traces) representing rotated early-rift faults. Relatively rapid periods of domino rotation, penecontemporaneous with silicic volcanism, are believed to reflect extreme heat flow and ductile necking of the lithosphere at relatively shallow depths (Chamberlin, 1978).

The Socorro Peak volcanic center lies along the Morenci lineament, a deeply penetrating crustal flaw with a marked tendency to "leak" magmas (Chapin and others, 1978). Within the rift, crustal extension in opposing directions has been accommodated at depth by lateral shearing along the lineament. North of this transverse shear zone, domino blocks are rotated westerly, and to the south they are rotated easterly. Where the transverse shear zone transects the Socorro Peak volcanic center (fig. 1) it appears to be a diffuse 8-km-wide zone of discontinuous transverse hinge faults and scissors faults that have accommodated differential rotation of the domino blocks. Narrow horsts and grabens formed by local overlap of opposing domino sets are relatively common in the transverse shear zone. Dips of strata generally decrease toward the axis of the shear zone that is locally marked by a null line of flat-topped mesas.

Early rift basins

Moderately tilted (10–30 degrees) Miocene strata of the Popotosa Formation, which crop out in the ranges and pedimented basin-margin blocks, represent fill of early-rift closed basins. By the early Miocene, domino-style extension had produced a broad sag across the rift. The distended floor of the lower Popotosa Basin in the Socorro Peak area was underlain by domino blocks tilted as much as 30 degrees. During the interval 25–20(?) m.y. ago, as much as 300 m of heterolithic mudflows and conglomerates, which are now anomalous in their extreme induration and brick-red color, were shed northward off cauldron-related highlands. The unusual character of the red mudflow facies may be due to contemporaneous hot-spring activity in the source area or to alteration during a subsequent geothermal event. Widespread potassium metasomatism of the Oligocene volcanic rocks in the Socorro–Magdalena area (Chapin and others, 1978) may be related to either an early Miocene hydrothermal event (Chamberlin, 1980) or a late Miocene hydrothermal event, or to both. At Socorro Peak, the red mudflow facies intertongues with more normal-looking gray fanglomerates shed from a persistent eastern margin of the Popotosa Basin. Oligocene rhyolite domes near the cauldron margin initially formed a topographic barrier separating the red and gray facies.

By middle Miocene time, about 20–12 m.y. ago, the heat-flow regime of the Datil volcanic period had dissipated. This caused a change in the style of rifting to that of wide tilted-block uplifts and basins (wide dominoes?). At this time, a large tilted block formed in the Magdalena area, approximately 15 km to the west, which changed the axis of the Popotosa Basin to a north-south trend. During this period, the Socorro Peak area was covered by as much as 800 m of playa deposits. These gypsum-bearing, calcareous, playa claystones intertongue with pale-red and buff-colored distal alluvial-fan deposits (conglomeratic sandstones) at the east and west fringes of the map area. At the Grefco perlite mine (fig. 1) uppermost Popotosa fanglomerates, which were derived from highlands east of the modern Rio Grande valley (Socorro Basin), bury the north flank of this 7-m.y.-old rhyolite dome.

From 12 m.y. to 7 m.y. ago, numerous silicic domes and tuffs of the *Socorro Peak Rhyolite,* which range from early rhyodacites to late-stage high-silica rhyolites, were periodically erupted onto the playa floor contemporaneous with ongoing sedimentation. The Socorro Peak volcanic center is essentially defined by this cluster of late Miocene silicic domes that now form the highlands of the Socorro Mountains. The vents for these domes delineate a north-northwest-trending intrusive belt, about 11 km long, which is widest where it crosses the buried ring-fracture zone of the Socorro cauldron. Thin flows of xenocrystic basaltic andesite (basalt of Kelly Ranch) and alkalic basalt (basalt of Bear Canyon) are interbedded in upper Popotosa playa muds, respectively below and above lavas of the *Socorro Peak Rhyolite.*

The modern ranges of the Socorro Peak volcanic center generally existed as shallow, suballuvial blocks prior to eruption of the *Socorro Peak Rhyolite.* This is indicated by prisms of the playa facies that wedge out under these lavas toward the crests of the modern uplifts. The playa facies also generally thins toward the south end of the map area. Here, blocks of Oligocene bedrock were unconformably overlapped by late Miocene lavas near the south (mostly structural) margin of the playa. During, or shortly after, the late Miocene silicic volcanism, a second period of domino-style normal faulting rotated upper Popotosa strata (and older faults and strata) as much as 15 degrees prior to deposition of the Sierra Ladrones Formation.

Late rift basins and ranges

Between about 7 m.y. and 4 m.y. ago, renewed high-angle normal faulting (horst and graben style), combined with epeirogenic

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uplift (Chapin, 1979), exhumed the Socorro and Lemitar blocks and elevated them sufficiently to topographically disrupt the Popotosa Basin. During this period, a major south-flowing river (the ancestral Rio Grande) entered and began to fill the developing Socorro Basin. Gently tilted (0–10 degrees) early Pliocene to middle Pleistocene strata of the Sierra Ladrones Formation form westward-thickening wedges in the Socorro and La Jencia Basins to the east and west of Socorro Peak (fig. 1). Just east of the high-angle (65–75 degrees) range-bounding fault zone at the foot of Socorro Peak, the Sierra Ladrones Formation is at least 350 m thick and may be significantly thicker. About 4 m.y. ago, olivine basalt lavas that were erupted from vents near Sedillo Hill (basalt of Sedillo Hill) flowed eastward down a broad valley cut on the upper Popotosa playa facies and onto channel sands of the ancestral Rio Grande (Sierra Ladrones fluvial facies). Since 4 m.y. ago, the modern ranges have continued to rise and shed piedmont gravels that intertongue with the fluvial sands.

In late Quaternary time continued uplift, faulting, and entrenchment of tributaries to the Rio Grande have all enhanced the modern topography. Upper Popotosa playa claystones on the flanks of the Socorro Mountains are largely masked by landslide blocks derived from the *Socorro Peak Rhyolite.* Patterns of elevation variation in late Miocene and Pliocene lavas, when coupled with modern drainage patterns, suggest the possibility of late Quaternary magmatic doming along an axis trending west-southwest from Socorro Peak.

Conclusion

The primary control of recurrent magma intrusion, hydrothermal activity, and silicic volcanism at Socorro Peak has been the "leaky" Morenci lineament, expressed as a transverse shear zone of the Rio Grande rift. Eruptive periods in the Socorro Peak volcanic center have been dated at 33–29, 12–9, 7, and 4 m.y. In light of this past history, it is not surprising that geophysically defined magma bodies, which provide a heat source for the present geothermal anomaly, are again rising under the Socorro Peak volcanic center.

ACKNOWLEDGMENTS—C. E. Chapin and G. R. Osburn, both of the New Mexico Bureau of Mines and Mineral Resources, critically reviewed this manuscript. Many of the key interpretations presented here were initiated by C. E. Chapin or developed jointly with him during the author's mapping of the Socorro Peak area. Financial support for the dissertation was provided by the New Mexico Bureau of Mines and Mineral Resources and by a grant (76-201) from the New Mexico Energy Resources Board through the Energy Institute at New Mexico State University.

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Chaco Energy donates $6,500 to Bureau of Mines

Chaco Energy Co. has given $6,500 to the New Mexico Bureau of Mines and Mineral Resources, a division of New Mexico Institute of Mining and Technology, as second-year funding to study fossil plant remains near Hospah in northwest New Mexico.

The nature of the plants is significant in the formation of the coal deposits leased by Chaco Energy Co. These plant remains include ancient tree stumps, leaves, and roots fossilized in place in the Cretaceous swamps, as well as driftwood bar and beach deposits. Standing fossil tree trunks in growth position are known from scattered areas of the San Juan Basin.

A. T. Cross, professor of geology at Michigan State University, and co-worker A. Jameossanaie are interpreting the plant collections. John Taylor of the Chaco Energy staff has mapped the geology of the fossil localities and provided cores of fossil-bearing rocks from Chaco's drilling program. Studies of nearby vertebrate fossils in coal-bearing Cretaceous rock beds are being conducted by D. L. Wolberg and studies of marine fossils by S. C. Hook, both paleontologists with the New Mexico Bureau of Mines and Mineral Resources.

Adobe production *(continued from p. 21)*

Map no.	County	Name and location	Telephone	Approximate annual production	Type production equipment
34	Santa Fe	Al Montano Rt. 2, Box 224 Santa Fe, NM	471-4227	2,000	Hoe, shovels, front-end loader, and wooden forms
35	Santa Fe	Albert E. Baca Rt. 1, Box 99 Santa Fe, NM	455-7542	3,000	Hoe, shovels, and wooden forms
36	Santa Fe	Rodriguez Brothers Rt. 6, Box 22 Santa Fe, NM	471-7570	100,000	Hoe, shovels, front-end loader, wooden forms, and delivery trucks
37	Santa Fe	Tod Brown c/o General Delivery Cerrillos, NM	No phone	3,000	Hoe, shovel, and wooden forms
38	Santa Fe	Montoya Adobes 420 Arroyo Tenorio Santa Fe, NM	988-3504	10,000	Hoe, shovel, and wooden forms
39	Taos	Emilio Abeyta P.O. Box 177 Rancho de Taos, NM	758-3022	12,000	Hoe, shovels, wheelbarrow, and wooden forms
40	Taos	Taos Pueblo Native Products P.O. Box 1846 Taos, NM Marrion Threehawks, Mgr.	758-8761	47,000	Backhoe, hoe, shovels, wheelbarrow, and wooden forms
41	Taos	Joe Trujillo P.O. Box 633 Rancho de Taos, NM	758-9768	60,000	Front-end loader, ready-mix mounted on ground, wooden forms, and delivery truck
42	Taos	Ralph Mondragon P.O. Box 199 Rancho de Taos, NM	758-3644	15,000	Pugmill, mud vehicle, and wooden forms
43	Taos	Joe Pacheco P.O. Box 174 Taos, NM	758-9848	2,000	Hoe, shovel, wheelbarrow, and wooden forms
44	Torrance	Humberto Camacho P.O. Box 631 Mountainair, NM	No phone	5,000	Hoe, shovels, wheelbarrow, and wooden forms
45	Valencia	Rio Abajo Adobes 105 W. Aragon Belen, NM Jerry Sanchez, Mgr.	864-6191	150,000	Front-end loader, wooden forms, and delivery truck
46	Valencia	Otero Brothers Rt. 2, Box 774 Los Lunas, NM	864-4054	40,000	Front-end loader, wooden forms, and delivery trucks
47	State of Chihuahua, Mexico	Alfonso Carrillo Las Palomas, Mexico	No phone	30,000	Hoe, shovels, and wooden forms
48	State of Chihuahua, Mexico	Leonardo Duran Las Palomas, Mexico	No phone	5,000	Hoe, shovel, and wooden forms