



Emory Cauldron, Black Range, New Mexico, source of the Kneeling Nun Tuff

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EMORY CAULDRON BLACK RANGE, NEW MEXICO

SOURCE OF THE KNEELING NUN TUFF

by

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INTRODUCTION

The Kneeling Nun Tuff, an ash-flow tuff (ignimbrite) of Oligocene age (33.4 ± 1.0 m.y.; McDowell, 1971), is best known for its exposures in the Santa Rita mining district. Its source is a large resurgent cauldron in the southern part of the Black Range in Sierra and Grant Counties, for which we propose the name *Emory cauldron*. It is one of the largest and best-exposed cauldrons yet described in North America. The central resurgent uplift, which nearly fills the cauldron, measures about 55 by 25 km, and is elongate parallel to the northerly trend of the Black Range. Peripheral fractures invaded by rhyolite domes extend outward for another 25 km from the cauldron margin. The outflow sheet of Kneeling Nun Tuff extends at least 30 km beyond the cauldron margin; its original extent is unknown and was probably much greater. Many of the faults associated with the cauldron were reactivated during a post-cauldron episode of Basin and Range faulting, which caused structural relief to be exaggerated. Deeper parts of the cauldron were subsequently exposed by dissection.

The southern part of the Emory cauldron is unusually well exposed and is accessible by many roads, including State Highway 90, a paved road. The northern part lies in the Black Range Primitive area and is poorly known and difficult to reach. This preliminary report deals mainly with the southern part.

The Emory cauldron is named after Emory Pass in sec. 15, T. 16 S., R. 9 W., which in turn was named after Lt. W. H. Emory, U.S. Army, who commanded a force that crossed the Black Range in 1846.

PREVIOUS WORK

The unit that later became known as the Kneeling Nun Tuff was noted by many early workers in the Santa Rita mining district. Prior to 1950 it was generally interpreted as a thick lava flow. Its welded tuffaceous nature was recognized by Eugene Callaghan and pointed out in 1950 to F. J. Kuellmer, H. L. Jicha, and W. E. Elston. Kuellmer (1953, and *in* Elston and Kuellmer, 1968) first described the anticlinal nature of the Black Range, which is now interpreted as a large resurgent dome. He also recognized a vent for the Kneeling Nun Tuff in a zone of large (up to 25 m) xenolithic blocks on the west side of the range (Fig. 1, in pocket). The Kneeling Nun Tuff is at least 400 m thick, and may be more than 1,000 m thick, in this area. Jicha (1954) and Elston (1957) recognized much thinner sections of the Kneeling Nun Tuff south and south west of the Black Range as an ignimbrite and part of an out-

flow sheet.

Giles (1967, 1968) made a detailed chemical and mineralogical study of the Kneeling Nun Tuff and showed it to be a zoned compound cooling unit made up of many flow units, using the terminology of Smith (1960). It is rhyolitic to quartz latitic at the base and latitic above. Ericksen and others (1970) prepared a reconnaissance map of the Black Range Primitive area, which includes the northern part of the Emory cauldron, and first suggested in print that the Kneeling Nun Tuff accumulated in a major cauldron and that the anticlinal nature of the Black Range may have resulted from resurgence. Their aeromagnetic map of the Primitive Area and our mapping of abrupt north-south thickness changes of Kneeling Nun in the vicinity of Hermosa are the basis of identifying the northern boundary of the cauldron.

Between 1971 and 1975, W. R. Seager and R. E. Clemons made geologic studies of the Black Range, including both detailed and reconnaissance mapping. These maps, as well as the geologic maps of the Dwyer and Lake Valley 15-minute quadrangles (Elston, 1957; Jicha, 1954), the Hillsboro Peak 30-minute quadrangle (Kuellmer, 1956), the section across the Black Range by Kuellmer (1954), and the map of Ericksen and others (1970), form the basis for this article. Current studies of the Hillsboro and San Lorenzo 15-minute quadrangles by D. C. Hedlund will provide further details of this complex range.

THE CAULDRON MODEL

According to the model of Smith and Bailey (1968), a resurgent cauldron is the usual source of a large ash-flow tuff sheet. The sheet has two facies: A thick cauldron facies, confined to a central area of subsidence and commonly more than 1,000 m thick, and an outflow facies that may spread over great distances but is considerably thinner (Figs. 2, 3). Its thickness ranges from tens or hundreds of meters down to a feather edge. The rocks of the cauldron facies may be domed by resurgence and the dome is commonly surrounded, and partly buried, by moat fill of pumiceous tuff, volcanoclastic sediments, landslide material, and lake deposits. The periphery of the cauldron is marked by a zone of ring fractures and radial fractures, which may be conduits for plugs, domes, and dikes of flow-banded rhyolite. At depth, cauldron fill is separated from an underlying stock that caused resurgence by a septum of pre-cauldron rocks invaded by dikes and sills.

Among the rocks in and around the Emory cauldron (Fig. 4), the Kneeling Nun Tuff occurs as both cauldron facies and

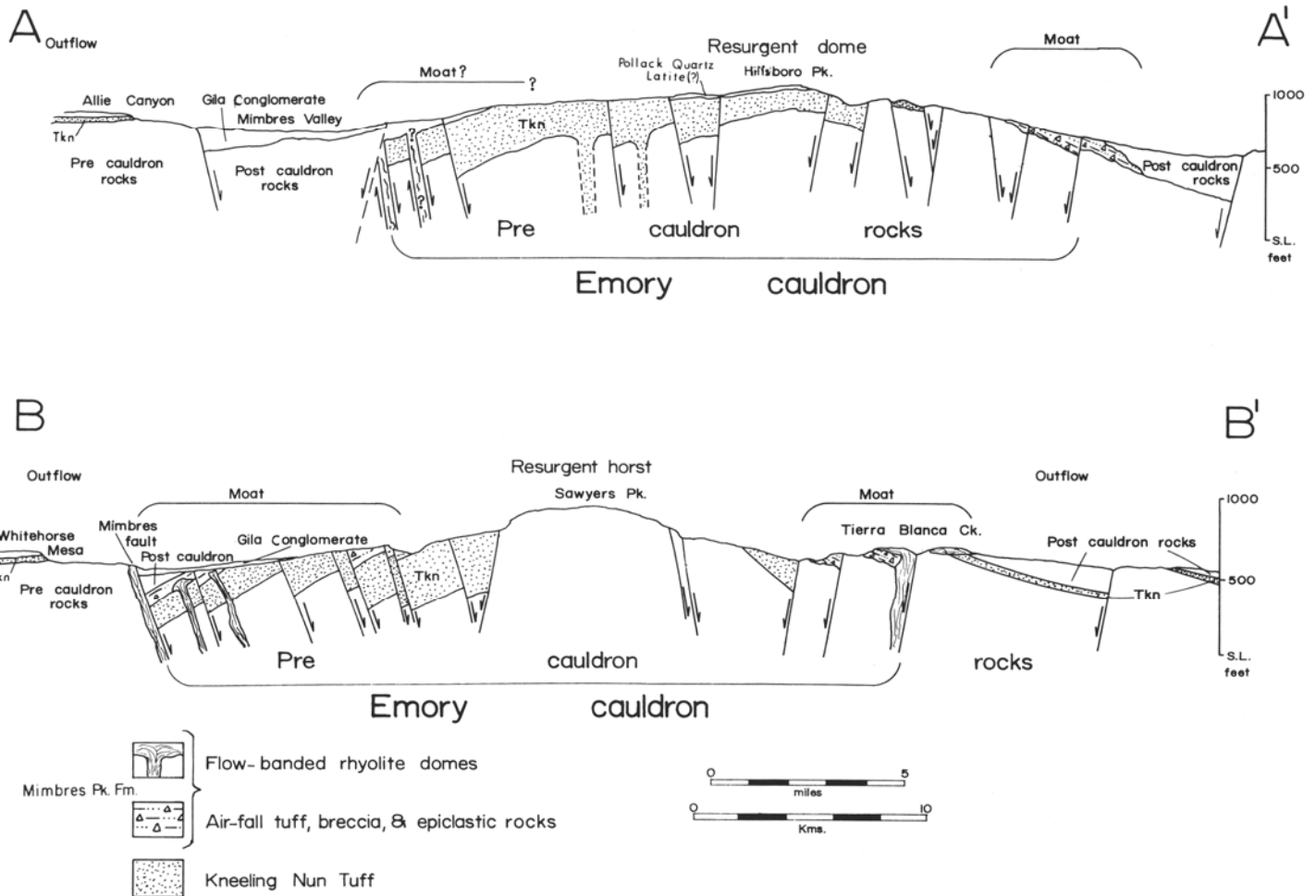


Figure 2. Cross sections through Emory cauldron and outflow areas.

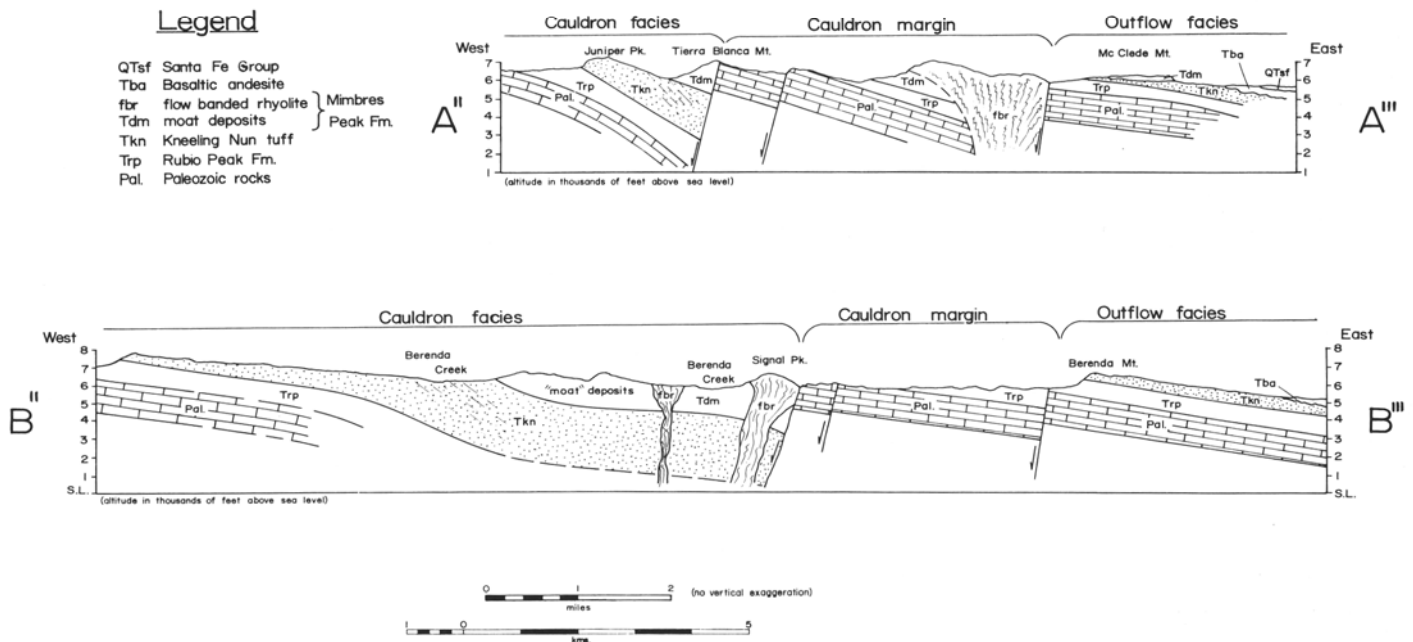


Figure 3. Cross sections through eastern margin of Emory cauldron.

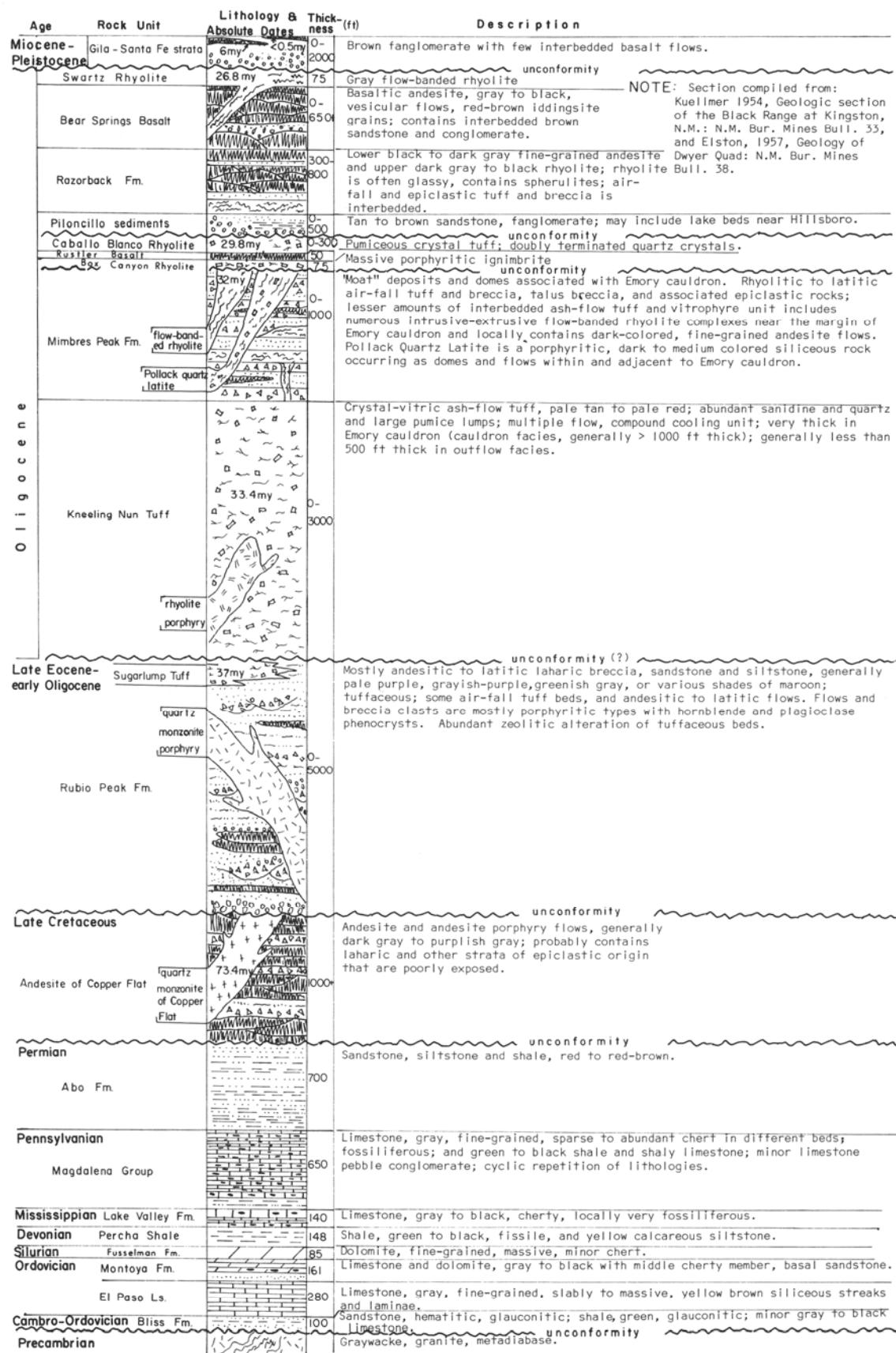


Figure 4. Composite columnar section of rocks exposed in and adjacent to the Emory cauldron.

outflow facies, totaling at least 900 cubic kilometers in volume and perhaps twice that amount. Pumiceous tuff and tuffaceous conglomerate of the Mimbres Peak Formation form moat fill. Domes of crystal-poor, fine-grained, flow-banded rhyolite of the Mimbres Peak Formation and of crystal-rich coarse-grained quartz latite of the Pollack Quartz Latite are controlled by ring-fracture faults and faults that transect the resurgent dome. Pre-cauldrón rocks are exposed in the core area of the resurgent dome, which includes a huge central horst, probably also of resurgent origin. Pre-cauldrón rocks also comprise much of the peripheral rim of the cauldron.

PRE-CAULDRON ROCKS

Precambrian and Paleozoic rocks underlie the Emory cauldron at shallow depth. Paleozoic carbonate rocks provide favorable ground for mineralization within the core area of the dome, particularly the central horst, where rocks are intensely fractured and altered, and around the periphery of the cauldron.

Brown to purple andesite and latite flows and flow breccias of the Rubio Peak Formation generally overlie the earlier rocks. West of the Mimbres River, along the boundary of the San Lorenzo and Dwyer quadrangles (Lambert, 1973; Elston, 1957), andesite overlaps Paleozoic and Cretaceous sedimentary rocks with angular unconformity, probably because of an intervening Laramide (50-75 m.y.) deformational episode. Although the Rubio Peak Formation has not yet been dated, its age is probably Eocene to earliest Oligocene; ages of similar rocks elsewhere range from 37 to 43 m.y. (Seager, 1973; Elston and others, 1973). At Copper Flat on the east side of the Black Range, rocks similar in appearance are locally altered and intruded by a monzonitic stock dated at 73 m.y. (Hedlund, 1974). So far, no reliable criteria are known for distinguishing pre-73 m.y. rocks from younger ones.

The rocks of the Rubio Peak Formation and those of the Emory cauldron follow smooth petrologic variation curves (Elston, 1957) and probably belong to a single calc-alkalic magma suite. The thickness of the Rubio Peak Formation is highly variable. The unit is absent beneath the Kneeling Nun outflow sheet near the Chino Mine at Santa Rita but thickens to an estimated 1,000 m or more toward the western margin of the Emory cauldron. Along the east side of the central horst of the Emory cauldron, the Rubio Peak Formation thins to a few hundred meters. It apparently erupted from a number of separate centers.

Around the western and southwestern flanks of the Emory cauldron, the Rubio Peak Formation and Kneeling Nun Tuff are separated by the Sugarlump Formation, which consists of light-colored beds of sandy tuff, tuffaceous sandstone, conglomerate, pumice flows, and thin ash-flow tuffs. On the western border and in the interior horst of the Emory cauldron, the Sugarlump Formation is thin or absent but toward the south and southwest its thickness increases to about 450 m. These relationships suggest that the area of what later became the Emory cauldron stood high before eruption of the Kneeling Nun Tuff. Overlap of Kneeling Nun Tuff on block-faulted Precambrian rocks north of Kingston indicates pre-Kneeling Nun tectonic uplift, but considerable elevation may also have been produced by the construction of Rubio Peak volcanoes in the Black Range area. At any rate, the Sugarlump Formation tends to fill low spots in the pre-Kneeling Nun topography and the base of the Kneeling Nun

Tuff forms a useful datum. A 36.9 m.y. date from the lowest of the Sugarlump rhyolitic ash-flow tuff beds at City of Rocks State Park suggests that the unit is substantially older than the Kneeling Nun, but uppermost pumiceous beds may be the earliest products of the Emory cauldron, precursors of the cataclysmic outbursts of Kneeling Nun Tuff.

CAULDRON ROCKS

Kneeling Nun Tuff

Cauldrón facies

The cauldron facies of Kneeling Nun Tuff consists of exceedingly massive rock, generally about 500 to 1,000 m thick. Jointing is rectangular rather than columnar and the rock lacks cavities. Eutaxitic foliation is expressed by abundant pumice fragments. The matrix of the tuff has been entirely recrystallized to spherulites of Na-sanidine and cristobalite, so that no shards are ordinarily preserved. Fragmented phenocrysts of zoned oligoclase-andesine, sanidine, quartz, and biotite are abundant.

Small xenoliths, mainly of Rubio Peak andesite, are sprinkled throughout the rock but become very large and abundant in a broad zone on the west side of the Black Range. Kuellmer (1954) interpreted the zone to be a vent for at least part of the Kneeling Nun Tuff. The rock there is a megabreccia which occurs in several north-trending bands up to 5 km long and 700 m wide. In places, the megabreccia zone contains considerably more xenolithic material than tuffaceous matrix. Individual blocks are up to 25 m long and locally are intimately intruded by veins and irregular bodies of Kneeling Nun Tuff. Even hairline fractures are filled with Kneeling Nun Tuff, evidence of extreme fluidity of the tuffaceous matrix. Abundance of rock types decreases with depth in the geologic column. About 90 percent consist of fragments of Rubio Peak andesite; the rest consists, in decreasing order, of red sandstone from the Abo Formation (Permian), Paleozoic carbonate rocks, and granitoid fragments (Kuellmer, 1954, and in Elston and Kuellmer, 1968). Some of the granitoid fragments appear similar to Precambrian granite, others resemble rhyolite porphyry that locally intrudes the Kneeling Nun, and others look like no other known rock of the region.

The thickness of Kneeling Nun Tuff of the cauldron facies has not been measured accurately. Apparently unbroken masses, of which neither tops nor bottoms are exposed, make up entire mountains of 300 to 500 m relief. Considering dips of 30 to 40 degrees and outcrop bands that are wide and apparently unfaulted, actual thickness could locally be greater than 1,000 m. Nearly 1,000 m of tuff was reported by Erickson and others (1970) from the Reeds Peak area.

Excellent sections of cauldron facies are exposed along Highway 90 west of Emory Pass, along the Royal John mine road, and on the southeastern side of the range in the upper reaches of Berenda and Tierra Blanca Canyons. In Tierra Blanca Canyon a zone of green tuffaceous sandstone separates two cooling units of Kneeling Nun Tuff. Farther north, Erickson and others (1970) recognized many flow units in the cauldron facies.

Outflow facies

The outflow facies of Kneeling Nun Tuff spread for at least 30 km from the cauldron margin (Fig. 1, in pocket). At Berenda, Sibley, and McClete Mountains on the eastern side of the

cauldron, the outflow facies is about 100 to 150 m thick. In the Cobre Mountains south of Santa Rita, about 15 km from the cauldron margin, the unit is up to 150 m thick (Giles, 1967). On the southwest side of the outflow sheet, the most distant exposures of welded Kneeling Nun Tuff form conspicuous cliffs 75 m high. Clearly the sheet spread farther than 30 km from the cauldron margin but has been eroded back. Columnar joints are well developed in the outflow sheet and the tops of columns are sheeted and cavernous.

The transition from cauldron facies to outflow facies is easy to locate because Kneeling Nun Tuff is thin or absent at the cauldron margin. On the southwestern side of the cauldron, for example, thick cauldron facies is exposed at Mimbres Hot Springs, in sec. 12 and MA sec. 13, T. 18 S., R. 10 W. Only 0.5 km to the south, in SEA sec. 13, T. 18 S., R. 10 W. the Kneeling Nun Tuff is absent and it is also missing at the point where the Mimbres fault crosses State Highway 61, in sec. 2, T. 19 S., R. 10 W. About 5 km to the west, outflow facies of Kneeling Nun Tuff about 75 m thick caps a prominent ledge called Rocky Ridge. Similar relationships can be seen in natural cross sections along Berenda and Tierra Blanca Canyons on the eastern side of the cauldron (Fig. 3).

The composite nature of the Kneeling Nun Tuff and its mineralogical and chemical variations were studied by Giles (1967, 1968). He described the outflow sheet in Lucky Bill Canyon, in the Cobre Mountains near Vanadium, N.M., as follows (Giles, 1968, p. 290-291):

The dominant exposures in the canyon are of the compound cooling unit of the Kneeling Nun, which in this area is around 420' thick. Five distinct and genetically related flow units have been recognized in the sheet; the upper four comprise the top 150'. The basal flow unit (270' thick) is a simply zoned cooling unit. It has a partially welded top and base (the grayish-pink slope formers) and a thick middle zone of dense welding (the bold red cliffs). Partings have been recognized in this flow unit, but they are scattered and discontinuous. The variations in welding are gradational and this part of the sheet has been interpreted as the result of a continuous eruptive episode.

"Phenocrysts in the unit range from 35 to 60%, and consist of quartz, sanidine, sodic plagioclase, biotite, opaque oxides, and trace amounts of sphene, zircon, hornblende, and clinopyroxene. The groundmass has been completely crystallized (devitrified), and there is a well-developed vapor-phase zone. The unit shows strong vertical compositional zoning that ranges from a basal quartz latite crystal-vitric tuff to an overlying latite crystal tuff. Variations may be abrupt but they are systematic, and consist of an upward increase in the number and size of phenocrysts, and in the proportion of ferromagnesian and plagioclase phenocrysts, with an accompanying decrease in the amount of quartz and the alkali feldspar/plagioclase ratio. Examples of such variation in the Lucky Bill Canyon section are the upward decrease in quartz from 36 to 5% (of phenocrysts) and of the alkali feldspar/plagioclase ratio from 2.0 to 0.25 ...

"All of the data is consistent with the explanation of an upward gradation and differentiation of progressively silicic and less crystal-rich melt within the pre-eruptive Kneeling Nun magma chamber."

MOAT AND RING-FRACTURE DEPOSITS

Mimbres Peak Formation

Eruption of the Kneeling Nun Tuff was followed by an episode of resurgent doming within the cauldron and by erosion of the tuff from the cauldron margin. This was succeeded by widespread eruptions of pumice flows, domes and

dikes of flow-banded rhyolite, and deposition of local conglomeratic and sandy beds. These were collectively defined as Mimbres Peak Formation by Elston (1957) and a date of 32.0 ± 1.0 m.y. for one of the domes was given by Elston and others (1973). We now interpret these deposits as moat fill and as material on the outer rim of the cauldron, erupted from a broad system of ring fractures.

The Mimbres Peak Formation is extremely variable in detail. In general, the basal part of the section consists of rhyolitic pumiceous tuff in beds 1 to 2 m thick intruded and overlain by flow-banded rhyolite. Curiously, the pumiceous tuff characteristically contains inclusions of the overlying flow-banded rhyolite. This suggests that the separation of rapidly-moving pumiceous foam from slowly-moving magma occurred at a depth where the magma was at least partly solidified. In at least one area close to the cauldron margin (Donahue Canyon, NE1/4 sec. 25, T. 18 S., R. 10 W.), rhyolite of a protrusive dome contains abundant irregular inclusions of Kneeling Nun Tuff without chilling effects. Phenocrysts are sparse in both tuff and flow rock. They consist of a few percent of quartz, sanidine, oligoclase, biotite, and rarely, hornblende. Along the eastern margin of the cauldron, andesite flows are interbedded with the rhyolitic moat deposits. It is not known whether the andesites are of intracauldron or extracauldron origin.

Within the Emory cauldron, the Mimbres Peak Formation evidently filled a subsiding moat that surrounded the resurgent dome. Rock masses exposed in fault blocks along the inner side of the cauldron margin are locally about 1,000 m thick. Outside the cauldron, moat deposits locally are entirely absent within a few kilometers of the cauldron margin (Fig. 1, in pocket). Elsewhere, however, the thickness of bedded pumiceous tuff decreases systematically with distance from the margin. This is well-documented on the southwestern side. Near the cauldron margin, in Carisa Canyon (sec. 15, T. 18 S., R. 9 W.), bedded pumiceous tuff is about 1,000 m thick. To the southwest, in Donahue Canyon, about 8 km outside the cauldron margin, the exposed thickness is 200 m but the base is not exposed. On Mimbres Peak (sec. 8, T. 19 S., R. 10W.) about 15 km from the cauldron margin, the thickness is about 100 m and south of Santa Rita, about 20 km from the cauldron margin, Hernon and others (1964) found only a few meters of pitchstone and sandstone. At greater distances from the cauldron margin the pumiceous tuff is absent, although domes and flows of rhyolite, of the type that elsewhere overlies the tuff, remain. This can be seen at Taylor (Mimbres) Mountain (sec. 17, T. 20 S., R. 11 W.), about 25 km from the cauldron margin, and near Faywood Hot Springs (secs. 15, 16, 21, 22, T. 20 S., R. 11 W.) about 30 km from the cauldron margin.

Progressive thinning of the Mimbres Peak pumiceous tuff on the flanks of the cauldron does not mean that it was once a continuous blanket. There is good evidence that it erupted from local sources along faults and thinned rapidly between fault zones. This can best be seen on Mimbres Peak, where a section of tuff about 100 m thick thins to a few meters over a distance of about 500 m. However, the ratio of pumiceous tuff to flow rocks seems to decrease systematically with distance from the cauldron margin.

The shape of intrusive rhyolite bodies of the Mimbres Peak Formation also seems to change with distance from the cauldron margin. In the zone of ring fractures the intrusions are domes, strongly elongated parallel to the cauldron margin.

This can be seen between Donahue Canyon and Mimbres Hot Springs. Some distance outward from the cauldron margin, dikes controlled by fractures radial to the cauldron margin, appear. This can be seen in the area where the Mimbres fault crosses the Mimbres River (secs. 1 and 2, T. 18 S., R. 10 W.) about 10 km from the cauldron margin. At a greater distance outward, intrusions of Mimbres Peak Rhyolite become nearly circular in plan and are no longer controlled by major faults. Examples can be seen at Taylor Mountain and near Faywood Hot Springs. These intrusions, 2 km in diameter, have domed surrounding rocks, somewhat in the manner of salt domes.

We interpret variations in the distribution of the Mimbres Peak Formation as reflecting the shape of an underlying magma chamber. The chamber may have had the shape of a broad cupola in which volatile constituents accumulated near the top. The highest apophysis was the source of the Kneeling Nun Tuff and became the Emory cauldron, but the magma chamber extended in the subsurface for at least 30 km from the southwestern cauldron margin. The greater the distance from the cauldron, the greater the depth to the magma chamber, the drier the magma and the lower the ratio of pumice froth to flow rock (Fig. 6, no. 4). On the eastern cauldron margin, the band of Mimbres Peak occurrences is only about 10 km wide and the east side of the magma chamber is interpreted as dipping more steeply than the west side.

The northward extent of Mimbres Peak Formation is unknown. Ericksen and others (1970) mapped a unit which they called the rhyolite of the Moccasin John area, and they discussed the "possibility that this rhyolite sequence is equivalent to the Mimbres Peak Formation of Elston (1957, p. 27)."

Pollack Quartz Latite

The Pollack Quartz Latite of Jicha (1954) is a flow-banded rock that forms dome complexes in the northern part of the Lake Valley quadrangle and in the northeastern corner of the Dwyer quadrangle. The latite porphyry of Holden Prong of Ericksen and others (1970), up to 500 m thick, is probably the same unit. It underlies a considerable area near the crest of the Black Range, north of Emory Pass.

Unlike the Mimbres Peak Rhyolite, which tends to be poor in crystals, the Pollack Quartz Latite is conspicuously porphyritic. Phenocrysts are up to 12 mm long. Oligoclase-andesine is the most prominent mineral and occurs with quartz, sanidine, biotite, and brown hornblende. Jicha (1954) stressed resemblance in the field to the Kneeling Nun Tuff, aside from phenocryst size. Ericksen and others (1970) mentioned that the lower part of the latite porphyry of Holden Prong intertongues with the upper part of the Kneeling Nun Tuff.

The occurrence of two sets of flow-banded dome complexes around cauldrons, one crystal poor and the other crystal rich, has been noted at the Bursum cauldron (Rhodes, 1970) and the Mount Withington cauldron (Deal, 1973). Elston and others (1970, 1972) termed the crystal-poor rocks "framework" lavas, because they seem to form a framework emanating from the larger pluton that fed the cauldron. They are interpreted as direct offshoots from the pluton that had begun to crystallize under equilibrium conditions. In contrast, the crystal-rich rocks are confined to the area of the cauldron and were termed "cauldron" lavas. They were interpreted as the residue of the volatile-rich fraction of the magma that accumu-

lated in a local apophysis of the pluton, or in a secondary magma chamber, and partially evolved into the ash-flow tuff. The large grain size reflects the high volatile content of their environment, and their disequilibrium textures (strongly zoned plagioclase, partly resorbed phenocrysts) reflect the progressive lowering of the liquidus as volatile content increased. The rhyolite of the Mimbres Peak Formation and the Pollack Quartz Latite appear to correspond to "framework" and "cauldron" lavas of the Emory cauldron, respectively.

Rhyolite Porphyry

Intrusive rhyolite porphyry of Kuellmer (1954), also called coarse rhyolite porphyry by Ericksen and others (1970), is a rock with granitoid, locally pegmatitic, texture (Rabb Canyon pegmatite, Kelley and Branson, 1947). It forms irregular, but generally north-trending dikes that transect Kneeling Nun Tuff along the crest of the resurgent dome, and along the western boundary fault of the central horst (Fig. 1, in pocket). Phenocrysts comprise up to 60 percent of the porphyry and consist largely of euhedral quartz and chatoyant sanidine with lesser plagioclase and biotite. Both Kuellmer (1954) and Ericksen and others (1970) noted the petrographic similarities, except for grain size, with the Kneeling Nun Tuff.

These similarities, together with its distribution along the axis of the resurgent dome, suggest that the rhyolite porphyry may be part of the magma pulse that caused resurgence. In that case, the rhyolite porphyry may be a phase of the framework lavas. Its greater degree of crystallinity, compared with flow-banded rocks of the Mimbres Peak Formation, and the occurrence of pegmatites may reflect volatile-rich conditions in the resurgent upper part of the magma chamber.

Rhyolite porphyry dikes also appear to have invaded the western boundary fault of the central horst. This indicates the central horst was raised initially as part of the resurgent process, although late Tertiary movement also may have been important. Base-metal mineralization in Paleozoic carbonate rocks adjacent to the western boundary fault probably was introduced by the rhyolite porphyry (D. C. Hedlund, personal communication).

POST-CAULDRON ROCKS

The resurgent dome-horst couplet of the Emory cauldron stood high above the surrounding region, and the highest part may never have been covered by later volcanic rocks. The flanks were progressively buried by post-cauldron rocks. For example, Box Canyon Rhyolite ash-flow tuff is known only from the Cobre Mountains, part of the outflow area of Kneeling Nun Tuff west of the Emory cauldron. It is not known from the cauldron area. The stratigraphically higher Caballo Blanco Rhyolite ash-flow tuff overlies moat deposits of the Mimbres Peak Formation in the zone of peripheral fractures and overlies the Kneeling Nun Tuff on the lower flanks of the dome.

Basaltic andesite flows equivalent to the Razorback and Bear Springs Formations of the Mimbres Valley (Fig. 4) are the youngest mid-Tertiary volcanic rocks to overlap parts of the Emory cauldron. Rocks equivalent to the great rhyolite complexes of the Mogollon Plateau (<28 m.y.) are absent. Large areas of the cauldron flanks were buried under late Tertiary fanglomerate (Gila or Santa Fe Groups) derived from Basin and Range fault blocks. Locally, basalt flows intertongue with fanglomerate. Later, modern drainage was incised and

Quaternary terrace and pediment gravels, as well as basalt flows, were deposited on local surfaces.

CAULDRON STRUCTURES

Regional Setting

The region of the Emory cauldron has undergone repeated periods of deformation, and it is generally difficult to distinguish structures related to the cauldron from those that formed earlier or later. Reactivation of faults is common. Some faults of the ring-fracture zone are reactivated Laramide structures and were again active during Basin and Range faulting, long after the cauldron had become extinct. For example, the Mimbres Fault was active in Laramide time (Jones and others, 1967). It was one of the conduits for rhyolite domes of the Mimbres Peak Formation during development of the Emory cauldron, and it became a Basin and Range fault in late Tertiary time. The Mimbres fault, and its probable southward extension, the Sarten fault, form an arc, convex to the north-east. Only in the area where this arc intersects the ring-fracture zone of the Emory cauldron, between the north end of Cookes Range and San Lorenzo, does it locally become convex to the southwest, concentric to the southwestern margin of the cauldron. It was in this segment that the Mimbres fault was invaded by rhyolite domes (Fig. 1, in pocket).

The Emory cauldron shares its northerly trend with other structures of different ages. The Santa Rita-Hanover axis (Aldrich, 1972) apparently began as a Laramide structure and was repeatedly activated. The Goodsight-Cedar Hills volcano-tectonic depression, of about the same age as the Emory cauldron (26-38 m.y.), has northerly elongation (Seager, 1973). Late Tertiary Basin and Range structures of the region have a pronounced northerly trend. They include the present-day Black Range and Rio Grande rift.

Ring Fractures

Most of the ring fractures bordering the eastern and western margins are nearly linear because the Emory cauldron is elongated. The ring-fracture zone is unusually wide, about 25 km on its southwestern side, but the cauldron margin proper, as shown by outcrops of cauldron and outflow facies, is only 3 to 5 km wide and involves only 1 or 2 major faults (Fig. 1, 2 and 3). The northern end of the Emory cauldron has not been mapped in detail and much of its southern end is covered by moat deposits or late Tertiary gravel. These margins are inferred from aeromagnetic data (Ericksen and others, 1970), gravity data (Fig. 5), and from the distribution of cauldron facies and moat deposits.

The ring fractures are sets of major normal faults that dip toward the cauldron and are downfaulted toward the interior of the cauldron. The two sides of the Emory cauldron, on opposite flanks of the Black Range, are nearly mirror images of each other. The geometry of the eastern cauldron margin is well exposed in Berenda and Tierra Blanca Canyons (Fig. 3). In this area, cauldron facies on the down side of a major fault are separated from outflow facies by a block in which moat deposits overlie pre-cauldron rocks. Flow-banded rhyolite domes are related to the faults. Faults of the ring-fracture system are not confined to the periphery of the cauldron, however; the resurgent dome is also faulted.

Ring-fracture faults seem to have been active in at least two stages during evolution of the cauldron: (1) during subsidence

to allow accumulation of the thick cauldron facies of Kneeling Nun Tuff, and (2) after resurgence to cause uplift of the cauldron margin and to provide conduits for Mimbres Peak and Pollack domes. In terms of total movement, uplift of the cauldron during doming was greater than collapse along ring-fracture faults. Overall structure of the Emory cauldron is that of a domal uplift in spite of the systematic inward down-stepping by faults of the ring-fracture system (Fig. 2, Section A-A').

Resurgent Uplift

Domal structure of the Emory cauldron developed in at least two stages: (1) during resurgence and (2) during Basin and Range faulting. Planar pumice fragments in the cauldron facies of Kneeling Nun Tuff dip away from the dome's axis with an average of about 35 to 40 degrees. Overlying post-cauldron rocks, such as Caballo Blanco Rhyolite, dip about 30 degrees. The original dip of the resurgent dome must have been about 10 degrees.

South of Emory Pass, the resurgent dome passes into the huge north-trending resurgent horst described earlier (Fig. 2, section B-B'). Because of uplift of the horst and subsequent erosion, pre-cauldron rocks as old as Precambrian are exposed at the crest of the dome. These rocks are altered, intensely fractured, and invaded by rhyolite and rhyolite porphyry dikes and sills. The rhyolite porphyry may represent apophyses of the magma body that pushed up the dome-horst couplet. The gravity pattern (Fig. 5) confirms that the core of the dome and the horst is underlain by low-density rocks, presumably intrusive, and that the exposed pre-cauldron rocks in the horst are rootless (Krohn, 1972; C. A. Swanberg, unpublished gravity maps). All other exposures of pre-Tertiary rocks in the region are associated with rooted basement uplifts and are marked by clear gravity highs. The block of pre-cauldron rocks at the heart of the Emory cauldron alone has a negative gravity signature. It is part of a large gravity low that marks the entire Emory cauldron.

Unlike some of the other resurgent cauldrons described by Smith and Bailey (1968), doming of the Emory cauldron occurred prior to deposition of moat fill. This is shown by the angular unconformity between Kneeling Nun Tuff and Mimbres Peak Formation and can be seen best in Tierra Blanca Canyon along the east margin of the cauldron (Figs. 2, 3).

POST-CAULDRON STRUCTURES

Much of the present topographic and structural relief results from late Tertiary uplift and faulting. Post-cauldron rocks as young as Gila and Santa Fe define an arch coincident with the resurgent dome. Late Tertiary arching may be an isostatic response to the buoyant effect of the lightweight batholithic roots of the range. Late Tertiary faulting on the flanks of the arch is generally confined to older cauldron-margin faults. The relative sense of movement is the same as in earlier episodes and has greatly increased the structural relief. This is indicated by the increase in dip of the Kneeling Nun Tuff from an initial 5 to 10 degrees to the present 35 to 40 degrees. Relative uplift of the central horst caused the Kneeling Nun Tuff to be entirely eroded away above it, exposing pre-cauldron rocks beneath. Total structural relief from the top of the horst to adjacent deep parts of the Rio Grande rift may be 5 km or more (J. Callender, personal communication).

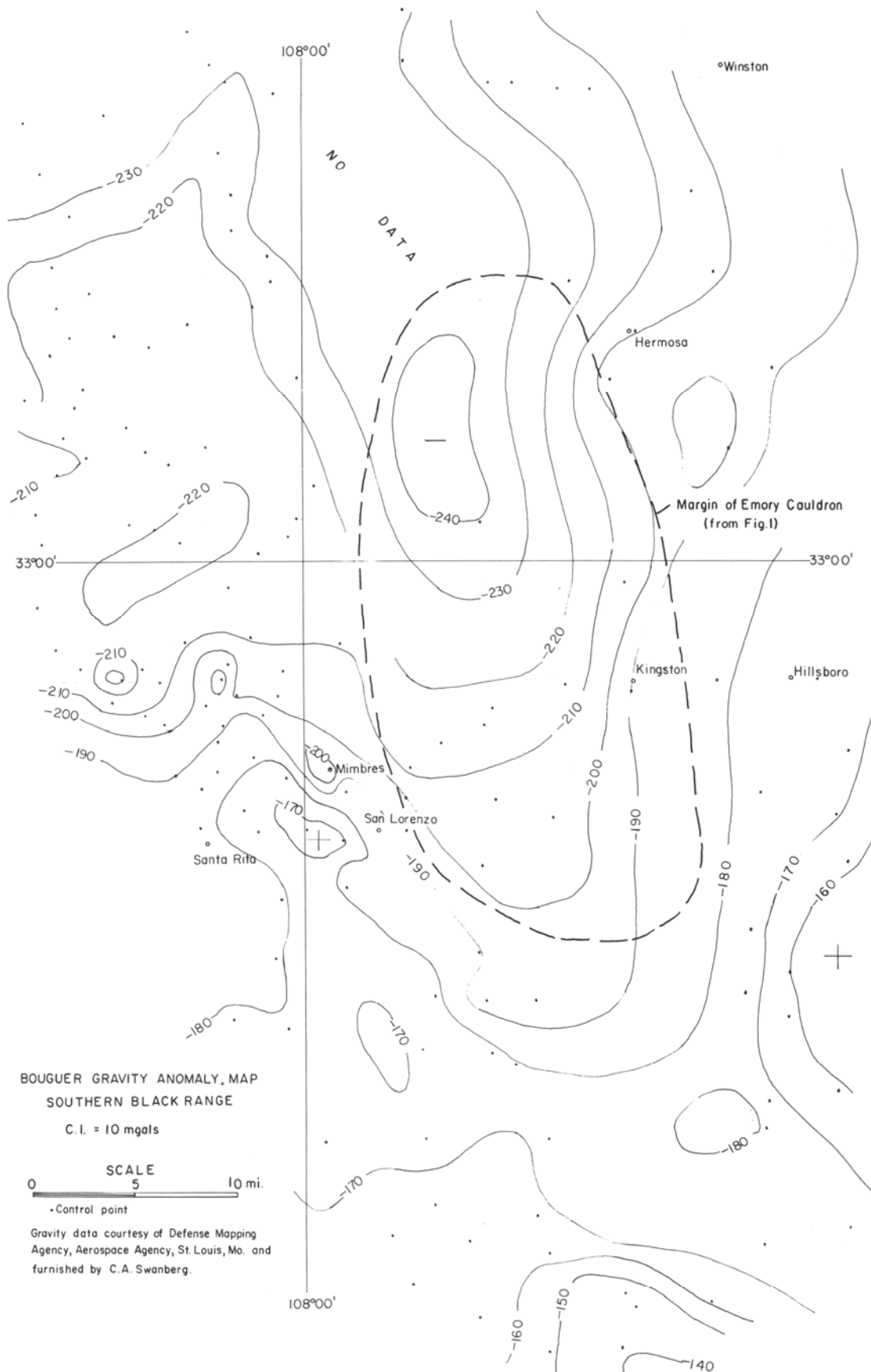


Figure 5. Bouguer gravity anomaly map of the southern Black Range area.

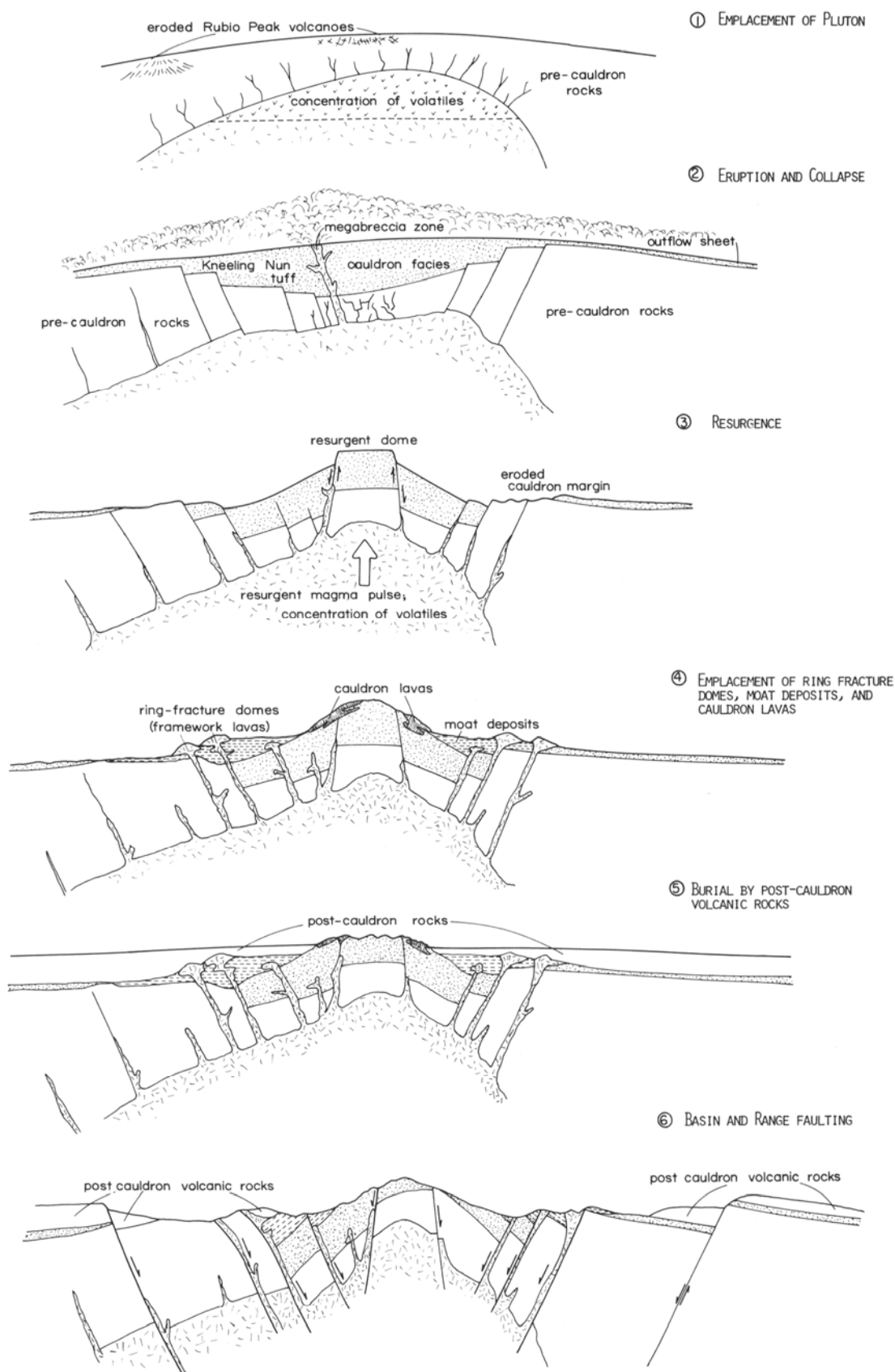


Figure 6. Diagram illustrating sequential evolution of the Emory cauldron.

There are no structural indications of absolute movements of Basin and Range faults. The Hillsboro and Hermosa fossil floras discussed by Axelrod (this guidebook) come from post-cauldron or moat deposits near the rim of the Emory cauldron. If Axelrod's analysis of climate and altitude of these floras is correct, Basin and Range movements would involve only differential collapse and subsidence of the region, rather than uplift of the resurgent dome and depression of surrounding basins. The cauldron rim would have been lowered about 700 m since the plants grew, but the surrounding basins would have been depressed 3 km or more.

SUMMARY OF GEOLOGIC HISTORY

Figure 6 illustrates an interpretation of the stages of development of the Emory cauldron.

1. Uplift of the site of the Emory cauldron, probably by block faulting and by construction of andesitic volcanoes, as suggested by thinning of the Sugarlump Formation and by pre-cauldron structures.
2. Eruption of Kneeling Nun Tuff along megabreccia zones; caldera subsidence along ring fractures.
3. Doming and uplift of the central horst by resurgence of underlying magma chamber; base-metal mineralization in Paleozoic rocks; erosion of Kneeling Nun Tuff from cauldron margin.
4. Deposition of moat fill and eruption of domes of Mimbres Peak Formation and rhyolite porphyry (framework lava) and Pollack Quartz Latite (cauldron lava) along ring fractures and at the crest of the resurgent dome. At some distance from the cauldron, the magma which was tapped was relatively dry, the framework lavas are relatively fine-grained, and the ratio of pumice to flow rock becomes progressively lower.
5. Partial burial of Emory cauldron by post-cauldron volcanic rocks.
6. Late Tertiary arching, renewed movement on ring fractures, and exaggeration of vertical relief. Relative movement may have involved differential collapse and subsidence or the high present-day elevation of the resurgent dome may reflect isostatic uplift. Subsequent erosion resulted in the exposure of pre-cauldron rocks within the resurgent dome.

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