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ORIGIN OF THE CAT MOUNTAIN RHYOLITE[1/]

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INTRODUCTION

The main rock unit exposed in the southern half of the Tucson Mountains was named the Cat Mountain Rhyolite by Brown (1939). He considered it to be a series of rhyolite flows and mud flows which he assigned to the middle of Tertiary time. In later work (Kinnison, 1958; Taylor, 1959), a *nuée ardente* origin was assigned to the unit and it became classified a welded tuff. Kinnison (1959) described and mapped the chaotic megabreccia which underlies the Cat Mountain Rhyolite, naming it the Tucson Mountain Chaos and postulating a sedimentary tectonic origin for the unit.

The current study suggests that the chaos is part of a volcanic sequence which includes the Cat Mountain Rhyolite, the lower portion of Brown's Safford Tuff in that area, and concludes with the spherulitic rhyolite intrusives. This sequence has been assigned to Maestrichtian (uppermost Cretaceous) time by K-Ar dating of Cat Mountain feldspars (Damon and Bikerman, 1963).

GENERAL PETROGRAPHY

The Cat Mountain Rhyolite is a welded tuff of ash-flow origin, following the usage of Smith (1960a). The main unit of the formation consists of at least two ash flows which can be distinguished on petrographic and radiochemical bases (Bikerman, 1962). The formation shows several vertical and horizontal changes in density and induration with the degree of welding. Using Smith's (1960b) definitions, zones of no welding and zones of partial to moderate welding as well as poorly developed granophyric zones are found, although they are somewhat obscured by later alteration.

The general rock type is a rhyolite-to-quartz latite containing phenocrysts of quartz, K-spar, altered plagioclase, and magnetite. Hornblende and biotite are rare to absent in all sections studied. The quartz shows characteristic embayment in all zones studied. The nonwelded zones have a matrix containing nearly undeformed glass shards and pumice fragments. This is seen particularly well in the distal end of a small ash flow exposed just south of Ajo Road and Quarry Hill (see also Kinnison, 1958). In the more indurated samples the matrix is generally brown or orange in color, sometimes nearly opaque and

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is composed of devitrified or altered glass and small pumice shards. The color is caused by the presence of hematite, either disseminated or in small discrete specks.

In the chaos portion of the sequence, the groundmass where observed was a devitrified altered glass having no recognizable individual glass shards. In both the chaos matrix and in the welded zones above the chaos, a pervasive calcite alteration on feldspars, particularly the plagioclases, was found. The main petrographic difference between the chaos and overlying ash flows is in the xenolith content of the various units. The chaos contains a variety of sizes of xenolithic material ranging from large blocks of Amole Arkose and Paleozoic limestones to millimeter-sized arkose and andesite inclusions. In thin section the foreign material makes up 30 to 40 percent of the rock. In contrast, the ash flows contain fewer and smaller xenoliths, and the upper unit is cleaner than the lower. Furthermore, the overlying Safford Tuff contains considerably fewer xenoliths, and the spherulitic rhyolite nearly none. In all cases the xenoliths are of the same arkose or andesite composition with rare carbonates present. This variation is important in the development of the following vulcanologic theory.

VULCANOLOGY

First, a review of modern thinking on pyroclastic volcanics may be of value to the reader. Early work considered acidic extrusive sheets as true liquid flows or as interbedded liquid flows, mud flows, and ash falls. Observations on the nuée ardente eruptions at Mount Pelee and La Sourfriere in 1902, 1903, and later, combined with studies of the Katmai eruption (Fenner, 1923) and those of Vesuvius and various volcanoes in Japan and the East Indies, brought about a change of thinking toward a particulate gas-flow origin for these rocks.

The importance of a gaseous suspension of liquid droplets and solid magmatic (and xenolithic) particles was emphasized in work by Gilbert (1938) and Reynolds (1954), among many others. Marshall (1935) defined the term "ignimbrite" for deposits formed by a nuée ardente mechanism. Lately the differences between the small observed nuée ardente eruptions and the large-scale eruptions that produce ignimbrites or ash flows (Smith, 1960a) have been emphasized. Papers by Smith (1960a and b), Ross and Smith (1961), van Bemmelen (1961), and Fisher (1960), among others, have established criteria for classification and identification of these units.

For example, the Cat Mountain Rhyolite, having an estimated area of nearly 30 square miles and an average thickness of 400 feet or so (an approximate volume of 10 cubic kilometers), would fall into the fissure- and multiple-vent source class. This class is thought to be associated with important subsidence structures (Smith, 1960a, fig. 3). It would furthermore be characterized as an ignimbritic eruption (high gas content and high viscosity magma) by van Bemmelen (1961).

Observations in the Tucson Mountains do not support the existence of cratering or caldera collapse. Possibly Mackin's (1960) ideas, that subsidence in the basins accompanied the ignimbrites, are applicable here.

The chaos unit is a pyroclastic flow breccia (Fisher, 1960) of probable true nuée ardente-type origin. A further application of the concepts of fluidization as originally applied to geology by Reynolds (1954) is being made by Mayo (1963) to explain the chaos unit and related problems in the Tucson Mountains.

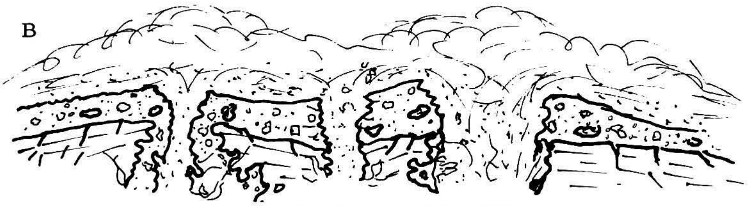
THE CAT MOUNTAIN VOLCANIC HISTORY

The postulated sequence of events for the Cat Mountain formation began with rising magma stoping its way slowly up through the basement complex, the Paleozoic limestones, and the Mesozoic arkoses and andesites. This material rose rapidly enough so that the stoped fragments did not have a chance to be assimilated into the magma and yet sufficiently slowly to allow silica replacement of parts of the limestone blocks. The upper front of the rising magma was cooled and its gas content increased by the presence of the included material. It probably was a partially molten, gas-rich mass when it pushed up through the pre-existing surface in several fissures (or possibly vents). On reaching the surface, the material erupted with sufficient force to spread large blocks of the competent limestone quite far from the sources (fig. 1A). The temperature of emplacement was below that needed to produce welding. This origin explains the "cooling rims" around some of the longer xenolithic blocks, as well as explaining the tuffaceous matrix and general appearance and distribution of the unit. However, the presence of rounded conglomerate zones (Kinnison, 1959) suggests interspersed times of erosion on the newly formed volcanic piles between successive pulses of eruption; or perhaps the rounded cobbles are the results of entrainment in the gas phase of the rising magma and subsequent dumping. The number of pulses of nuee activity has not been determined as yet. Part of the problem in determining the number of pulses lies in the dual nature of a nuee ardente. A nuée ardente consists of a lower avalanche portion containing the bulk of the solid material which closely follows the existing depressions in the terrain (the "ladu"), and an upper freely moving cloud (nuage) whose deposits closely resemble an ash or tuff fall, or the nonwelded portions of an ash flow. This upper part produces thin, easily eroded ash zones.

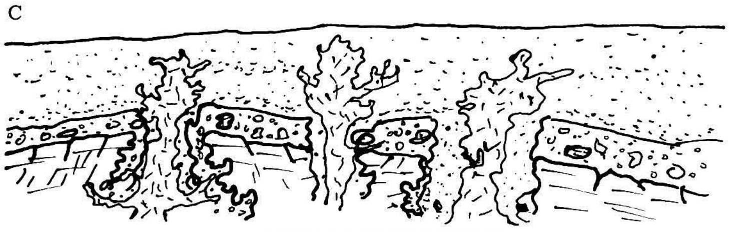
The main series of ash-flow eruptions followed the nuée ardente deposits, using the same orifices in some cases and new ones in others (fig. 1B). There were at least two main ash flows, separated by some short time interval. This separation is indicated by the fact that the two main welded zones are divided by a partially welded tuff phase. If there had been only one eruption, or if insufficient time for cooling had elapsed between the two, then the whole formation would have been but a single cooling unit (Smith, 1960a). If the time interval was long, then the unwelded upper portion of the lower flow would have been eroded and the lower portion of the second flow would have a chilled contact on some sort of relief. The actual contact between flows is not a well-marked line but rather a transition from a fairly clean, partly welded tuff to a slightly more xenolithic, equally welded unit. This situation is due to two factors: the first is the continuation of vapor-phase crystallization from the lower welded unit into the fresh ash, and the second is the baking and surface mixing of the contact by the upper flow.

The lower flow is less competent and less welded than the upper and hence probably was emplaced at a lower temperature. Furthermore, it contains a greater proportion of its total bulk in xenoliths than the upper flow. The xenolithic content of both flows decreases slightly towards the tops of the flows, probably as a result of gravity working on the blocks in the fluidized suspension.

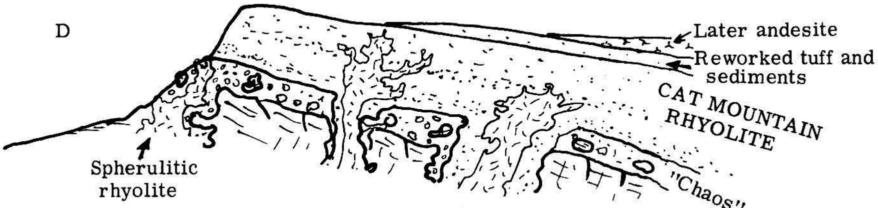
NUÉE ERUPTION



ASH FLOW ERUPTIONS



RHYOLITE INTRUSION



POST-BLOCK FAULTING

FIGURE 1

Starting with the unwelded tuff at the base, the rock passes through a zone of partial welding (using the definitions of Smith, 1960b) into a fairly well-developed zone of dense welding. None of the Cat Mountain units show the extreme welding of the vitrophyre zone, as was shown to the author in the Superior Dacite (D. W. Peterson, 1961, Arizona Geological Society field trip). From the zone of dense welding, the upward progression through the zone of crystallization to the nonwelded top is masked by the upper flow. Weathered-out, flattened pumice shards in the moderately welded zones give these zones a characteristic streaked appearance. This contrasts with the highly jointed welded phases which present a somewhat more homogeneous appearance, and which weather into near-vertical cliffs rather than into the rounded hills formed on the softer material. Radiometric analyses (Bikerman, 1962) give additional proof of the differences in the zones, as the welded zones have an average potassium content in the whole rock of about 4 percent, while the nonwelded zones have a higher potassium content ranging from 4.4 to 5.8 percent.

The second or upper flow presents characteristics similar to the lower one, showing a stratification from the partially welded interflow material through densely welded material into a nonwelded tuff capping. This soft tuff is not preserved on top of the western escarpment but is found in the lower reaches of the eastern dip slope, as in the Twin Hills area, where it shows evidence of water reworking in its upper parts. Brown (1939) mapped this tuffaceous phase as part of his extensive Safford Tuff unit. However, recent K-Ar dating of biotite from the Safford Formation (renamed by Kinnison, 1958) in the northern portion of the range gives a date of 25.2 million years (Damon and Bikerman, 1963), or Oligocene-Miocene. It is now proposed that the "Safford" name be restricted to the mid-Cenozoic rocks, while the Maestrichian tuffs be included in the Cat Mountain Rhyolite and a new name be given to the sediments previously included in the Safford formation in the Twin Hills region.

The final action of this volcanic cycle was the intrusion of gas-free, comparatively clean remnant magma through the old vents and through some new planes of weakness formed by structural adjustment to produce the spherulitic rhyolite (fig. 1C). This unit is interpreted as having a similar relationship to the Cat Mountain sequence as did the famous spine at Pelée to the Pelean eruptions.

Examination of outcrops of the spherulitic rhyolite shows that this intrusive usually outcrops in areas of thickest chaos unit, or near the postulated vents, and that it intruded with sufficient heat and force to weld the chaos around it while disrupting any bedding previously present. An estimation of importance of this intrusion in forming the steep dip angles on the range relative to the importance of the more general dislocation caused by the major structural changes associated with the block faulting (fig. 1D) is not undertaken here.

SUMMARY

From the original highly xenolithic chaos member of nuée ardente origin through the progressively cleaner ash flows and to the almost xenolith-free spherulitic rhyolite, the entire Cat Mountain sequence is considered to be caused by evolution of a single magma.

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