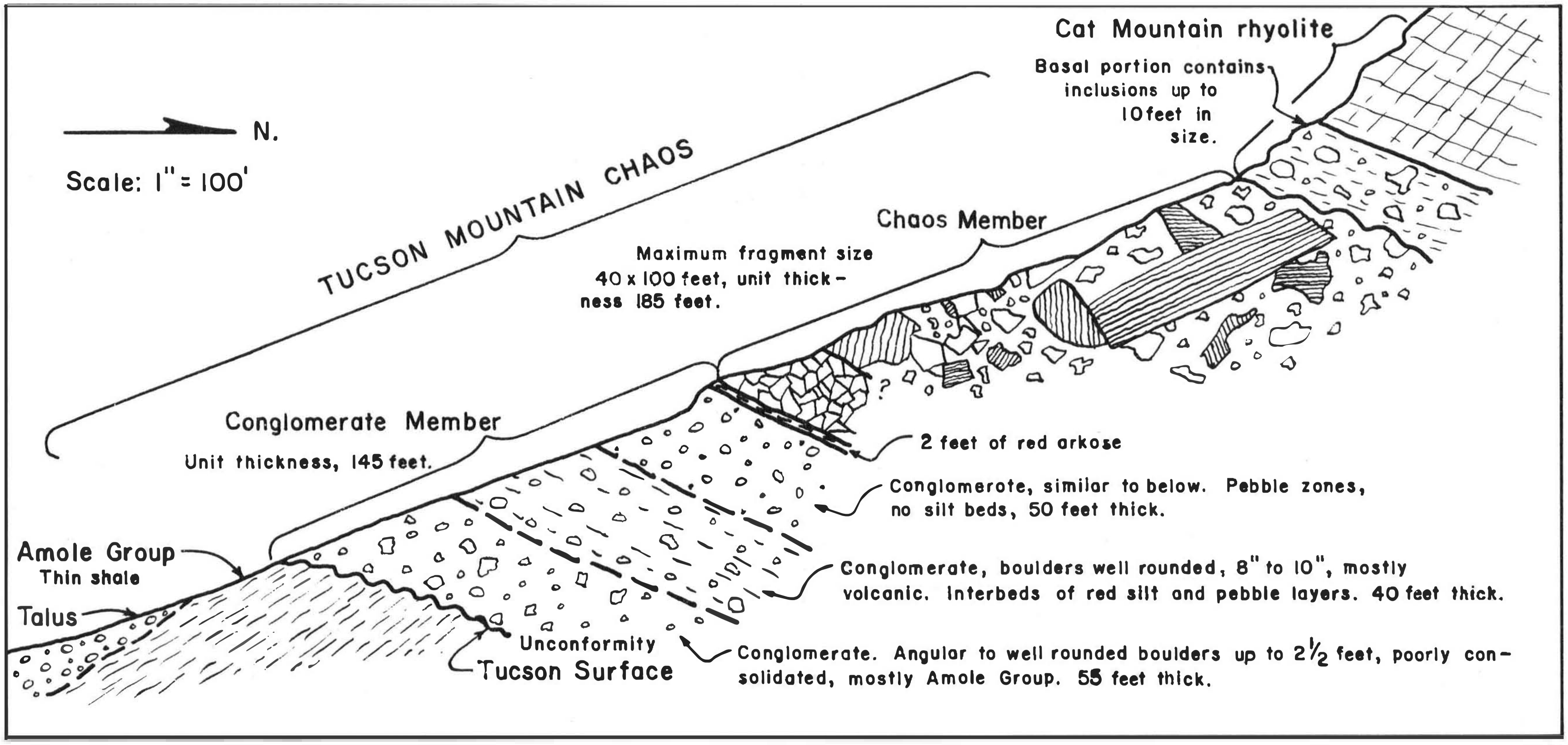


FIGURE 5A. Cross section of Tucson Mountain chaos at Cat Mountain (fig. 27, A-A'; Field Trip II, Stop 3), Tucson Mountains, Pima County, Arizona. Cross section is viewed looking west and is a composite of exposures of the conglomerate and chaos members in adjacent gullies.

# CHAOTIC BRECCIAS IN THE TUCSON MOUNTAINS, ARIZONA

John E. Kinnison

## INTRODUCTION

The object of this paper is to describe the Tucson Mountain chaos (Kinnison, 1958), a generally unrecognized and unusual formation in the Tucson Mountains. This formation was not recognized as a stratigraphic unit by Brown (1939), who made the original study of the range.

Acknowledgment is gratefully given to J. H. Courtright, K. E. Richard, J. F. Lance, and L. A. Heindl, who materially assisted in the preparation of this report. These men do not, however, necessarily agree with all of my opinions. I am aware that some of my conclusions are based on incomplete data; they should be considered within that limitation.

## GEOLOGIC SETTING

The Tucson Mountains are a few miles west of Tucson, Arizona, and form a low elongated range which trends northwest. The range can be divided into three physiographic divisions (Brown, 1939) -- the pediments, the western escarpment, and the eastern dip slope. The pediments are carved on the clastic sediments of Mesozoic age and are well developed along the western margin of the range. The western escarpment is formed of Tertiary volcanic rocks which dip gently to the east and underlie most of the moderately incised eastern dip slope. The range is surrounded by alluvium of the Santa Cruz and Avra Valleys.

The rocks of the range are grouped into two major divisions. The lower sequence consists of Paleozoic, Mesozoic, and early Cenozoic(?) rocks and Tertiary and Quaternary rocks comprise the upper sequence. The Tucson Mountain chaos lies between these two major divisions.

Paleozoic rocks consist dominantly of limestone with subordinant amounts of quartzite and shale. The Amole group (Kinnison, 1958) overlies the Paleozoic rocks and consists mainly of arkose and shale. The Amole group includes the Recreation red beds (Brown, 1939) and, possibly, andesitic volcanic rocks (Kinnison, 1958) whose exact stratigraphic positions are unknown. The age of the Amole group is probably Lower and Upper Cretaceous, and some of the strata may be as young as early Tertiary. The thickness of the Paleozoic section may be somewhat greater than 4,500 feet (Brown, 1939), and the Cretaceous-Tertiary(?) rocks may have a combined thickness in excess of 8,000 feet (Kinnison, 1958).

The upper sequence consists of Tertiary and Quaternary volcanic rocks, lake beds, and alluvium. The volcanic rocks consist of the Cat Mountain rhyolite at the base (Brown, 1939) and a number of younger andesitic and rhyolitic flows, tuffs, and lake beds. Basaltic rocks overlie older tilted volcanic rocks with angular unconformity.

A granitic stock intrudes the northern part of the range and may be older than the Tertiary volcanic rocks in that area (Brown, 1939). In the southern part of the range, a small monzonite porphyry intrusive is younger than the Tertiary volcanic rocks and is the site of porphyry copper-type alteration and sulphide mineralization (Kinnison, 1958; 24). Other igneous rocks, ranging in composition from andesite to rhyolite, intrude the volcanic sequence.

Two structural events dominate the range. The first includes broad folding in the northern part of the range and intense deformation in the southern part which affected the Amole group and older rocks (Kinnison, 1958; 24). The second event consisted of block faulting and tilting and post-dates most of the Tertiary volcanic pile. Block faulting, but not tilting, continued until after the eruption of basalt, the youngest rock in the range.

The porphyry intrusions and the mineralization in the southern part of the range are of types that are usually assigned to the "Laramide," however, these features are younger than the lower rock unit of the Tertiary volcanic sequence, and may be younger than all rocks except Tertiary(?)-Quaternary basalt, conglomerate, and alluvium.

The intense deformation affecting the Amole group and older rocks is separated from the later volcanism and faulting by a period of extensive erosion which formed the Tucson surface (Kinnison, 1958; 24). This surface of erosion marks a major change in the course of geologic events in the Tucson Mountains. Similar erosion surfaces occur in other ranges of southern Arizona. In this paper, "Tertiary structure" refers to structure younger than the Tucson surface, and "Laramide structure" is limited to post-Amole group, pre-Tucson surface deformation.

## TUCSON MOUNTAIN CHAOS

The Tucson Mountain chaos is composed predominantly of strikingly large and disoriented fragments of all older rocks. The Tucson Mountain chaos was previously interpreted as a complex overthrust block by Brown (1939) who said, "Along the western escarpment... is a conspicuous belt of boulder-like masses of Carboniferous limestone as much as 100 feet in diameter and less conspicuous Cretaceous volcanic rocks... These masses of Carboniferous limestone clearly rest on the Cretaceous, and the Cretaceous volcanic rocks also rest on the Amole arkose in the same belt... These relations have been interpreted as a great thrust fault, which practically parallels the surface of pre-Tertiary erosion and whose overthrust block was largely removed by erosion." Brown was partly aware of the chaotic nature of this zone, because he states, "... The distribution of outcrops along the covered base of the western escarpment suggests that this belt of overthrust masses is a jumble... Recently, B. S. Butler has discovered on the eastern side of the range an outcrop which... is clearly a conglomerate... This conglomerate occurs between one of the larger limestone blocks and the Cretaceous formations, suggesting that the fault may have extended out onto the surface..."

The suggestion I offer is that the Tucson Mountain chaos is a sedimentary formation. If the chaos was formed by accumulation in front of a thrust fault scarp, such thrusting was post-Laramide and probably local in its significance.

Noble (1941) first described a formation of this type. He states, "The Amargosa chaos or features resembling it are widespread in the southern Death Valley region, and if they occur in other regions the term chaos, as a common noun, may prove to be a useful geological term." Thus this formation, which occurs throughout the Tucson Mountains, derives its name from its location and from the word "chaos" as used by Noble.

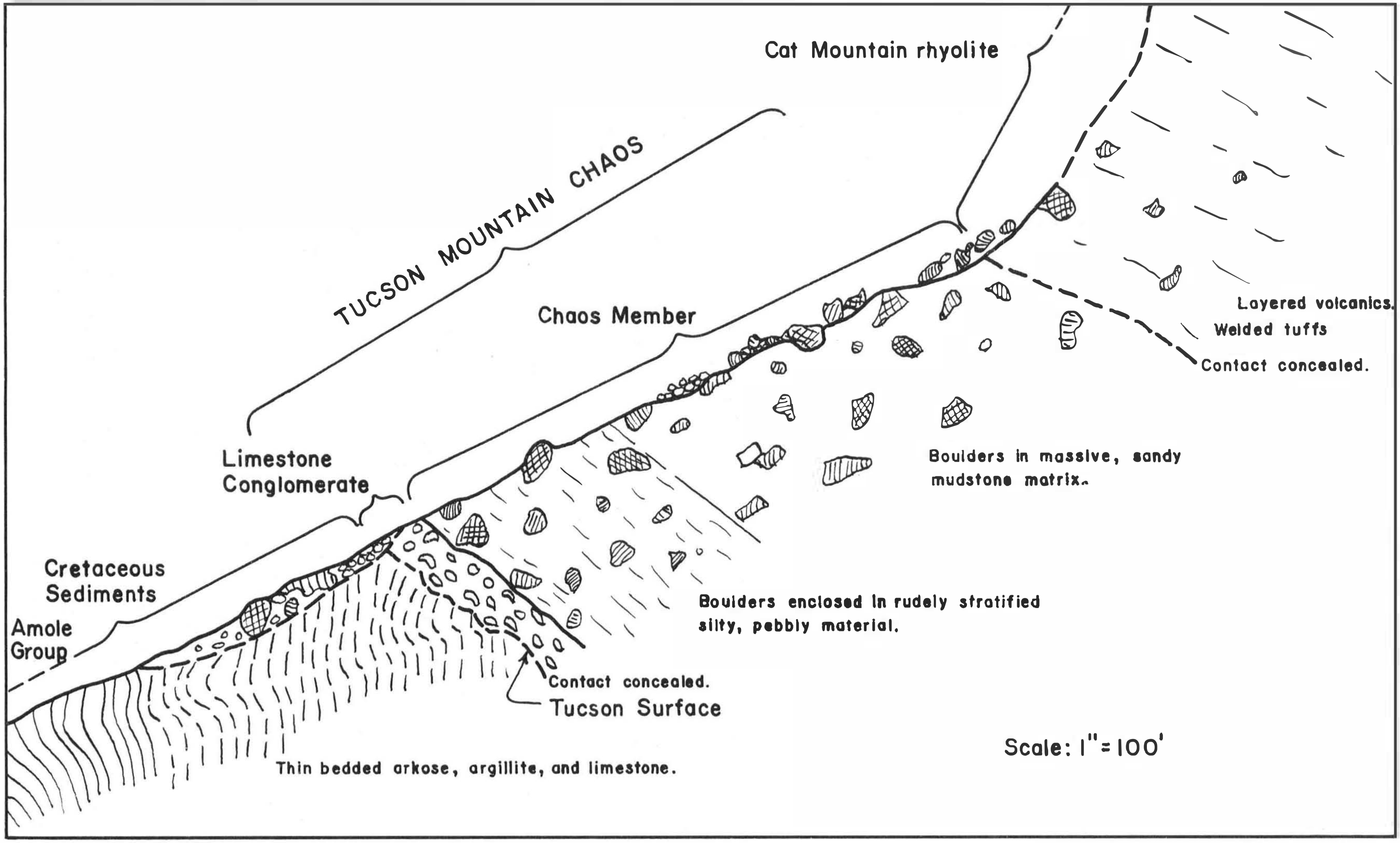


FIGURE 5B. Cross section of Tucson Mountain chaos south of Gates Pass, Tucson Mountains, Pima County, Arizona. Cross section is viewed looking north through a part of the western escarpment east of Golden Gate Mountain (fig. 27, B-B'; Field Trip II, Stop 5).

## Distribution and Topographic Expression

The Tucson Mountain chaos crops out extensively in the Tucson Mountains (figs. 27, 47) as a tabular unit about 14 miles long and about 2 to 4 miles wide. Along the west side of the mountains, it is exposed on the pediment and in the low escarpment south of Ajo Road. North of Ajo Road, in the area between Cat Mountain and Gates Pass, and possibly as far north as Amole Peak, it is exposed at scattered points at the base of the western escarpment. It is also widely exposed in the central part of the eastern side of the range. There are no exposures of the chaos in the northern part of the range, and the Tertiary volcanic rocks are underlain by dark-colored andesitic rocks.

Where the chaos is not capped by a protective layer of volcanic rocks, it is eroded to a gentle, rolling topography. The effect of differential erosion on blocks of different materials produces small knobs separated by flat areas covered by loose debris. The differences in rock types and sizes and orientations of individual blocks, stand out clearly.

## Description

The Tucson Mountain chaos rests on steeply dipping rocks of pre-Laramide age and is overlain by the Cat Mountain rhyolite. The chaos and the Cat Mountain rhyolite are essentially conformable, although locally stratified lenses within the chaos dip at slightly steeper angles than the overlying volcanic rock. There are differences in the thickness of the chaos that suggest some pre-Cat Mountain rhyolite erosion, but in some areas, as at Cat Mountain, the chaos appears to grade upward into the Cat Mountain rhyolite. The thickness of the chaos varies from essentially zero to more than 400 feet, and is greatest in the central part of the east side of the range. The Tucson Mountain chaos includes twc members -- a lower conglomerate member and the upper chaos member.

### Conglomerate Member

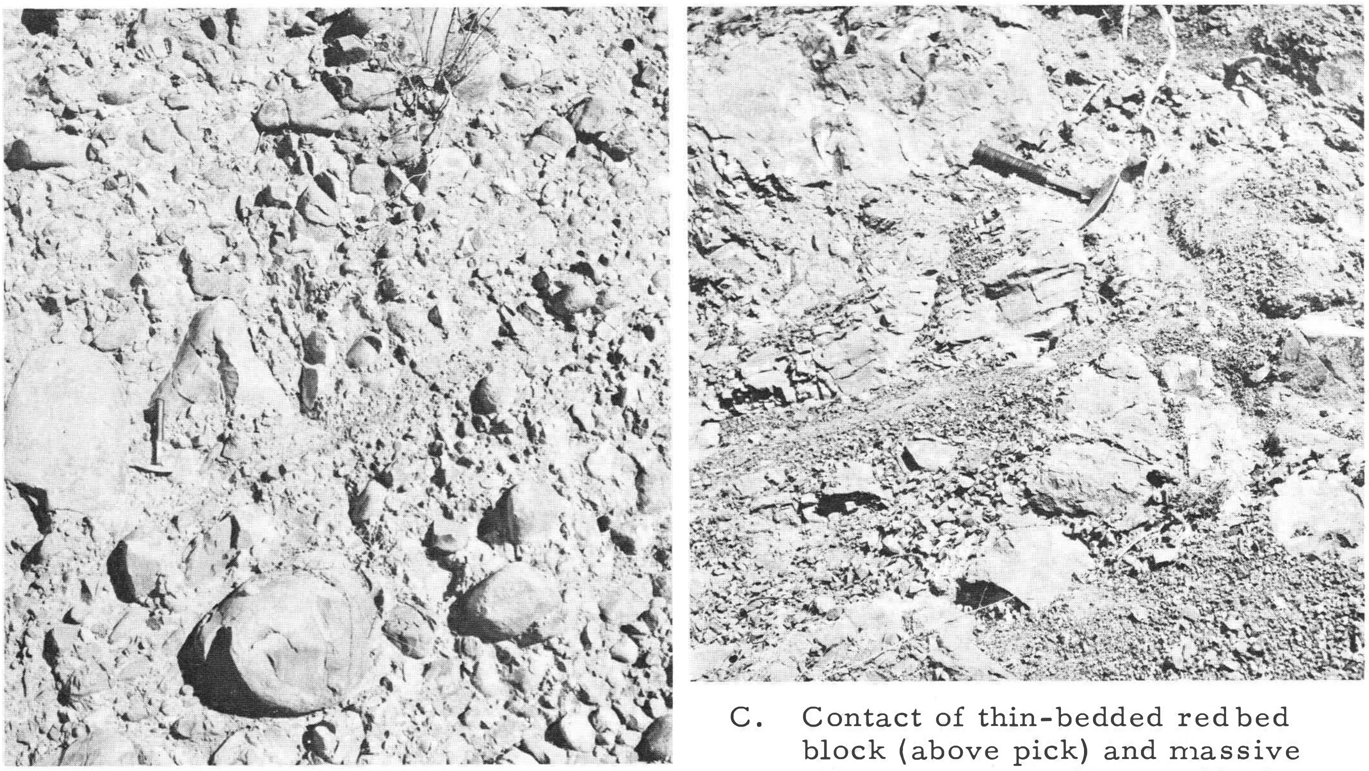
The conglomerate member is known to crop out in three localities, and apparently is only a local feature.

At Cat Mountain (figs. 5A and 6B; Trip IV, Stop 3) the base of the conglomerate member is a poorly consolidated, well-rounded, reddish-brown cobble conglomerate with numerous boulders. The bedding is marked by sorted pebble lenses and aligned and elongated cobbles. The cobbles and boulders consist of arkose, siltstone, and red beds of the Amole group, and dark andesite porphyry. The upper part of the conglomerate contains more numerous boulders and is well consolidated. The maximum thickness is about 150 feet, and the conglomerate appears to thin laterally.

Near Gates Pass (fig. 5B) at the base of the Tucson Mountain chaos, there is an exposure of poorly rounded pebble conglomerate which may correspond to the conglomerate member at Cat Mountain. It crops out to expose a thickness of about 10 feet, but the base is covered.

South of Ajo Road, the Tucson Mountain chaos locally overlies andesite, and the conglomerate member is composed of a few feet of reddish-brown rounded cobble conglomerate and thin silt beds.

A. Boulder in Tucson Mountain chaos (right center) enclosed by light-colored clastic layer with faint concentric banding; small boulders in upper and left parts of picture.



B. Conglomerate at base of Tucson Mountain chaos; note pebble lens below pick; dip is to the north.

C. Contact of thin-bedded red bed block (above pick) and massive siltstone; note undistorted bedding in red bed block, which is about 100 x 40 feet in size; picture is rotated 45° counter-clockwise.

FIGURE 6. Tucson Mountain chaos at Cat Mountain, Tucson Mountains, Arizona. Photos by Tad Nichols.

## Chaos Member

The chaos member of the Tucson Mountain chaos is characterized by blocks ranging in size from less than 10 to more than 200 feet in maximum dimension. In the southern part of the range, fragments in the chaos member of the Tucson Mountain chaos consist mainly of clastic rocks of the Amole group and numerous blocks of Paleozoic limestone. Blocks of the Recreation red beds are particularly evident because of their color. A few blocks of andesite porphyry are present and, rarely, a block of granite. At scattered places there are blocks of a gray sericite-quartz schist which resembles the Precambrian Pinal schist. Andesite and andesite breccia or conglomerate of Cretaceous or early Tertiary age are a common fragment type in the chaos in the central part of the range. No members of the overlying Tertiary volcanic sequence are recognized.

I made no attempt to analyze statistically the fragment composition and size. The following observations are based on field impressions alone, and are, as such, subject to error. Fragments of the Amole group constitute about 60 percent of the total, and range in size from about 1 foot to more than 200 feet in maximum dimension. Many are on the order of 100 feet long. Blocks of Paleozoic limestone, although prominent due to differential weathering, rarely exceed 100 feet, but in some places, as in the Sweetwater Drive area, exceed 200 feet in length. The majority of blocks ranges in size between 10 and 40 feet, with blocks ranging from 1 to 10 feet in size next in abundance. The blocks are commonly seen to be separated by a gougelike or earthy material (fig. 6A).

Blocks of thin-bedded arkose or red beds of the Amole group tend to be tabular, and the more uniform Paleozoic limestone and other directionless rocks tend to be equidimensional. Individual blocks are oriented at random within the formation. Bedding within the blocks usually is not distorted, even in blocks of thin-bedded shale of the Amole group (fig. 6C).

Angular limestone conglomerate bodies without well-defined boundaries are erratically distributed throughout the chaos member. Some of them are locally stratified and sorted, and clearly are not fault breccias. The conglomerate bodies are most common near large limestone blocks, many of which are enclosed by a shell of angular conglomerate or breccia. The conglomerates are conspicuous due to weathering. The less resistant limestone pebbles are leached and a siliceous shell stands out clearly. A few conglomerate bodies consist dominantly of pebbles and cobbles of andesite porphyry.

At Cat Mountain the chaos member is exposed in a series of steep, narrow gullies where it lies on the conglomerate member with apparent conformity (figs. 5A and 6; Trip IV, Stop 3). The fragments in the chaos member here range from 3 feet to more than 100 feet in maximum dimension, and are surrounded by clastic material (fig. 6A) which locally shows concordant layering around the blocks. The chaos member here appears to grade into the overlying Cat Mountain rhyolite.

Near Gates Pass (fig. 5B; Trip IV, Stop 5) the basal part of the chaos member is composed of crudely stratified clastic material containing rounded to angular small fragments, and thin silty beds. This material is suggestive of mud flow debris. The upper part is typical chaos, and appears to grade into the overlying Cat Mountain rhyolite.

On the eastern slope near Sweetwater Drive, there is a large area of rolling hills composed of the Tucson Mountain chaos. Here the chaos is divisible into two parts. The lower part, which constitutes most of the exposure, is typical chaos. The upper part is composed of a group of separated blocks of Paleozoic limestone These blocks cap several small knobs which range in size from about 200 to 1,000 feet in length, and overlie the chaos with a horizontal contact. The limestone blocks have similar strikes and dips and lie at about one elevation which suggests that they are erosional remnants of a once continuous unit (Whitney, 1957).

On the north side of the largest limestone block the chaos is seen to be deposited against a steep contact with the limestone, and the interstitial debris of the chaos contains stratified silt and gypsum.

Light-colored rhyolite, which I tentatively correlate with the Spherulitic rhyolite (Brown, 1939) of Tertiary age, intrudes the Tucson Mountain chaos in an irregular and intricate pattern. These small bodies of rhyolite commonly appear as poorly exposed patches up to about 30 feet in diameter, and as ribbonlike intrusions between chaos fragments. Larger bodies of Spherulitic rhyolite intrude the Tucson Mountain chaos as dikes and plugs, and commonly are crowded with inclusions of limestone, arkose, and red beds.

### Age

The chaotic breccias lie on a surface cut on the Amole group of Cretaceous and possibly early Tertiary age and are capped by or grade into the Cat Mountain rhyolite of Tertiary age. The age of the chaotic breccia is tentatively considered to be of probable early to middle Tertiary age.

## Associated Andesitic Rocks

Brown and purple andesite and andesite breccia and/or conglomerate crop out locally in close association with the Tucson Mountain chaos (figs. 27 and 47). Rocks of this type are common as fragments in the chaos, particularly in the central part of the range.

The relationship of the andesites in the northern part of the range to the Tucson Mountain chaos and the Amole group is not definitely known. In this area, these andesites are probably several thousand feet thick (Brown, 1939), and may lie stratigraphically within the Amole group (Kinnison, 1958). In the southern part of the range, the andesites south of Ajo Road are overlain by the Tucson Mountain chaos, with a thin conglomerate along the contact. In the basin northwest of the Ajo and Mission Road intersection, the chaos also appears to overlie andesite.

South of Ajo Road the andesites near Stop 2 (fig. 27) are located along the projection of the strike of folded Amole group sediments exposed half a mile northwest. These andesites may lie on the truncated edges of Amole group sediments, and form a thin layer between the Tucson Mountain chaos and the underlying folded Amole group (Kinnison, 1958; fig. 28, C-C'). The relationship of the Tucson surface to this "slab" of andesite is not known.

## Origin of the Chaos

Any theory of formation of the Tucson Mountain chaos must explain the following facts which are established by field evidence.

1. The formation is composed of blocks of all older rocks.
2. The blocks range in size from less than one foot to more than 200 feet in maximum dimension.
3. The thickness is commonly about 200 feet but ranges from zero to more than 400 feet. The formation is exposed over an area 14 miles long and 2 to 4 miles wide.
4. The size of the blocks appears to vary directly with the thickness of the chaos, i. e., the thicker sections have generally larger blocks.
5. The chaos generally rests on the Tucson surface. South of the Ajo Road the chaos may overlie an erosion surface cut on andesite.
6. Limestone conglomerate bodies occur throughout the chaos.
7. The dip of the chaos is essentially conformable with that of the overlying Cat Mountain rhyolite.
8. The stratified material exposed on Cat Mountain and at Gates Pass dips in the same direction as the overlying Cat Mountain rhyolite, although possibly at a steeper angle.
9. The appearance of the chaos at Cat Mountain and Gates Pass suggests analogy to modern talus slopes. The basal half of the chaos at Gates Pass is suggestive of a mud flow.

Items 5, 6, and 9 suggest a dominantly sedimentary origin for the Tucson Mountain chaos. Item 2 suggests that the chaos was derived from a mountainous area or steep scarp, and a reasonable assumption is that such a scarp was a structural feature. The following discussion, then, is based on the postulation that the chaos resulted from a combination of tectonics and sedimentation.

Prior to the deposition of the Tucson Mountain chaos, the Laramide orogeny intensely deformed all older rocks (Kinnison, 1958). After this deformation, erosion planed these deformed rocks to a surface of moderate or gentle relief – the Tucson surface. A post-Tucson surface fault scarp might be expected to expose various rocks brought together by the Laramide deformation.

Such a scarp would be an excellent source for the diverse rock types found in the chaos, particularly if the fault continued to be active during deposition. In front of this postulated fault scarp, a thick talus would accumulate. The thickness of the pile and size of blocks within it probably would be related to the height of the scarp.

Under proper conditions of lubrication, extremely large blocks, or large masses of blocks, impelled only by gravity, can slide for considerable distances down a very low gradient. The postulated talus pile, subjected to seismic activity associated with concurrent faulting, would be especially susceptible to landslide and mud flow movements. As each earth movement occurred, the talus pile would be locally thinned, but expanded laterally. Seismic vibrations would continually set in motion landslide and mud flow masses, as well as large individual blocks, and these would then slide down gentle slopes. The chaos would thus be spread in a thin layer for a distance of several miles from its source. The muddy matrix of the mud flow or landslide mass would produce a breccia and gougelike zone around the larger blocks of the chaos, and might even produce slickensided surfaces.

While the chaos was being deposited and spread out, it was subjected to erosion, and deposition of conglomerate took place along intermittent rills. The direction and location of these small water courses changed with each new earth movement, probably disrupting the conglomerates previously deposited.

Summing up the nine basic characteristics of the chaos, item 1 is satisfied by the assumption of an originally complex area which was elevated along a fault scarp; items 2, 3, 5, 6, 7, 8, and 9 by the suggested mechanism of formation; and item 4 by the probability that the thicker areas of chaos would be nearer the source.

## Comparison to Other Chaotic Breccias

The Tucson Mountain chaos bears a striking resemblance to other chaotic breccia formations, a few of which are mentioned below.

Noble's (1941) investigation of the Virgin Spring area of Death Valley, California, disclosed a chaotic sequence about 2,000 feet thick, the Amargosa chaos, which he believed to be a brecciated overthrust sheet of post-Miocene age.

Jahns and Engel (1950) summarized chaos formations in southern California as follows: "Tabular to lenticular masses of unusual breccias are widespread in both desert and coastal regions of Southern California... Many of the breccias are sedimentary rocks... (and) resemble modern mud-flow and debris-flow accumulations... Some of the breccias, including several types that have been described as 'chaos' have been interpreted as crackled... parts of low-angle thrust faults... Although certain breccias seem correctly interpreted as essentially tectonic in origin, others so interpreted are wholly sedimentary... Only further studies, however, can accurately define the respective roles of faulting and sedimentation in the development of these rocks."

Jicha (1958) has mapped "landslide debris" in western New Mexico. He states: "... the northern flank of Mesa del Oro for a distance of 10 miles is an apron of slide blocks more than a mile wide... Pico Pintado... has on its east side two immense landslide blocks, more than one-half mile long and several hundred yards wide." The relief of the basalt-capped mesas from which these landslides originated is relatively slight, and the surfaces on which they are deposited are of gentle gradient. These landslides are related to present topographic features, and they appear to be features of the late Pleistocene (Jicha, 1958).

An account of a recent debris flow by Sharp and Nobles (1952) illustrates the inherent mobility of mud flow on a gentle gradient. "On May 2, 1941... (the) community of Wrightwood on the north side of the San Gabriel Mountains was partly inundated by a series of debris waves... Debris was transported 15 miles by mass movement, and on a gradient as low as 75 feet per mile at the outer extremity... Velocities of most waves did not exceed 3-5 miles per hour (estimated)."