A DESCRIPTION OF THE LIMESTONE BLOCKS OF THE TUCSON MOUNTAIN CHAOS PIMA COUNTY, ARIZONA

by

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ABSTRACT

The Tucson Mountain Chaos (Kinnison, 1958) is a breccia in which large blocks of Paleozoic limestones occur in the midst of jumbled Cretaceous sedimentary rocks. The ages of the blocks range from Devonian to Permian with blocks of different ages mixed together. The attitude of the blocks is generally without preferred orientation. Andesite porphyry consistently occurs near the blocks.

The Chaos was formed by the intrusive action of viscous andesite, in which blocks of limestone and other rock were torn loose and rafted upward without alteration along east-west trending zones of weakness. The overlying rock was fractured and carried toward the surface by the rising column. The andesite and contained blocks failed to reach the surface in most areas and are now exposed where the former cover has been removed by erosion.

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INTRODUCTION

Purpose and Scope

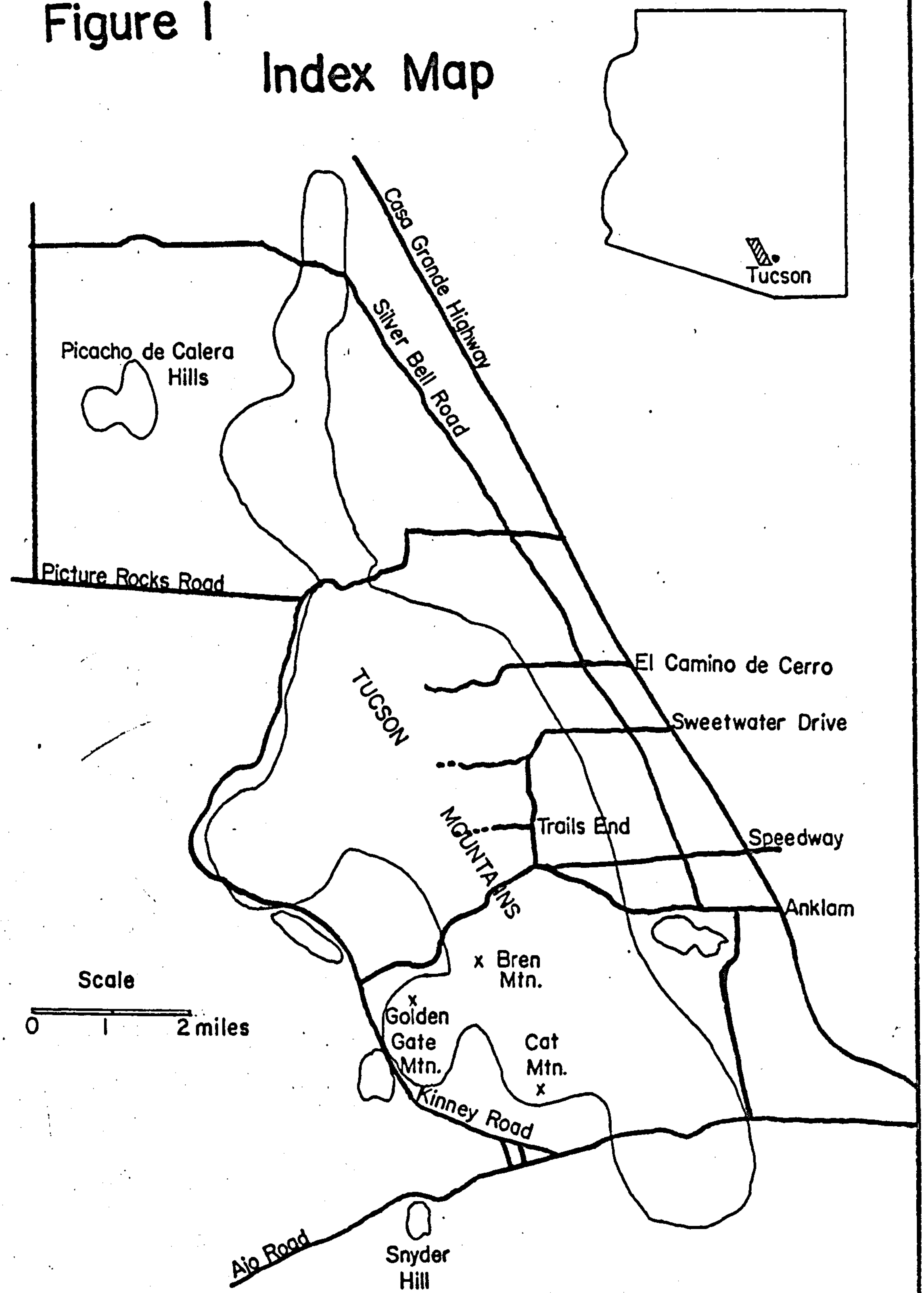
The purpose of this study of the limestone blocks of the Tucson Mountain Chaos was to determine the physical nature and ages, where possible, of the individual blocks, and the overall relationships of age, distribution, and orientation. This information should enable the evaluation of the various theories concerning the origin of the Chaos. For many of the blocks, it proved to be impossible to determine the age because of a lack of distinctive fossils or lithology. Enough were determined, however, to arrive at some general conclusions concerning the distribution of rocks of the same age. This, in conjunction with the associated rocks, seems to shed definite light on the mode of origin.

Location and Access

The principal outcrops of the limestone blocks are in the northeastern portion of the Tucson Mountains between Trails End Drive and West Sunset Road, with major concentrations at the end of Trails End Drive and Sweetwater Drive (Figs. 1,3). The southern outcrops

Figure I

Index Map



are readily accessible from Trails End Drive immediately east of the Saguaro School for Asthmatic Children. The Sweetwater area can be reached by turning south off of Sweetwater Drive about one half mile west of the end of the paving and continuing southwest to the abandoned limestone quarry. The northern area is close to the western end of El Camino de Cerro near the Idle Hour Ranch.

In addition to the blocks along the northeastern flank of the mountains, other limestone blocks crop out on the west and south sides of Bren Peak, east of Tucson Estates on the south side of Cat Mountain, and south of Ajo Road (Fig. 1). The west side of Bren Peak is accessible from the jeep trail between Bren and Golden Gate Mountains. The southside of Bren Peak and the Tucson Estates areas are served by numerous desert roads going east from Kinney Road. The south side of Cat Mountain can be reached from Ajo Road. The outcrops south of Ajo Road are near the desert road going south from Ajo Road one mile east of the Ajo-Kinney Road junction.

Previous Work

The first extensive work on the Tucson Mountains was done by Horatio Brown in 1939. This comprehensive work included a geologic map showing the location of the limestone blocks and a theory concerning their origin.

R. L. Whitney (1957) mapped in detail the area at the end of Sweetwater Drive including all the limestones, giving their relative ages. J. E. Kinnison (1958; 1959) mapped the area south of Anklam Road and suggested explanations for the entire Chaos. E. B. Mayo (1963) reviewed the earlier literature and presented a detailed discussion of the latest ideas on the origin of the Chaos.

Other publications which did not deal specifically with the limestones, but which make some mention of them were theses by Michael Bikerman (1962), Richard Champney (1962), and Gerald Greenstein (1961). Although the Paleozoic rocks of Snyder Hill and the Picacho de Calera Hills are several miles from the main mass of the Tucson Mountains, they probably owe their present position to the same processes as those which formed the Chaos. These areas were discussed by Bryant (1952; 1955).

Method of Study

During the fall and winter of 1963, general reconnaissance work was conducted in the northeastern portion of the mountains and along the western escarpment from Gates Pass south to Ajo Road including a small area south of the road (Figs. 3,4). Locations were plotted on enlarged portions of the San Xavier and Cortaro topographic sheets of the U. S. Geological Survey.

Notation was made at each outcrop of any distinguishing feature such as color, attitude, fossils or associations with the surrounding rock. These were then compared to the descriptions of southern Arizona Paleozoic formations, particularly those of Ransome (1904), Gilluly, Cooper and Williams (1954), and Bryant (1955). In some areas fossils were absent, but the rocks could be correlated by lithology.

Acknowledgments

I would like to thank the following members of the Geology Department of the University of Arizona for their help in the preparation of this thesis: Dr. D. L. Bryant for his aid in the preparation of this manuscript; Dr. E. B. Mayo for his stimulation of interest in the Tucson Mountain area; and Dr. W. C. Lacy for his many helpful suggestions concerning the origin of the Chaos.

GEOLOGY AND STRATIGRAPHY

General Geology

The Tucson Mountains are located in the Sonoran Desert portion of the Basin and Range Province, and are the remnants of a fault block trending northwest-southeast which is tilted toward the east. Brown (1939) divided the range into pediments, a western escarpment, and an eastern dip slope. The elevation ranges from 2,050 feet in the Santa Cruz River valley north of the mountains to 4,700 feet at Wasson Peak. Many of the higher points approach 4,000 feet in elevation.

The mountain block consists of a basement of a lustrous sericitic schist similar to the Precambrian Pinal schist, overlain by Paleozoic and Cretaceous sedimentary rocks, and Tertiary extrusives (Jenkins and Wilson, 1920). Tumamoc Hill and Sentinel Peak on the eastern side of the range are capped by Quaternary basalt. The block has been folded and faulted at various times in its history. Intrusions of granite, latite and andesite further complicate the history.

The Tucson Mountain Chaos

The Tucson Mountain Chaos was first described as a formal unit by Kinnison in 1958 for the zone of mixed rocks between the Cretaceous Amole Arkose and the Tertiary Cat Mountain Rhyolite. It is a tabular body that ranges in thickness from less than ten feet in the southern part of the mountains (south of Ajo Road) to more than 400 feet in the northeastern part (Kinnison, 1958), containing undistorted blocks of Amole Arkose, Recreation Redbeds, Paleozoic limestone and quartzite, andesite and sericitic schist.

Stratigraphy of the Tucson Mountain Area

Blocks in the Chaos probably represent portions of all formations found in either the Picacho de Calera Hills which are north of the range or Snyder Hill located west of the southern part of the mountains. The presence of unconformities between the rocks of Precambrian and Cambrian age, Cambrian and Devonian, Mississippian and Pennsylvanian allows the possibility that rocks similar in age to those missing at Picacho de Calera may be included in the blocks of the Chaos.

Pinal Schist.-- The Pinal Schist (Ransome, 1903) is a blue-gray sericitic schist of Precambrian age in southern Arizona, and named for the Pinal Mountains south of Globe, Arizona. It crops out beneath the Bolsa Quartzite in the Picacho de Calera Hills and is found as blocks in the Chaos in the Trails End area and on the western slope of Bren Mountain (Fig. 3,4).

Bolsa Quartzite.-- The Bolsa Quartzite (Ransome, 1904) is a light brown orthoquartzite, commonly conglomeratic or cross-bedded, of Cambrian age, as described in the Bisbee, Arizona area. At the Picacho de Calera Hills it has a thickness of 700 feet (Bryant, 1952) but was not recognized elsewhere in the Tucson Mountains.

Abrigo Formation.-- The Abrigo Formation (Ransome, 1904) is a thinly-bedded bluish gray limestone with thin layers of micaceous sandstone and siltstone, also Cambrian. The limestones are locally dolomitic and contain some chert. Fossils are small phosphatic brachiopods and pieces of trilobites. The upper part of the formation is pink coarse-grained limestone containing trilobite fragments (Bryant, 1952; Stoyanow, 1936). At the Picacho de Calera Hills the formation, including the Cochise Formation and Rincon Limestone of Stoyanow (1936), is 640 feet thick (Wilson, 1962). No rocks of the Abrigo Formation were recognized in the Tucson Mountains.

Martin Limestone.-- The Devonian Martin Limestone (Ransome, 1904) is a dark gray, massive limestone which weathers dark yellowish brown. The type section is on

Mt. Martin near Bisbee. At Picacho de Calera the limestone has a thickness of 350 feet. The lower part is cherty and contains some brachiopods, whereas the upper part is relatively unfossiliferous (Bryant, 1952). Blocks of Martin Limestone are in the Sweetwater area (Whitney, 1957) and on the western side of Bren Mountain.

Escabrosa Limestone.-- The Mississippian Escabrosa Limestone (Ransome, 1904) is a thick-bedded, nearly white to dark gray, granular limestone which is locally crinoidal. At Picacho de Calera it is 600 feet thick with tetracorals and brachiopods locally abundant. Blocks of Escabrosa Limestone are in the Sweetwater area (Whitney, 1957) and may be present at El Camino de Cerro locality (Fig. 3).

Horquilla Limestone.-- The Horquilla Limestone (Gilluly, Cooper and Williams, 1954) is the Pennsylvanian portion of Ransome's (1904) Naco Formation. At the type locality in the Tombstone Hills, the base is an obscure disconformity located within a twenty foot zone. The limestone is a thinly-bedded bluish-gray limestone interbedded with thicker units of coarsely crystalline limestone containing abundant crinoid stems. At Picacho de Calera the Horquilla is a thinly-bedded bluish-gray limestone with layers of siltstone (Bryant, 1952). Whitney (1957) mapped blocks of the Horquilla

Limestone in the Sweetwater area but the Horquilla was not recognized in other localities.

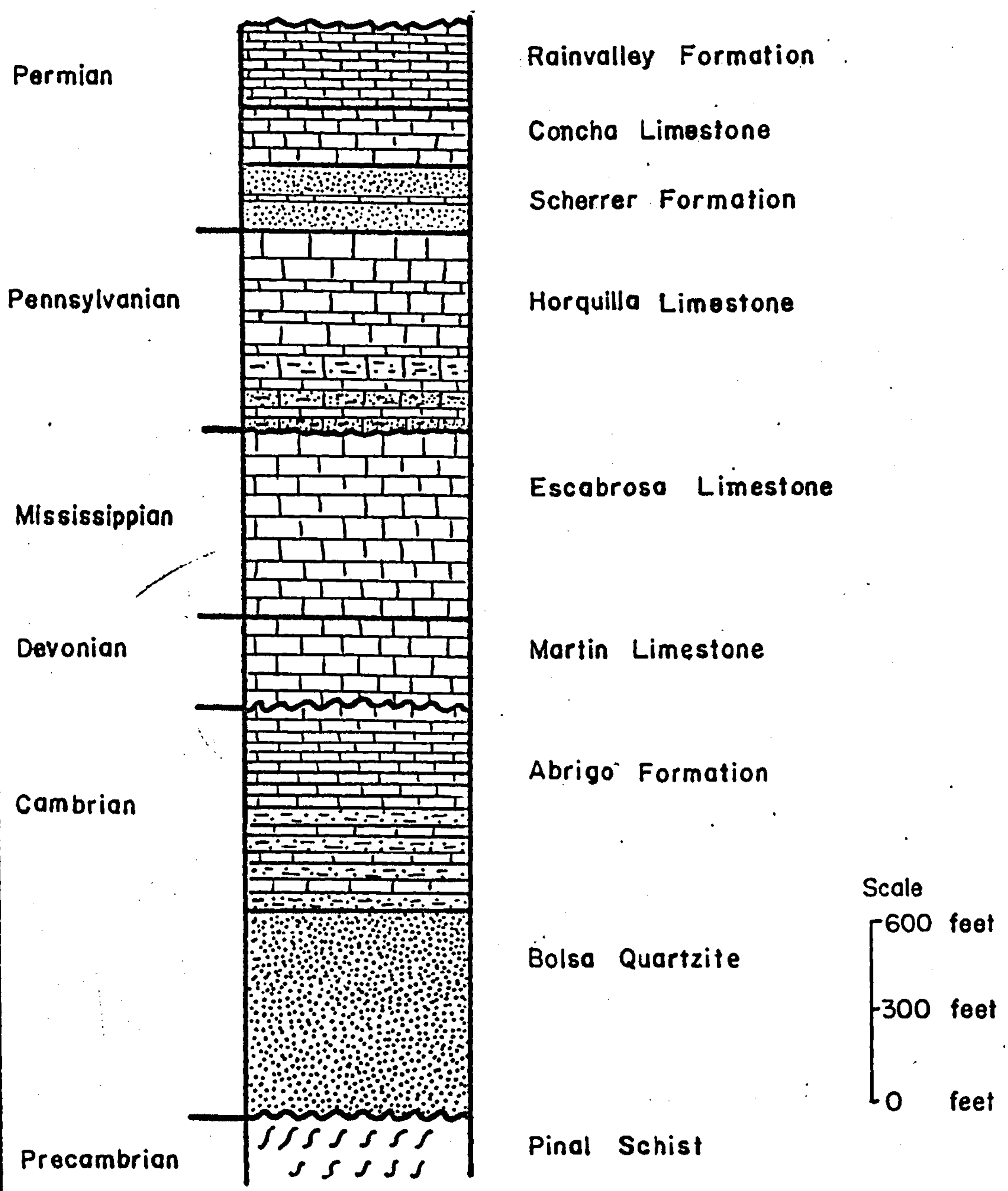
Scherrer Formation.-- The Permian Scherrer Formation (Gilluly, Cooper, and Williams, 1954) consists of upper and lower units of white sandstone which weather reddish brown separated by limestone. Blocks of the formation crop out in the Sweetwater area (Whitney, 1957) and are present in the Trails End and El Camino de Cerro locations.

Concha Limestone.-- The Concha Limestone, defined by Gilluly, Cooper, and Williams (1954) is a massive light to medium gray limestone of Permian age which is resistant to erosion. Included in the Concha are most of the rocks that were called Snyder Hill Limestone by previous authors. Black chert which weathers brown is common throughout, locally approaching 75 percent of the rock (Bryant, 1955). At Snyder Hill the Concha is 118 feet thick. It crops out at El Camino de Cerro, Sweetwater, Idle Hour Ranch, Trails End and Bren Mountain localities.

Rainvalley Formation.-- The Rainvalley Formation (Bryant and McClymonds, 1961) is a relatively thin-bedded limestone consisting of a lower unit of alternating light to medium gray limestones and black fetid limestones and an upper unit of light gray to brown limestones. The rocks now assigned to the Rainvalley were formerly included in the upper part of the Snyder Hill Limestone. Chert is less common than in the Concha and quartz geodes and calcite nodules are prevalent in the upper portion. At Snyder Hill 108 feet of dolomite are considered to be Rainvalley (Bryant, 1955). Rainvalley Formation blocks occur at the Sweetwater Drive (Whitney, 1957), El Camino de Cerro, Trails End, the south side of Bren Mountain, Tucson Estates localities and south of Ajo Road.

Figure 2

Generalized Stratigraphic Column



LITHOLOGY OF THE BLOCKS

The Northeastern Area

El Camino de Cerro.-- In the eastern ½ of Sec. 22, T. 13 S., R. 12 E. (Fig. 3), several blocks of limestone crop out along the top of a low mound to the south of the road. The individual blocks are small, ranging in size from one to twenty feet across, with an average of ten feet. In addition to the limestone, there are blocks of quartzite and arkose. The major portion of the hill appears to be porphyritic andesite. In a semi-arid climate, limestone and quartzite blocks are about equally resistant to erosion, and rise several feet above the surface of the surrounding andesite.

The individual limestone blocks vary somewhat in color, but are generally light to medium gray which weathers to a medium gray. Black chert, which weathers to a dark brown is common making up 75 percent of the rock in some places. Where the chert is relatively rare, the limestone has been quarried.

The purer limestone are crossed by thin calcite veins up to an eighth of an inch in width. In the larger veins calcite crystals with visible cleavage surfaces are common. The color of this calcite is usually white, but in some places is a pale pink.

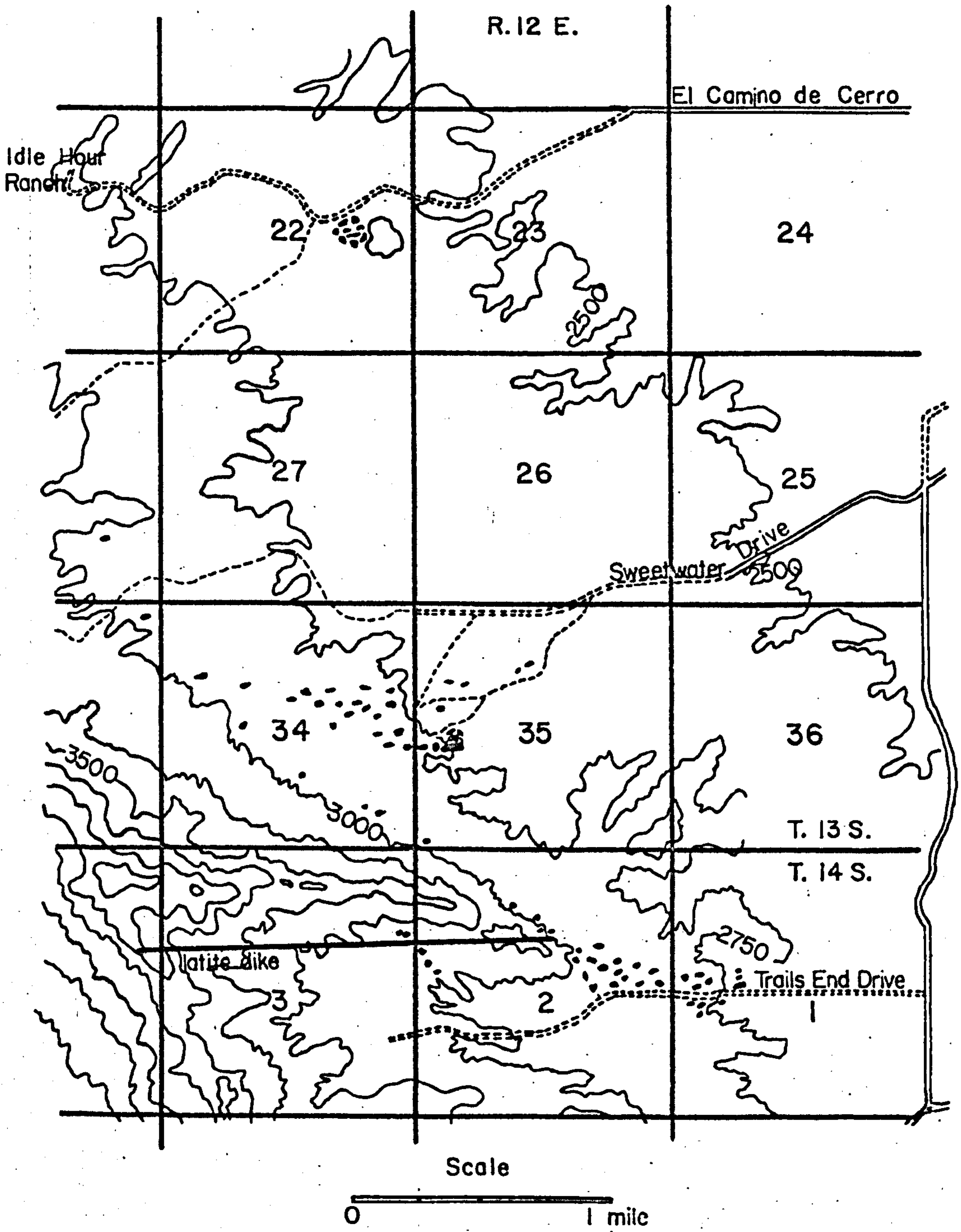
The blocks along the western side of the mound are somewhat silty and weather to a lighter gray or to white. The limestone has very fine brown laminae which are more resistant to erosion than the gray limestone.

The blocks are generally unfossiliferous, but a few crinoid stems, horn corals and one Dictyoclostus were found. Although neither the euomphalid zone nor the five foot chert zone with Composita (Bryant, 1959) were found, a tentative correlation has been made with the Rainvalley Formation on the basis of lithology. This correlation was based on the varying colors of the limestone, its siltiness and the amount of chert. A few of the blocks may be part of the Concha, but this could not be definitely determined.

The contact of the limestone with the surrounding andesite at this locality is very distinct. The limestones appear to be sitting in the andesite with the vertical relationships observable at several of the blocks. As the mound of andesite is roughly circular and raised above the surrounding area, it is unlikely that the andesite is the remnant of a flow which flowed around the blocks while they were in their present

Figure 3

Location of Limestone Outcrops in the Northeastern Area



position. This possibility will be discussed more fully, however, in the chapter on the origin of the blocks. The dark red andesite appears to be the turkey track porphyry which is found over much of the Tucson Mountains. Some of the blocks are in contact with a medium gray andesite porphyry apparently associated with the red andesite porphyry. The color difference makes the two andesites appear distinct, but in the outcrops at Trails End (Fig. 3) it is apparent that they are the same intrusion.

Idle Hour Ranch.--On the flank of the ridge due east of the Idle Hour Ranch in Sec. 21, T. 13 S., R. 12 E. (Fig. 3) there is a single block of limestone twenty feet in width. It is medium gray and weathers to lighter gray. The contained black chert weathers brown and is relatively abundant. Bedding is not apparent. The block contains Fenestrellina and small pockets of brachiopod fragments, characteristic of part of the Concha limestone. The block is surrounded by light gray andesite porphyry with small plagioclase phenocrysts. The rock appears to be the same as that in the El Camino de Cerro outcrops. A dike of red andesite porphyry crosses the stream bed to the west of the ridge and appears to pass directly beneath the limestone block.

Trails End Road.-- Along Trails End Road in Sec. 1,2,3, T. 14 S., R. 12 E. (Fig. 3) are approximately one hundred separate blocks of limestone. These vary in color from dark gray to light gray and weather from dark gray to pink. Some of the blocks are fossiliferous and others completely devoid of fossils. Common fossils are echinoid spines, crinoid stems, horn corals, productid brachiopods, and gastropods. Recognizable genera are the brachiopods, Juresania, Composita, Dictyoclostus, and the coral Lophophyllidium. Fenestrellina was also found in at least one block.

The chert content is variable, ranging from zero to about 75 percent of the rock. It occurs as replacement of fossils and as small and large nodules, lenses, and distinct layers. It weathers dark brown, but a fresh surface may be pale yellow to black. The chert usually stands out in strong relief above the less resistant limestone.

Although the contacts of the blocks with the surrounding rock are usually obscured, many of the blocks are associated with dark red andesite porphyry, the turkey track. Adjacent to the large block in Section 1, north of the road, the andesite is exposed in a shallow road cut. The limestone block appears to be resting in the andesite because the andesite continues around the western side of the block. Fifty yards farther west along the road, several small blocks of limestone, quartzite and limestone conglomerate are surrounded by andesite.

Bedding was discernable in several of the blocks and strikes measured from N. 81° W. to N. 26° E., with dips of 33 to 81 degrees. There appears to be no alignment of the blocks such as Whitney (1957) found in the Sweetwater area.

Both the Concha and Rainvalley formations are present in the area. Whereas no blocks of the Martin, Escabrosa or Horquilla were identified by fossils, it is possible that they are represented in the relatively unfossiliferous blocks. A zone of abundant Fenestrellina, with Composita, indicative of Concha Limestone, was found in one of the blocks high on the slope of the ridge in the north-central part of Section 2 (Fig. 3). The large block on the road, mentioned in connection with the andesite, appears to be Concha Limestone. Immediately to the east of it, separated by a covered zone a few feet wide, is a large block of varicolored limestone assigned to the Rainvalley formation. It consists of both dark, medium, and light gray limestones. In the darker layers, small calcite nodules appear to be replacement of fossils.

The western end of Trails End Road is in a large sub-circular valley (Fig. 3). Ridges both north and south of the road extend eastward from the high ridge of the Tucson Mountains. At their eastern limits, these ridges trend toward the road enclosing the valley. The new Saguaro School for Asthmatic Children is located in the gateway to this valley. Most of the limestone blocks are clustered to the east of the ridge in the north-central portion of Section 2 and outside the valley. Five blocks, however, were found in the enclosed valley. The easternmost of these is a small light gray block about eight feet across located in a side wash of the main drainage. The wash makes a right angle turn around the limestone block. The northern bank of the wash, across from the limestone, has outcrops of arkose and conglomerate, while the eastern bank, across from the block, is an andesitic intrusion. The andesite appears to be part of a dike. The remaining blocks are located along a line trending northwest from this point. Their color ranges from light to dark gray. One block contains abundant brachiopods, horn corals and Fenestrellina. Adjacent to this is a block that is light to dark gray, contains a few chert nodules, but has no fossils. South of these blocks, a small area of the Cat Mountain Rhyolite appears to be domed over sandstone.

The northern edge of this enclosed valley is transversed by an east-west latite dike. Just north of where the dike crosses the boundary between Sections 2 and 3 (Fig. 3), a block of limestone conglomerate crops out. The fragments are subangular, light to dark gray limestone. The block strikes N. 34° E. and dips 70° SE. To the east of the block, andesite crops out on the far side of a deep wash. The side of the wash adjacent to the block is covered by limestone talus, but the block may be underlain by the andesite, which also crops out north of the block.

The westernmost block of the enclosed valley lies just north of the andesite and is a light gray limestone. Fossils are scarce, but Dictyoclostus and crinoid stems were recognized.

Although the majority of the blocks are clustered in an elongate area along Trails End Road, isolated outcrops occur in a line along the eastern flank of the ridge (Fig. 4) north to Sec. 28 and 33, T. 13 S., R. 12 E. Here in the vicinity of Sweetwater Drive, the area of outcrops widens into another elongate east-west pattern.

Sweetwater Drive.-- The Sweetwater Drive area was mapped in detail by R. L. Whitney in 1957. The limestones are predominantly Concha and Rainvalley although rocks of the Martin Limestone were identified (Whitney, 1957). The size of the blocks is variable, from a few feet to almost a thousand feet in length. The larger blocks appear to be fractured and the sections rotated slightly, relative to each other.

Along the base of the south side of the block containing the quarry in Sec. 35, T. 13 S., R. 12 E. (Fig. 3), red andesite porphyry crops out. In the saddle between the large block and a smaller quarried block to the west, the andesite surrounds two small blocks of limestone and one of quartzite. The andesite outcrop continues on the slope below the base of the smaller quarried block on its eastern and southern sides. Fossils are found in both of the larger blocks, and the lithology is distinctly Concha.

Extending west from these blocks there is a series of elongate outcrops of Rainvalley (Whitney, 1957). The andesite occurs along the southern side of these blocks, but the outcrops are not continuous.

North of the quarried blocks there is a small block of quartzite south of the wash extending along the road. The block is surrounded by andesite which has several good exposures in the wash itself. At the southwestern corner of the quartzite, a boulder of limestone rests on andesite. This is the expected position of the blocks in the theory that they have been rafted into position by the andesite. There is no evidence of alteration along the contact, however.

The surface of most of the blocks in the Sweetwater area is jagged because of small pits and channels. This "desert etching" is probably due to infrequent rainfall and rapid evaporation rather than a result of a period of greater rainfall. Along the western side of the smaller quarried block there is a line of pits which was formed by water running down the face of one block and dripping onto another. In a crack in the rock where there is protection from the force of desert thunderstorms, white secondary calcite growths have formed on top of the pits and channels.

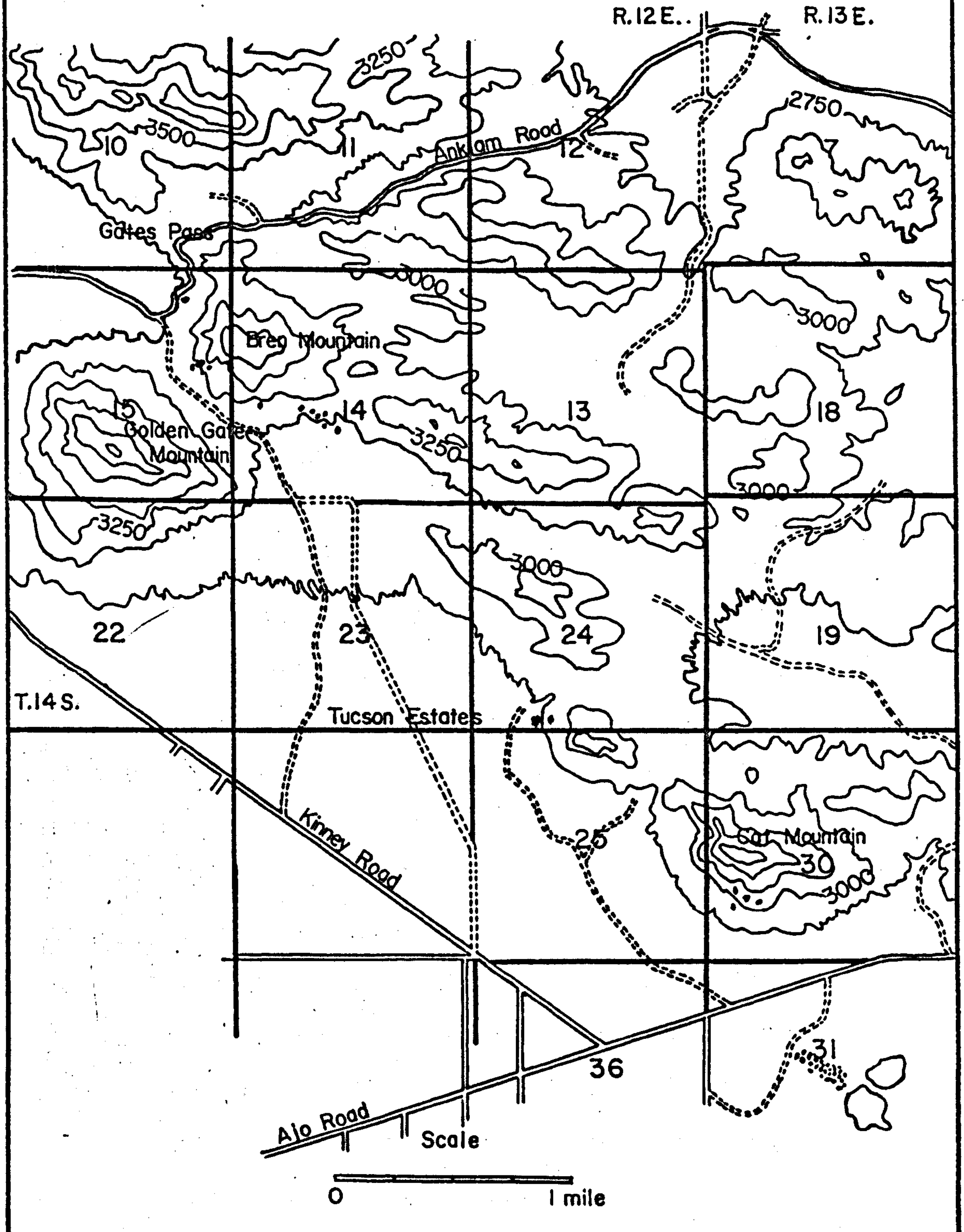
The Western Areas

Bren Mountain.-- Most of the outcrops of blocks in the Bren Mountain area are located on the southern slopes of the mountain. The rocks are light to dark gray and contain small quartz geodes, chert nodules and calcite veins. The largest block is about 30 feet in diameter, but the average is slightly smaller. In one block the chert is of two types, one a fine-grained yellow variety and the other a coarser black chert, both of which weather brown.

In only one of the nine blocks on the southern flank were fossils found, a few crinoid stems in a dark gray limestone. Some of the nodules in the other blocks appear to be replaced fossils. On the basis of lithology

Figure 4

Location of Limestone Outcrops in the Western Areas



three of the blocks are considered to be definitely the Rainvalley Formation, with all of them possibly of this formation.

The strike of the beds could be determined in one of the blocks and measured N. 15° E. The beds are vertical at the base of the block and bend to the east at the top (Fig. 5).

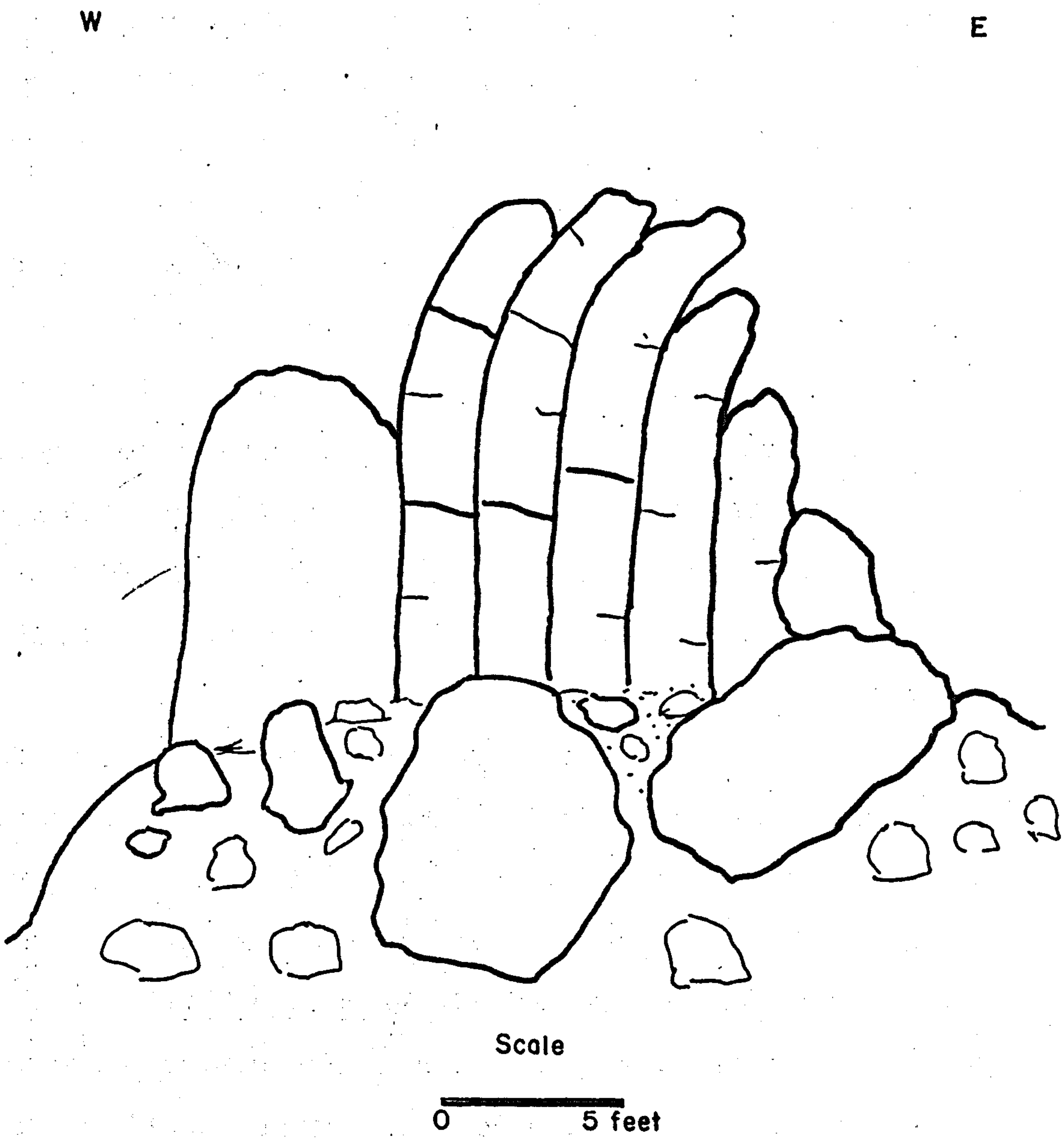
Andesite crops out near four of the blocks, whereas the others are surrounded by steeply dipping Amole Arkose. The andesite appears to underlie the limestone blocks and no alteration of the limestone at the contact with the andesite is apparent.

On the western slope of Bren Mountain facing Golden Gate Mountain, there are two limestone blocks exposed on the slope and a single block along the Gates Pass Road. This single block is 30 feet in diameter, medium gray, weathering to light brown and is unfossiliferous. The block is in contact with Amole Arkose which has been sheared and powdered in a zone several inches wide next to the limestone.

The smaller of the two blocks facing Golden Gate Mountain is a very dark brown-weathered limestone that contains no fossils. The color of the block is characteristic of the Martin Limestone and a tentative correlation was made on this basis.

Figure 5

Folded Bedding in a Limestone Block
South of Bren Mountain



The larger of the blocks is an abundantly fossiliferous dark gray limestone. The fossils are predominantly horn corals, crinoid stems, and brachiopods. Brown-weathering chert is locally abundant and occurs in nodules and small bands. Steeply dipping Amole Arkose appears at the base of the block on the western side. Red andesite porphyry crops out on the northern and eastern sides. There is small block of Pinal Schist at the eastern edge in addition to the andesite (Fig.7).

Tucson Estates.-- In the Tucson Estates locality are two large blocks of limestone perched on the western slopes of the mountain northwest of Cat Mountain (Fig. 4) and due east of the Tucson Estates Trailer Park. The large block containing a quarry is about fifty feet long and is medium gray limestone, silty and containing thin layers of chert. A smaller varicolored limestone block is exposed higher on the slope to the east of the first block. Chert is not abundant and there are small quartz geodes. Both blocks are unfossiliferous, but similar in lithology to the Rainvalley Formation.

Cat Mountain.-- The blocks on the south side of Cat Mountain are medium gray, silty limestone. They are small and unfossiliferous, and no attempt was made to assign them to a specific formation.

South of Ajo Road.-- In the Central part of Sec. 31, T. 14 S., R. 13 E., (Fig. 4) there is a large zone of rubbly limestone. The outcrop area is about 1500 feet long and 300 feet wide. It consists of many small blocks rather than a single large one. The limestones are silty and range in color from light to dark gray. Chert nodules and layers are not abundant. The lithology suggests that these blocks are Rainvalley.

SUMMARY OF CHARACTERISTICS

Age

The identified blocks range in age from Precambrian to Permian, the Pinal Schist to the Rainvalley Formation. Although the Abrigo Limestone has not been identified in the Chaos, it may be present, as it is found nearby in the Picacho de Calera Hills. The blocks are arranged in no particular sequence, with blocks of different ages adjacent to each other. The majority of the identified blocks are Concha Limestone and Rainvalley Formation, probably because the thickness of these rocks is greater than those of other formations and they contain more abundant fossils.

Size

The size of the blocks is not uniform and the individual outcrops vary from one foot to nearly a thousand feet in length. The largest blocks, however, attain this dimension in a single direction only. Most of the blocks are less than 200 feet in diameter and appear to have a much smaller vertical dimension, reaching a maximum of about 50 feet.

Orientation

With the exception of the limestones in the Sweetwater area, which have generally east-west strikes, there appears to be no preferred orientation of the blocks.

Occurrence

The occurrence of the blocks is predominantly in localized areas, which are elliptical in shape. The Trails End and Sweetwater outcrop areas are elongated in an east-west direction, whereas the Bren Mountain area seems to be elongated northwest-southeast parallel to the western escarpment. This apparent arrangement may not be valid because the outcrops are located on the flank of the mountain, and limestone blocks continue beneath the Cat Mountain Rhyolite.

Association

The association with andesite appears to be quite important in the interpretation of the origin of the Chaos. The andesite is present in each area studied, and occurs near most of the individual blocks. Where the contact is visible, there is no alteration of the limestone. The andesite usually occurs on one or two sides of the individual block and in some areas surrounds the block.

ORIGIN OF THE BLOCKS

Historical Development

Brown (1939) suggested that the limestones were klippe from an overthrust from the west. This thrusting took place near the surface as indicated by the jumbled orientation of the blocks. The conglomerates were formed where the advancing front over-rode the surface. This theory was further developed by Whitney (1957). The preferred orientation in the Sweetwater area seemed to indicate thrusting.

The following year Kinnison (1958) advanced the sedimentary chaotic breccia concept. Thrusting resulted in a scarp or headland of high relief. At the base of this, talus of all sizes accumulated. Periodically portions of this pile of sediments became saturated with water and flowed over wide areas. Thus the Chaos was a result of both landsliding and mudflowage. The Sweetwater area included both a lower Chaos and an upper thrust sheet, indicated by the parallel strike and concordant elevation of the larger blocks.

Bikerman (1962) proposed a volcanic origin for the Chaos. The magma was supercharged with gas which was released as the material neared the surface. This gas abraded the walls of the vent and large fragments of the country rock were entrained in the rising gas-solid system. The Chaos is the deposit of this material where it moved out onto the surface. Later eruptions of the welded flows of the Cat Mountain Rhyolite followed the same vents which had been cleared of the limestones and arkoses. Thus the later flows contain much smaller fragments of foreign material and in lesser amounts.

Champney (1962) in mapping a rhyolite flow between Trails End and Sweetwater Drives noted the association of andesite porphyry with the limestone blocks. He did not elaborate in the text, but did include a diagram illustrating an idea for the emplacement of the limestone. As the andesitic magma rose, the large blocks of limestone were picked up on the upper surface of the magma and forced upward with it. The blocks were thus rafted into place by the andesite.

The most recent work has been done by Mayo (1963). He suggests that hot magma may have fluidized the sediments that now constitute the Amole Arkose and then lifted the limestone blocks through this system. Thus the Chaos is a result of both fluidization and rafting.

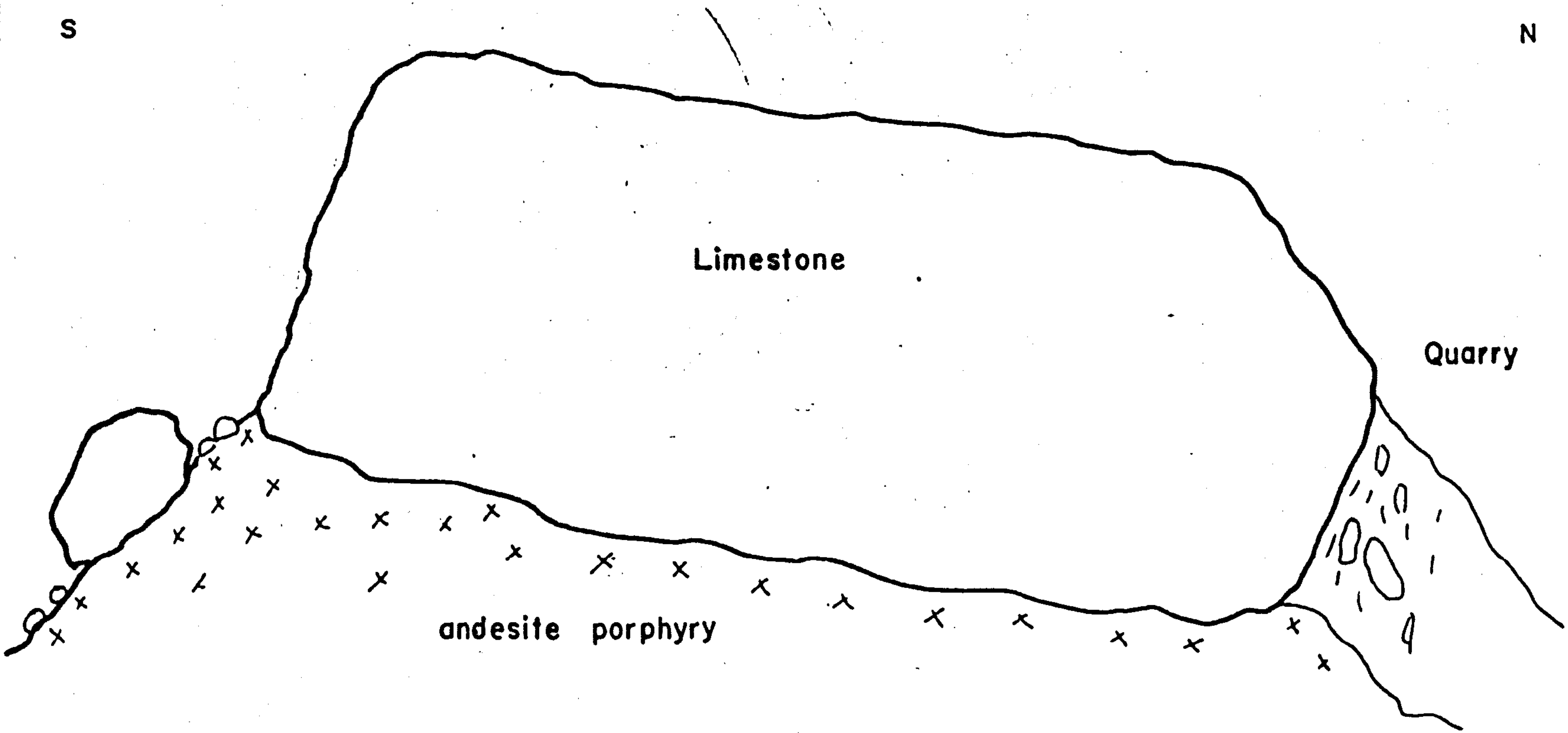
Conclusions

The occurrence of the andesite with the limestone appears to be a decisive factor in the interpretation of the origin. Kinnison (1958) regarded the andesite as part of the Chaos rather than as a distinct intrusion. The andesite at El Camino de Cerro location crops out in a large low circular mound with the limestone blocks resting on top. This outcrop suggests an origin by rafting or possible interpretation as an andesite flow surrounding isolated blocks of limestone. The vertical relationship is not clear at this location so the two interpretations cannot be evaluated, but Kinnison's mudflow origin does not appear likely.

Andesite crops out on the southern slope beneath the large block of Concha Limestone containing the quarry in the Sweetwater area. In the wall of the quarry on the north side of the block there is no andesite, but a zone of gouge with large boulders of Recreation Redbeds (Fig. 6). The andesite is continuous on the slope below the southern side of the block and it appears to be resting on the andesite. Other blocks in the area show similar relationships.

In the Trails End area andesite appears near or around almost every block. In the east-central part of Sec. 2, T. 14 S., R. 12 E. (Fig. 3), two exploration pits

Figure 6



Cross Section of the Limestone Block Containing the Quarry, Sweetwater Drive Area

Scale
0 50 feet

have been dug. One pit is in a large block of Pinal Schist about 15 feet high. The foliation of the block is vertical in the lower part and bends to the east in the upper part. The other pit has been dug along the contact of turkey track porphyry and an altered porphyry. The andesite appears to expand downward, suggestive of an intrusive origin rather than as the result of mud-flowage or landsliding.

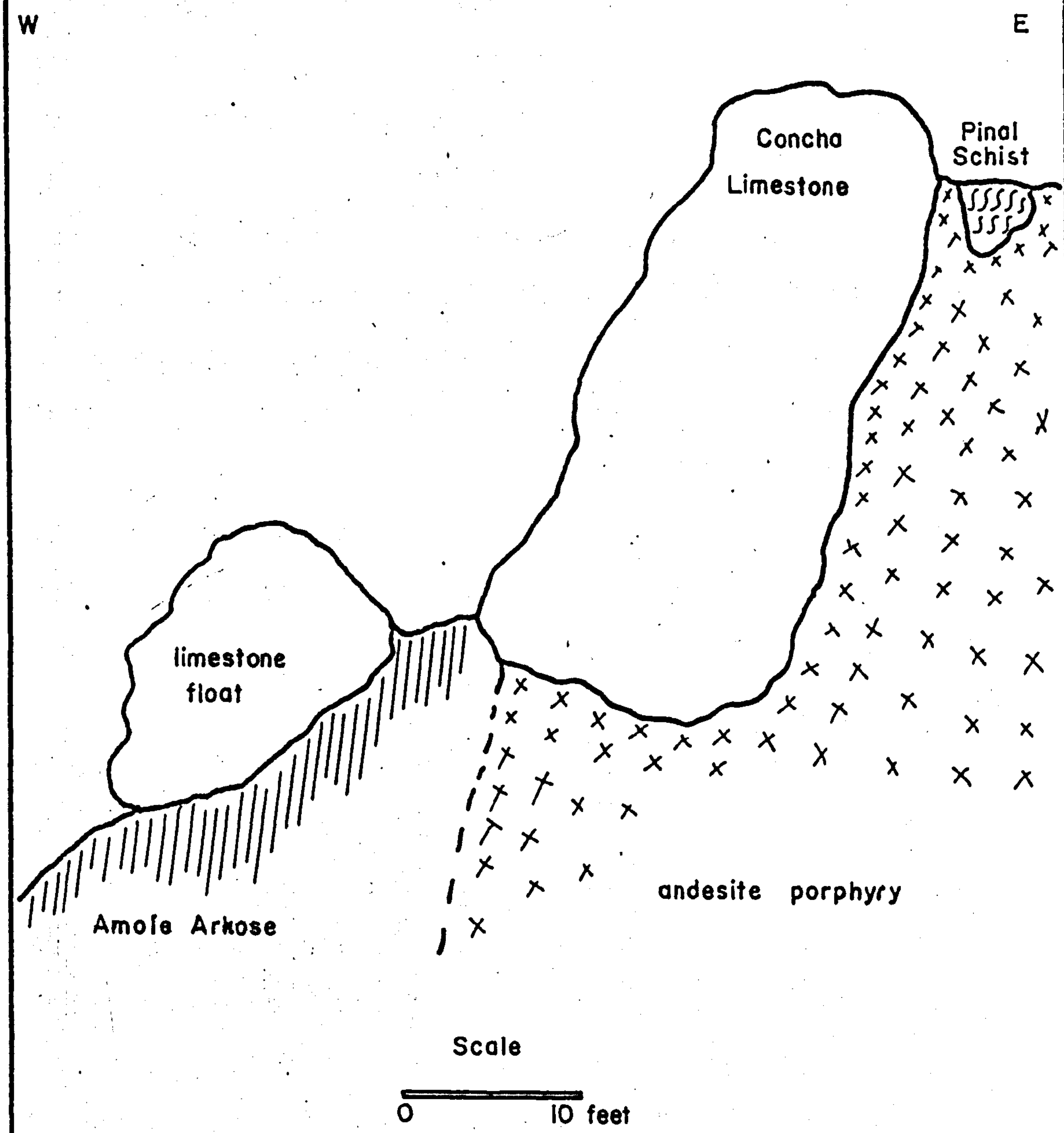
On Bren Mountain the andesite is in contact with the limestones, but the contact is less noticeable. The andesite crops out along the northern and eastern side of the large block of Concha Limestone facing Golden Gate Mountain (Fig. 7). The blocks on the southern slope are all near andesite float, but the relationship is not clear.

The theory of emplacement by andesite seems to explain the field evidence, but in turn raises several problems, The first of these relates to the lack of alteration of the limestone. If they have been carried by a molten rock, it seems that there should be some contact metamorphism, but this might not be necessary if the andesite was viscous material of very low temperature.

The andesites were considered to be flows (Jenkins and Wilson, 1920), so the problem arises as to

Figure 7

Cross Section of a Limestone Block on the Western Slope of Bren Mountain



where the blocks were picked up and how they were moved through relatively narrow fissures. The arkoses appear to be steeply dipping in the vicinity of the limestone and andesite. As the andesite rose along fractures or other zones of weakness, being viscous it shoved the overlying rocks apart and dragged the edges upward. Fragments were broken off and carried toward the surface. The material directly above the rising column of andesite would be highly fractured with the weaker material being ground to powder by friction with the more resistant limestones, arkoses and quartzites. This would explain the gouge material in the wall of the quarry on Sweetwater Drive. Gas may have caused some fluidization of the powdered material, but the extent of fluidization is unknown.

The zones of weakness appear to be nearly east-west. This is the same direction along which many of the Tertiary latite dikes were intruded. With the differential movement of the column of magma, some of the limestones were in the same area could have a common orientation as found by Whitney (1957). Along the edges of the moving material, large sections were broken and wedged upward. Such thrusting might explain the Picacho de Calera Hills and Snyder Hill, but was not investigated.

Figure 8

Early Stages in the Development of the Chaos

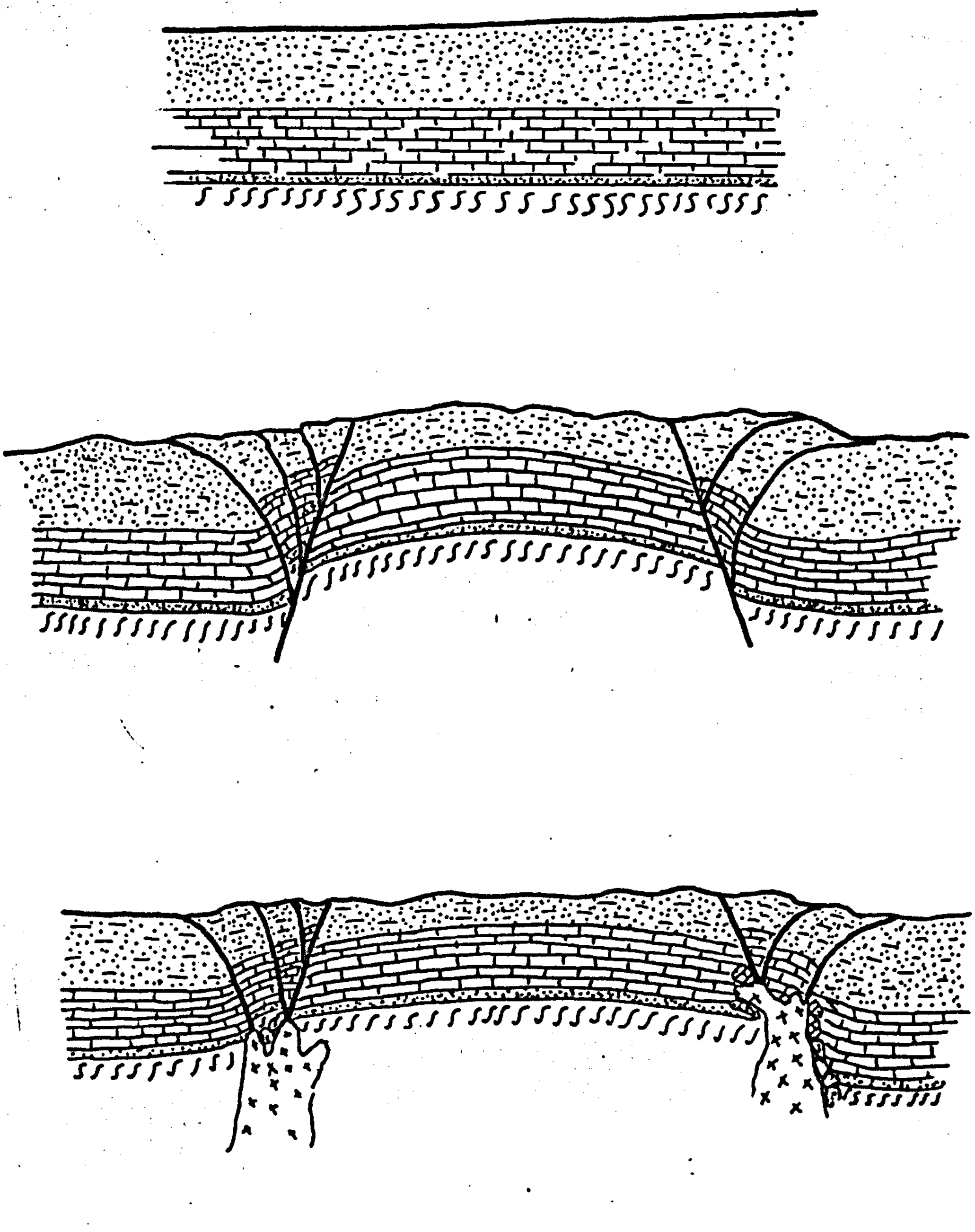
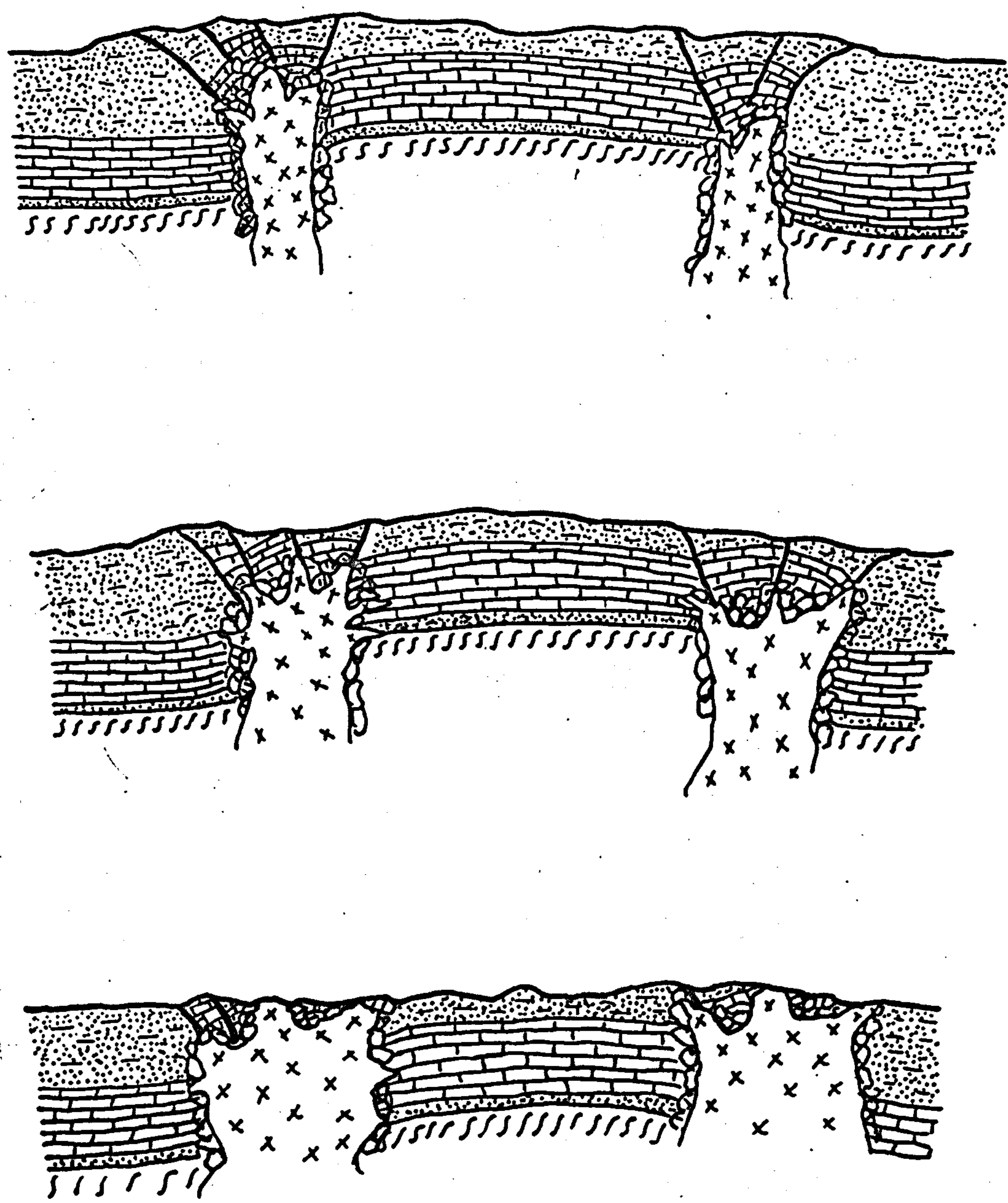


Figure 9

Later Stages in the Development of the Chaos



Geologic History

During the Precambrian fine-grained clastics were deposited in a shallow nearshore environment (Ransome, 1903) and later metamorphosed to the Pinal Schist during the Mazatal Revolution. The area was probably high during the younger Precambrian and undergoing erosion. Sediments accumulated in adjacent areas.

By the Middle Cambrian the seas covered the high area and the Bolsa Quartzite and Abrigo Formation were deposited in a deepening sea. The seas retreated in the Upper Cambrian or Ordovician and erosion began. The Martin Limestone of the Devonian and Escabrosa of the Mississippian indicate a deepening sea by the nature of their lithology (Ransome, 1904). Again the seas retreated and a slight erosion surface formed. A reinvasion resulted in the Horquilla to Rainvalley sequence.

Rocks of Triassic and Jurassic age are unrecognized in southern Arizona and probably indicate a period of uplift and erosion. The seas transgressed in the Early Cretaceous but probably did not extend much farther west than the area of the present Tucson Mountains. The Amole Arkose and Recreation Redbeds represent a nearshore environment (Wilson, 1962). During the Laramide Revolution andesite intruded the sediments and resulted in the Tucson Mountain Chaos. In many places the andesite failed to reach the surface and remained covered by the chaotic material. In the Early Tertiary the Cat Mountain Rhyolite was extruded (Champney, 1962). The present mountain area was later faulted and the eastern side in the vicinity of the present Tumamoc Hills capped by Quaternary basalts (Jenkins and Wilson, 1920).

MEASURED SECTIONS

Section 1

Section across the limestone block 200 yards north of Trails End Drive in the west-central part of Sec. 1, T. 14 S., R. 12 E.

(Strike N. 25 W., dip 82° W)

Unit		Feet
Cretaceous--gray andesite porphyry		
Permian		
	Rainvalley Formation--55.5 feet	
10.	Limestone: thinly bedded, fine-grained, medium gray; small quartz geodes............	6
9.	Limestone: medium gray, weathers very light gray or white; small veins of calcite.......	2
8.	Limestone: dark gray, weathers light gray; white chert, weathers reddish brown; thin layers of chert.............................	10.5
7.	Limestone: medium-grained; dark gray, weathers light grayish brown; partly dolomitic; irregular nodules and thin veins of gray chert, weathers dark brown.........................	9
6.	Limestone: fine-grained; dark gray, weathers medium gray; thin calcite veins; small quartz geodes....................................	4
5.	Limestone: fine-grained; black, weathers dark gray; massive; calcite layers at right angles to strike; some chert; partly dolomitic.....	9

Unit	Feet
4. Limestone: fine-grained; dark gray, weathers light gray; thin veins of calcite; veins more resistant to erosion than the limestone; no chert..........................	2
3. Limestone: fine-grained; massive; dark gray, weathers dark gray; shattered with calcite filling the fractures; thin bands of chert..................................	11
2. Limestone: fine-grained, dark gray, weathers medium gray; thin veins of calcite..	12
1. Limestone: dark gray, weathers light gray; banded chert weathers brown; thin veins of calcite; partly dolomitic..................	8

Cretaceous--gray andesite

Section 2

Section across a limestone block 500 yards north of Saguaro School in NE $\frac{1}{4}$, Sec. 2, T. 14 S., R. 12 E.

(Strike N. 60 W., dip 37° N)

Unit	Feet
Cretaceous--andesite	
Permian	
Rainvalley Formation--46 feet	
6. Limestone: coarse-grained; light gray, weathers pink; silty near top; chert increases in upper part of section...........	8
5. Limestone: coarse-grained; light gray, weathers pink to light gray; thin veins of calcite..................................	2.5

Unit		Feet
4.	Limestone: coarse-grained; light gray, weathers dark pink	20.5
3.	Limestone: medium-grained; bluish green, weathers greenish brown; no chert	9
2.	Limestone: coarse-grained; light gray to pink, weathers gray to pink; thin veins of calcite and chert	4.5
1.	Limestone: coarse-grained; light brown; silty; thin veins of calcite	1.5

Cretaceous--andesite

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