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FEEDERS OF AN ASH FLOW SEQUENCE ON BREN MOUNTAIN, TUCSON MOUNTAIN PARK, ARIZONA[1]

By

Evans B. Mayo
Department of Geosciences, University of Arizona
Tucson, Arizona

INTRODUCTION

Publications on ignimbrites, or ash flows, are many (Cook, 1959, 1960, 1966) but reports that describe in some detail the intrusive tuffisite feeders of such flows, and the relations of these to the pre-volcanic wall rocks, seem to be few.

In the Tucson Mountains, west of Tucson, Arizona, the Cat Mountain Rhyolite (Brown, 1939) was first recognized by Kinnison (1958) as an ash flow sequence. Potassium-argon dates (Damon, 1964) indicate an Upper Cretaceous age (near the Campanian-Maestrichtian boundary) for these ash-flow tuffs. The tuffs, being resistant to erosion, occupy upper slopes and crests in the central Tucson Mountains, whereas the less durable and somewhat older Amole Arkose makes up the lower slopes and basin floors. Thanks to this circumstance, the contact, or marginal zone, between the arkose and feeders of the ash flows, is exposed, albeit poorly, below the cliffs of tuff on the western slope of the range. These incomplete exposures present a seemingly unusual opportunity to study the relations of the underlying roots of an ash flow sequence to their sedimentary walls. One of the most favorable of these exposures is on the southwest slope of Bren Mountain, opposite Golden Gate Mountain (Fig. 1; inset, Fig. 3). The purpose of this report is to describe and to attempt an interpretation of these exposures.

The view shown in the inset (Fig. 3) gives the impression that the Cat Mountain Rhyolite, exposed in the cliffs on Bren, is a stratiform body tilted rather gently northeastward. From this impression it has been inferred that the rhyolite rests with angular unconformity on folded Cretaceous sedimentary rocks; yet this inference cannot apply in the area studied, as is easily seen by consulting the structure profiles (Fig. 3) or the map (Fig. 2). The features shown are the steeply folded sedimentary walls and the tuffisite-filled eruptive channels, <u>not</u> the spreading ash flows (but see Fig. 5-H).

Figure 2 was constructed, at 50 feet to the inch, from a pace-compass traverse of access road and trail. With this frame established, control points, mostly saguaros, were located by resection. The geology was then mapped in the usual way. The structure profiles (Fig. 3) were measured with cloth tape and clinometer and the structure was plotted on the profiles in the field. The reasonable fit between profiles and map is assurance that no intolerable error remains in the survey. A few special plans and profiles (Fig. 4) were constructed at ten feet to the inch in order to reveal certain details more clearly. Some hypothetical constructions (Fig. 5) were made to illustrate an inferred mode of emplacement of older blocks among younger strata.

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[1] Contribution No. 32, Department of Geosciences, University of Arizona, Tucson, Arizona.

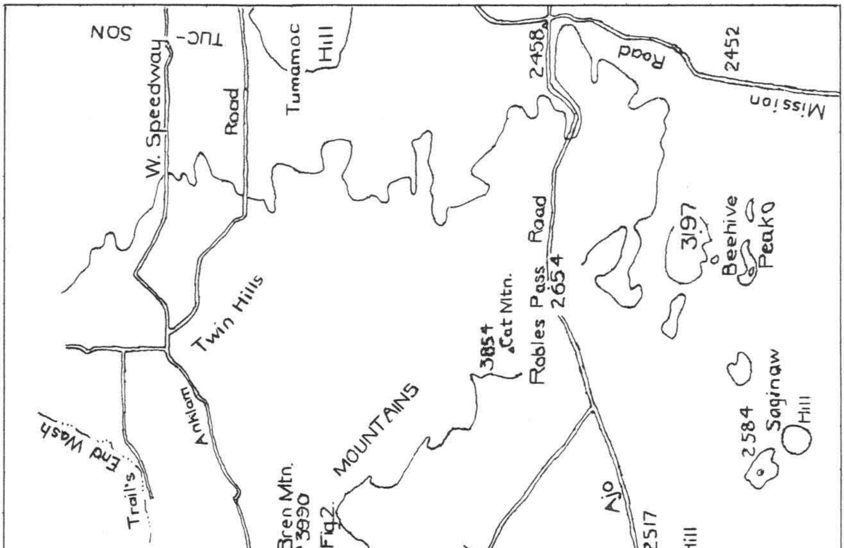


Figure 1.--Location Sketch.

The locality is easily reached from Tucson via. West Speedway and Anklam Road to Gates Pass, thence down Saguaro Road to the Parking place (x, Fig. 1 and Fig. 3, inset) at the sharp turn on the western slope. From the parking place a very rough access road leads southeastwards, up slope, to the unnamed col between Golden Gate and Bren mountains.

I take pleasure in thanking Professor Donald L. Bryant for several consultations regarding sources of the two Paleozoic blocks exposed at this place.

PREVIOUS INVESTIGATIONS

This locality is a very small part of the region mapped and described by Jenkins and Wilson (1920) and in more detail by W. H. Brown (1939). In 1958 Kinnison published a structure section of this very place and Mayo (1963) presented a longer profile across the Sedimentary Hills, Golden Gate Mountain and the southwest slope of Bren Mountain. At the same time Bikerman reported the important discovery of devitrified glass in the matrix of a very coarse fragmental unit marginal to the Cat Mountain Rhyolite. S. M. Assadi (1964) submitted a Master's thesis on the structure of Golden Gate Mountain, in which he concluded that the Cretaceous sedimentary rocks had undergone an episode of updoming followed by collapse accompanying expulsion of the Cat Mountain Rhyolite. P. A. Geiser (1964) reported on the structure of part of Bren Mountain. He suggested that Bren is what remains of an endogenous dome. Mayo and McCullough (1964) published a section across a limestone block in this area and Scott McCoy (1964) wrote a Master's thesis on the exotic limestone blocks in the Tucson Mountains. McCoy, prejudiced against the idea of upheaval from depth, was forced by the weight of his own accumulating evidence to conclude that the blocks had indeed been upheaved. In none of the above studies, except perhaps Geiser's, was the mapping sufficiently detailed to reveal in a satisfactory manner the nature of the contact between Amole Arkose and the intrusive feeders of the Cat Mountain Rhyolite.

GEOLOGIC FORMATIONS

The rocks exposed in this small area range in age from older Precambrian to probable final Cretaceous. The older Precambrian is present as one small block and as numerous chips. There is no younger Precambrian and the Paleozoic succession is represented only by two exotic blocks, a few masses of rubble, and some small pieces. Most of the rocks by far are of Mesozoic age.

Older Precambrian Pinal Schist

A shining mica schist, considered to be the Pinal, is very sparingly exposed. One small mass of this schist, perhaps 6 x 4 feet in plan (Fig. 4-C) is exposed below the Silver Lily dike in the northeastern part of the area (L-2, Fig. 2). At the southeast end of the Concha Limestone block (L-4, Fig. 2; Fig. 4-C) a concentration of chips of this same schist suggests that a local sheath of Pinal may coat the limestone below surface. Chips of the schist are also to be found in certain masses

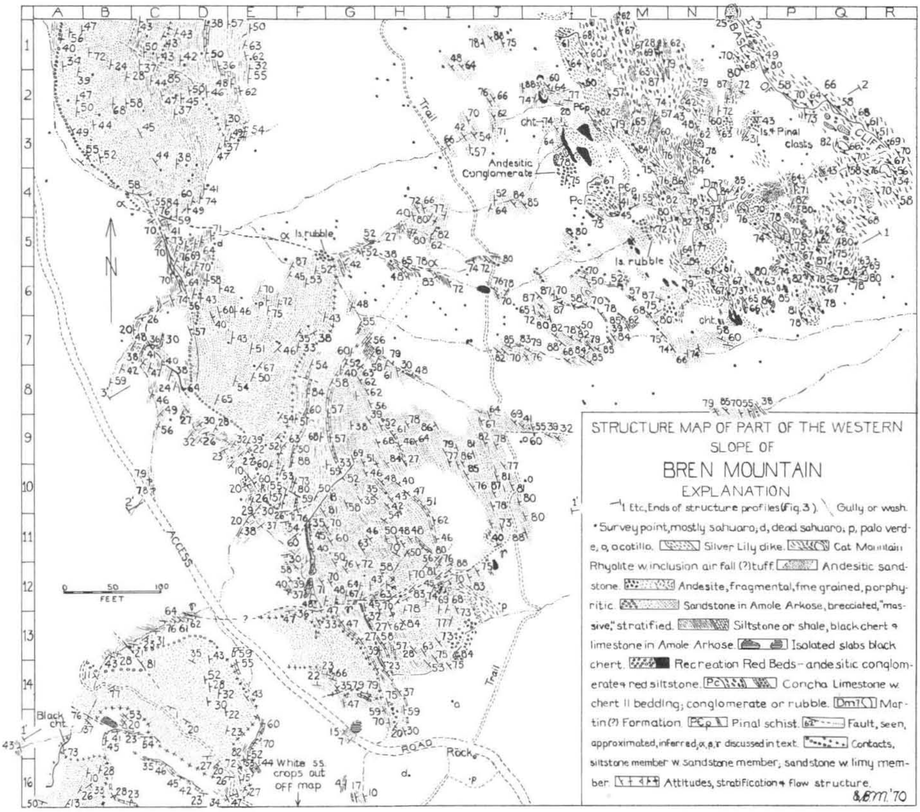


Figure 2.--Structure Map of Part of the Western Slope of Bren Mountain.

(pipes ?) of limestone rubble and at some places in the intrusive Cat Mountain Rhyolite. As now exposed, all these pieces of the basement are in alien surroundings presumably thousands of feet above their proper stratigraphic level.

Late Devonian Martin Formation (?)

A single steep-sided block, 8 1/2 x 19 feet in plan (Fig. 4-E) of dark, yellowish-brown weathering carbonate, is exposed in the wall of a small ravine between two segments of the Silver Lily dike (N-4, Fig. 2). Much of the carbonate is replete with the tiny rods, or tubes, of the coral Syringopora. To my knowledge no other fossil has been found in this block. According to Professor Donald L. Bryant (oral communication) Syringopora has been reported from Devonian, Mississippian and Pennsylvanian formations in Arizona. Further, beds of carbonate similar to this mass are known from post-Devonian Paleozoic formations. Accordingly, this block is assigned questionably to the Martin.

Permian Concha Limestone

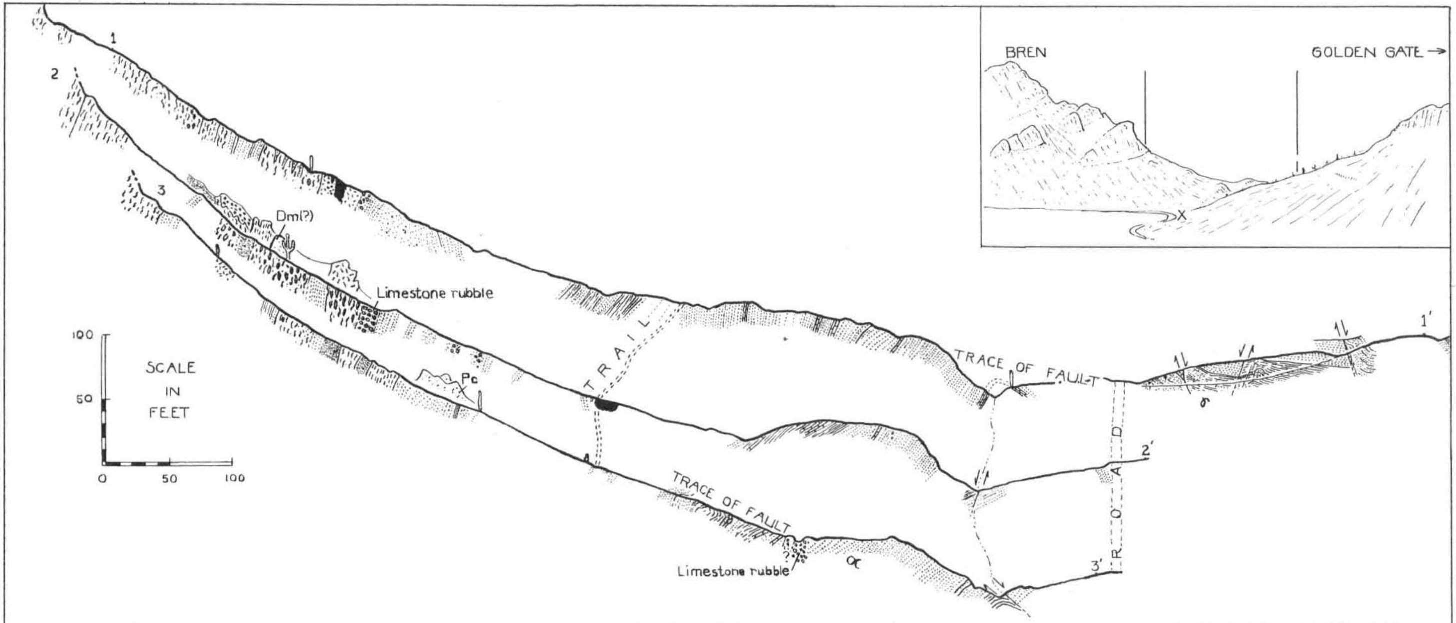
A mass of dark, blue-gray limestone, with northeast-dipping stratification revealed by aligned chert nodules, crops out 100 feet west of the Martin (?) block (L-4, Fig. 2; Fig. 4-C). This limestone was illustrated in profile by Mayo and McCullough (1964, Fig. 2-B, p. 83). According to Scott McCoy (1964, p. 26) fossils found in this rock "are predominantly horn corals, crinoid stems and brachiopods." Professor Bryant (oral communication) is inclined to think that this limestone was derived from the Concha.

The block is 55 feet long and may average 20 feet in width (Fig. 4-C). It was formerly much larger; a belt of huge fragments derived from it extends down slope to and beyond the trail. Further, beyond the southeast corner of the mass, and separated from it by a 15 foot gap with no exposure, there is a steep zone, or septum, of apparent Concha rubble (M-5, Fig. 2). Other rubbly masses and isolated pieces of apparent Concha will be mentioned under 'observations and inferences.'

Triassic (?) Recreation Red Beds

R. E. Colby (1958) working in the Piedmontite Hills and Red Hills (Fig. 1, at and northwest of Fig. in the word Figure), proposed to combine the Recreation Red Beds of Brown (1939) with Brown's Cretaceous volcanic rocks, making one formation of what had previously been two. Because the volcanic conglomerate, of the volcanic rocks, and the red siltstone, of the red beds, are interstratified, Colby's suggestion has merit. Professor P. E. Damon (1967) published the results of a K-Ar analysis of the Desert Museum andesite porphyry, which is intrusive into the Recreation Red Beds. Results of the analysis indicate an apparent age of 150 ± 5 m.y. for the intrusion, thereby opening the possibility of a Triassic age for the red beds.

Small exposures of red siltstone, identical to that of the Recreation Red Beds, and locally accompanied by volcanic conglomerate, are shown in black (Fig. 2). With the exception of two small outcrops below the trail, all exposures of the red rock lie in a belt (the "zone of intrusive upheaval") about one



LOOKING S 30°E. FOR LOCATIONS & ROCK SYMBOLS SEE FIG. 2. INSET IS VIEW SE., TOWARD COL BETWEEN BREN & GOLDEN GATE MOUNTAINS. STRUCTURE PROFILES ARE BETWEEN VERTICAL LINES.

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Figure 3.--Structure Profiles.

third way between trail and base of the cliff. These Triassic (?) rocks, together with the Paleozoic limestones and the little Precambrian block, are weirdly out of place in their Cretaceous surroundings.

Cretaceous Amole Arkose

The Amole Arkose (Brown, 1939, p. 716-720) occupies almost the entire southwestern three-fourths of the study area and is present as isolated strips, blocks, and lesser inclusions in intrusive tuffisite in the northeastern part. Of the Amole units recognized by Assadi (1964, p. 12-26) the siltstone, no. 2, sandstone, no. 3, and limey, no. 4, can be identified here. There seems to be general agreement that the Amole Arkose is Cretaceous in age, but some uncertainty exists as to what part of Cretaceous time is represented.

This formation was once the only one at this stratigraphic level. All other rocks shown (Figure 2) are foreign elements that have usurped the place of the Amole.

Cretaceous Andesite

In the northeastern part of the mapped area andesite is present as small intrusions into the Amole Arkose and as blocks, huge "boulders" and lesser inclusions in tuffisite of the Upper Cretaceous Cat Mountain Rhyolite. These relations would seem to leave no doubt of the Cretaceous age of most of these dense, fine-grained, or porphyritic sub-volcanic rocks. However, the possibility has not been precluded that some andesitic conglomerate (e.g., K, L, -4, Figure 2) was derived from the Recreation Red Beds as defined by Colby (1958). In this case, the conglomerate would be pre-Cretaceous.

Besides the andesitic conglomerate there are other fragmental andesites that seem to have been tuffisized (rendered tuff-like) by fluids escaping perhaps from the Cat Mountain Rhyolite. What appears to be an early stage in this process is revealed in the rubbly andesite shown in profile 2-2' (Figure 3), 40 feet left (northeast) of the symbol Dm(?). Here the andesitic rubble is underlain with flat, irregular contact by intrusive rhyolite which breaks upward on the northeast side. Other, less favorably exposed examples are in 0-3 and K-1 (Figure 2).

Immediately up-slope from the example shown in profile 2-2' is an exposure of faintly- to non-stratified, steeply-dipping, brown graywacke with sporadic granules and pebbles of andesite. This material does not resemble any seen in the Recreation Red Beds, and to derive it by erosion from an intrusion into the Amole Arkose seems impossible. Perhaps the brown graywacke represents a further stage of disaggregation (fluidization and elutriation) of rubbly andesite.

The intrusive andesites furnish the first definite hint of a possible mechanism for emplacing older, exotic blocks in younger, stratigraphically higher surroundings.

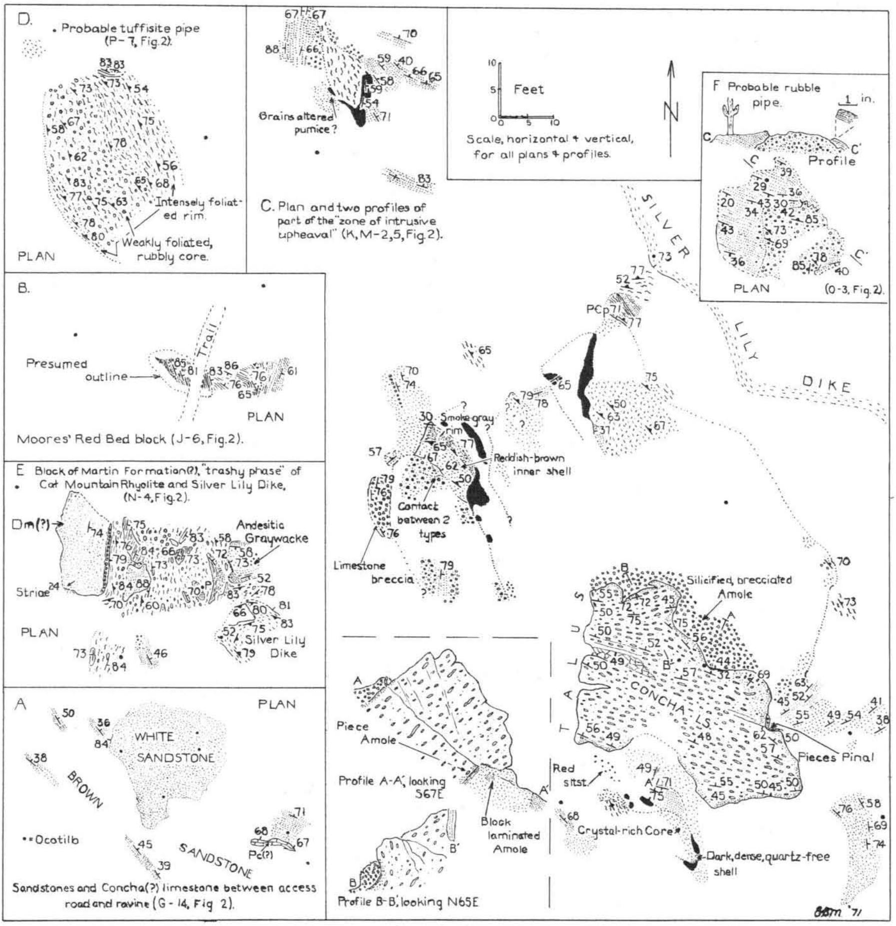

Figure 4.--Plans and Profiles.

Cretaceous Cat Mountain Rhyolite

This volcanic formation has been dated radiometrically (Damon, 1963, p. A-IX-1) and the apparent age is lowermost Maestrictian or uppermost Campanian. The intrusive tuffisitic phase is the rock of at least the lower part of the cliff along the northeast border of the area (Figure 2) and this tuffisite also crops out irregularly on the slope below. The tuffisite intrudes the Amole Arkose and the andesite and contains many large and small inclusions of both these rocks.

Upwelling of the rhyolite also contributes a suggestion about emplacement of pieces of the pre-Cretaceous formations.

Cretaceous(?) Silver Lily Dike

According to Brown (1939, p. 742) the Silver Lily dikes are probably composed of quartz latite porphyry. The field relations of these dikes to dated igneous rocks in the Tucson Mountains have been discussed (Mayo, 1966, p. 26-27). The present writer does not doubt the upper Cretaceous age of the dikes, but perhaps it could still be maintained that the evidence of this age is as yet inconclusive.

The one Silver Lily dike present in the study area exists as several apparently isolated segments that might be connected as depth. The surface arrangement of these segments suggests that, at the time the dike was emplaced the adjustments accompanying intrusion and extrusion of the Cat Mountain Rhyolite had not yet ceased. Further, this dike deviates from the eastward trend common to the Silver Lily dikes as though to pass around, rather than through, the still active (?) emission center of Bren Mountain.

SUMMARY

The geologic formations, actors in the Upper Cretaceous drama at this place, have been introduced. The next task is to consider the internal structures and the mutual arrangements of these rocks and to attempt certain inferences, therefrom.

OBSERVATIONS AND INFERENCES

Structural Setting

The area originally chosen for study lay on the northeast flank of a southeast-plunging anticline (Assadi, 1964, colored geological map). As the 50-scale mapping progressed, many complications appeared which had not been shown on Assadi's 500-scale plan. Because of this, and to confirm the presence of the fold, the 50-scale mapping was extended southwestward onto the hinge and toward the southwestern flank. The fold seems to be present, but its previously-represented smooth, graceful form now appears to have been severely damaged.

On the slopes of Golden Gate and Bren mountains, to southwest and northeast, strata on the flanks of the anticline dip away from the hinge toward eruptive centers of the Cat Mountain Rhyolite (Mayo, 1963, Figure 4). This relation suggests that the

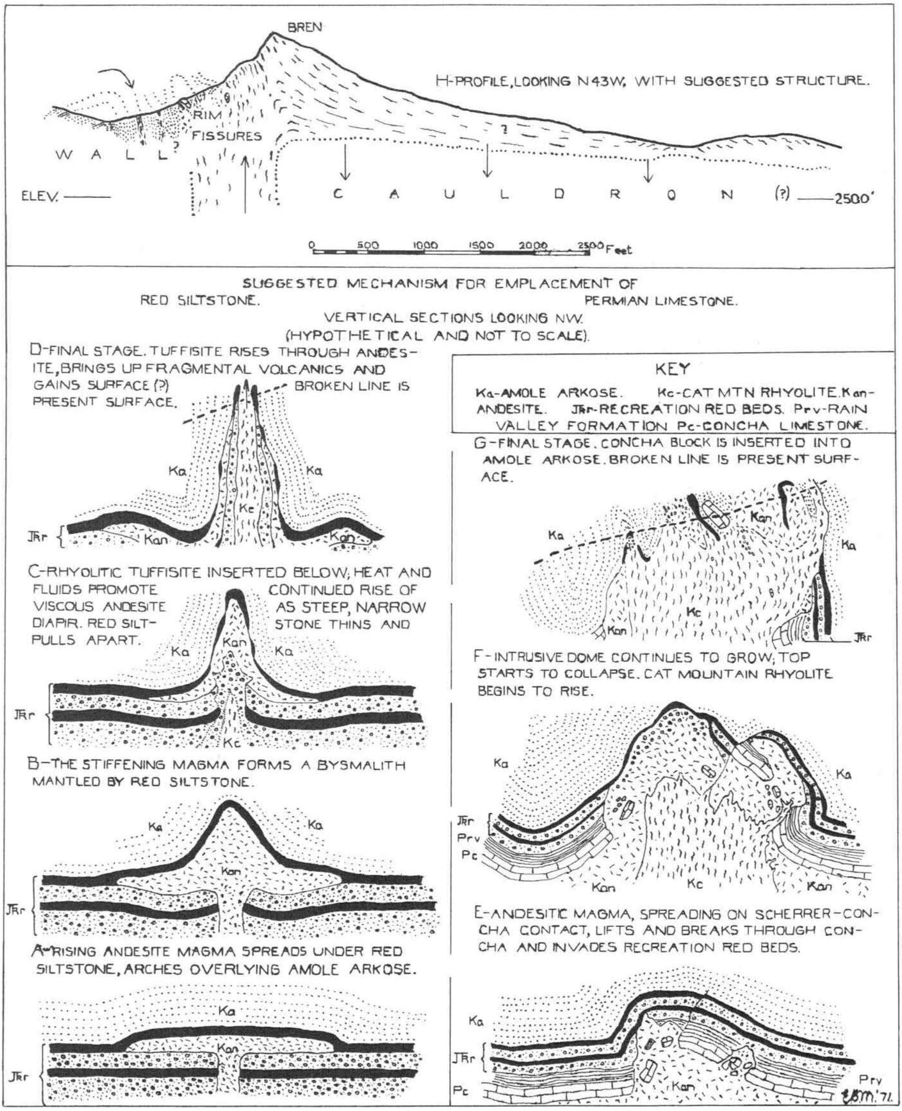

Figure 5.--Profile and Vertical Sections.

anticline may have formed by subsidence of the flanks toward the eruptive foci, leaving a central horst as hinge.

What follows is a description and attempted interpretation of structural features observed on the hinge and northeastern flank of the fold. A detailed study of the southwestern flank is not contemplated, but it might be rewarding.

The Fold Hinge

The hinge of the fold proved difficult to locate. It was sought in the southwest where, according to Assadi's map (1964), the sandstone unit of the Amole Arkose should curve smoothly around the nose of the southeast-plunging anticline. The 50-scale mapping reveals, instead of such a uniform adjustment, three separate sandstone blocks in the hinge region. Two of these sandstone bodies lie southwest of the access road; the third is between the road and the nearby, northwest-draining ravine (Figure 2).

Some features of the last-mentioned block require discussion. This segment, which is cut off at the north by fault γ , consists of a core of very coarse-grained, unordered, white arkosic sandstone to granule conglomerate, encased in a shell of light cinnamon-brown, coarse-grained, laminated arkosic sandstone, a few to 20 or more feet thick. Near the southern end of this exposure, the contact between white, "massive" core and stratified shell is irregular. A few feet beyond a small, southeast-pointing digitation in this contact, an elongated sliver, apparently of Paleozoic limestone, rests on, or in, the brown sandstone (A, Figure 4).

Excavation would be required to prove whether this limestone is float, resting on the surface, or is actually embedded in the sandstone, but for the following reasons the limestone is thought to be embedded. First, the original surface of the splinter, where still preserved, shows evidence of solution or abrasion, is stained black, probably by manganese oxide, and is liberally sprinkled with angular chert granules considered to be fragments of former nodules that were shattered at the contact. Taken alone, this evidence is not convincing, because pieces of talus derived from the Concha block (L-4, Figure 2) locally have the above kind of surface. In conjunction with the next observation, however, the evidence gains weight.

The steep sides of this elongated sliver appear to go down approximately parallel to the dip of stratification in the sandstone, and the splinter is elongated about parallel to the strike of the enclosing stratification. Finally, as already mentioned, the little block lies at the end of a digitation of the white sandstone core like an island off a mainland peninsula. The chance seems remote that a piece of Recent debris would have the above-described surface, orientation and position.

If the piece of limestone is not float, how was it emplaced in the sandstone? The size and shape preclude transport over any appreciable distance in a sand-laden current, but perhaps the little block slid from some former outcrop into a site of deposition. This interpretation might account for the orientation of the splinter, but the location would have to be regarded as accidental and the peculiar surface would be unexplained. An alternative is needed.

The white sandstone core has been bleached - cleared of those constituents that make the shell brown. It might follow that during this clearing-out process the core lost its stratification and acquired a coarser grain by elimination of the finer fractions. Perhaps the core became fluidized and mobilized. Could the limestone splinter have been pushed up from below as a result of such action? This seemingly absurd suggestion should be kept in mind as other exposures are examined.

The two sandstone blocks southwest of the access road differ from the one just discussed in that cores and shells are scarcely distinguishable and the sandstones are faintly stratified throughout.

In the overlying limey unit a prominent argillaceous limestone bed, underlain by from a few inches to two or more of coal-black chert, forms a marker a few feet stratigraphically above the sandstone unit. The two isolated blocks of black chert (B-15 and G-15, Figure 2) are remnants which indicate that the marker bed once covered this part of the area. A third chert block lies beyond the southern edge of the map. The marker now seems to be preserved only in synclines between the sandstone bodies. There can be little doubt of a syncline between the two southwesternmost sandstones, but between the blocks just east and west of the access road the structure has to be inferred from very incomplete exposures.

The question arises whether the apparently separate sandstone bodies actually are separate, or whether the unit was compressed and buckled into waves, in the troughs of which the marker now rests. Perhaps an unequivocal choice cannot be made, but available evidence does suggest that the sandstone is in separate blocks (profile 1-1', Figure 3, southwestern part). The broad, horst - or box fold-like hinge region and the numerous normal faults suggest uplift and extension rather than buckling under compression. Further, the structure suggests that the sandstone unit was disrupted while gliding on the siltstone unit from the higher, southwestern edge to the somewhat lower northeastern margin of the hinge. If so, the little "dog ear" fold at the ravine (Figure 3, profile 1-1') might be a pressure ridge forced upward where the glide sheet encountered the obstacle of the northeastern flank.

In summary, observations suggest that the hinge region of the major anticline was uplifted, extended and torn apart rather than shoved together. Extension might have facilitated the rise from below of activating fluids into the more permeable units.

The Northeastern Flank Between Access Road and Trail

Except in the southern third of the mapped area, exposures in the northwest-draining ravine and its southwestern tributaries are almost exclusively in Assadi's siltstone unit. As can be appreciated by walking up the ravine, certain beds of siltstone and shale in the upper part of the unit have been intensely deformed. Adjustments have taken place parallel to bedding as well as on normal faults inclined to stratification. In general, hanging walls have moved relatively downward toward northeast (profile 2-2', Figure 3), but antithetic movements (profile 3-3') also occurred. All of the above were adjustments either of gliding or of extension; they functioned to adjust between the broad, flat hinge and the steeply down-tilting northeast flank.

The overlying sandstone unit is exposed on the northeast flank as two blocks, separated and displaced by fault α (Figure 2). Alpha may be a normal fault, north side down, or an oblique-slip fault, or a left-lateral strike-slip. Striations, which would permit a choice, have not been found, but less direct evidence (Figure 2) favors the third, strike-slip possibility.

In the northwest corner of the mapped area the northern of the two sandstone blocks consist of three layers - a thick, basal western one consisting of vaguely stratified, very coarse-grained, white arkosic sandstone, a thinner central layer composed of medium-grained, laminated, light brownish-gray, arkosic sandstone, and an uppermost relatively thin, coarse-grained, white arkosic sandstone. Within the thick western band are places where the faint stratification is bent out of the usual strike. At such places there are exposed vaguely-defined masses of unstratified, very coarse-grained pebbly arkosic sandstone similar to the unstratified core of the above-described easternmost block in the hinge zone. Many of the pebbles are gray chert (derived from limestone ?) some of which may reach an inch in diameter. Andesite is sparingly represented among the clasts and one small pebble was found which appeared to be andesitic graywacke. Larger inclusions, or blocks, of gray-brown arkosic sandstone, some of them reaching 15 feet in length, are present in the stratified white sandstone. These inclusions are oriented to the enclosing stratification, and they appear to be remnants that have escaped bleaching. Here again the white sandstone has somehow been cleansed of colored constituents, but a few tell-tale relics remain.

All of the above-mentioned features, except the division into three separate bands, or sub units, are present in the southern sandstone block also. Seen from the access road, beds near the base of the southern block intersect and cut one another off in a manner resembling large scale cross bedding. The surfaces of discordance may be hiati, but are thought to be faults not quite parallel to bedding. One of these surfaces is shown (Figure 2, below the dip value 57 in D-7, 8) and two more are indicated on profile 3-3' (Figure 3, above DEN in GOLDEN GATE). The entire basal contact of this block, and of the northern one also, may be a steep glide surface concealed by talus.

The southern end of this sandstone segment, south of fault α, (E, F - 9, 10, Figure 2) is a puzzling feature. Here the sandstone unit narrows into a south-pointing finger, around the end of which swing the medium-grained strata of the limey unit. Unless the sand was deposited as lenses, one of which wedges out here, then the sandstone unit may have been tectonically thinned and pulled apart, or perhaps the south-pointing finger plunges beneath the above-mentioned "dog ear" fold. If the last case holds, then the sandstone unit reappears farther south as a result of uplift on fault γ.

At the northeast corner of the southern sandstone block, where fault α crosses the contact between the sandstone and limey units, there is a mass of apparently Paleozoic limestone rubble with many pebbles of Pinal Schist (F-5, Figure 2). This material is definitely not coarse gravel recently deposited in the gully where it is now exposed. Nor does it appear to have been deposited in some geologically ancient stream channel. The location, on the trace of fault and on the intersection of this trace with the junction of two physically dissimilar Amole units, suggests that the rubbly mass rose on a tectonic channel. On the east side of the rubble is a small exposure of Cat Mountain Rhyolite. This may be a large, partially buried talus block, but as tentatively suggested on profile 3-3' (Figure 3) it might be the tip of an intrusive apophysis responsible for emplacement of the rubble. Regrettably, exposures are poor at this place.

In review, the sandstone unit appears to have slid off the anticlinal hinge and to have subsided an unknown amount down the northeast flank. The unit might have torn partly or completely away from its counterpart on the hinge. Further, the sandstone on the flank became separated into two blocks, the southern of which might have been abruptly thinned and pulled away from its own southward continuation - or perhaps the unit warps and plunges out. While the above adjustments were in progress the unit was buckled internally and was traversed by ascending hot (?) fluids which bleached the rock and might have eliminated the finer grades and emplaced foreign pebbles from depth. Finally, a probable pipe of limestone rubble rose on fault α at the northeast corner of the southern block. It remains to see what happened in the overlying limey unit.

The behavior of the marker bed near the base of the limey unit corroborates and adds to the evidence of displacement on transverse and other faults, and furnishes an example of the pulling apart of a bed. Beginning in D-1 (Figure 2) the east-dipping marker, minus the underlying black chert, migrates down a steep hillside to reappear in a small gully in E-3. The marker should intersect fault α somewhere in D or E-5, but is actually seen again in H-6, on the south side of the fault. The marker is also exposed in a gully in G-7, from which it is traced southwards in an eastwardly-concave arc to intersect fault B in F-10. Fault β offsets the marker to F-11. In F-12 the bed of impure limestone, underlain by black chert, is pulled apart and medium- to coarse-grained sandstone has flowed into the gap. Perhaps this structure is a miniature of the pull-apart of the sandstone segment in E-10, 11. Beyond its pull-apart the argillaceous limestone curves around the south-plunging axis of the "dog ear" fold, then disappears under alluvium.

The marker, with its black chert underlayer, is next seen south of fault γ in G-12, 13. The displacement suggests that γ is a right-lateral strike-slip fault, but the curvature of strata on either side indicates the contrary. This situation can be reconciled if a relatively moderate strike-slip component were combined with, or perhaps alternated with, a larger dip-slip component, north side relatively down.

South of fault γ, in strata above the marker (I-12, 13, Figure 2) are some features of unusual interest. On both sides of the small gully in I-13, sandstones of the limey unit contain pebble-sized angular to sub-angular inclusions -- of the same sandstones! Apparently the arenite, perhaps when only weakly consolidated, was shattered and partly disaggregated. The remaining "sedimentary autoliths" might subsequently have become cemented in their own debris. This condition has been observed at many places where the Amole Arkose has received igneous injections, therefore, it is no surprise to find just such an intrusion a short distance upstream.

Southwest of the Palo Verde is an elongated body of intrusive rhyolitic tuffisite. The northeast contact of this small mass can with difficulty be traced with no change of trend down the steep side of the gully. Accordingly, the contact must be steep. The tuffisite appears to have inserted itself sill-like along Amole stratification. On the southwest contact of this little intrusion are limited exposures of fine-grained andesite, and just beyond the northwest end is a small, concordant insertion of fragmental andesite. Heat and fluids from these little intrusions, or from their larger underground extensions, may have caused disruption and fluidization of parts of their sandstone walls.

Just south of fault γ, in J-12, is a barely exposed block of red siltstone, and on the opposite side of the fault is a small, poorly exposed outcrop of tuffisite. These suggestive features arouse interest, but because of extensive cover they add little information.

On and below the trail in J-6, and on the projected strike of fault α, another block of red siltstone is partially exposed in a small gully (Figure 4-B). Around the east end of this block stratification in the limey unit changes trend from east-southeast to south-southwest. Could the red siltstone have been driven upward on a steeply-plunging pucker formed and opened by drag on fault α?

The red block was partly excavated, cleaned, washed, and photographed in color by graduate student, R. C. Moores, II (1969). Moores found that the margins of the red siltstone were quite irregular but that the sides dipped very steeply. The red siltstone was at least partially enclosed by a somewhat disintegrated carapace of tuffisite about 18 inches thick. Within a few inches of the red rock the carapace contained small red inclusions, and hear its external contact the tuffisite contained small inclusions of Amole Arkose. A shell of Amole was silicified in contact with the tuffisite and beyond this shell the arkose was unaltered.

If Moore's results are valid, as they appear to be, the red rock rests in, not on the Amole Arkose. Further, the block must indeed have been driven upward at a tectonically weakened spot by intrusive Cat Mountain Rhyolite. Moore's conclusion that the "rhyolite acted as both energizer and lubricant" is supported by other evidence to be presented below.

Observations have been presented which suggest that during deformation the more permeable units of the Amole Arkose were traversed by copious fluids from depth. At that time, apparently, small igneous intrusions were emplaced on the steep stratification of the Amole. One mass of Paleozoic limestone rubble, mixed with Pinal clasts, rose from depth on a structural intersection and at least one small pre-Cretaceous block was lifted high into Cretaceous strata. As the eruptive center northeast of the trail is approached more closely, evidence of upwelling should become much more impressive.

Exposures Between Trail and Silver Lily Dike

This north-northwest trending band, above the trail and below the dike, can be conveniently divided into northeast and southwest parts. The southwest strip, bordering the trail, is somewhat more than 100 feet wide in its northwest part where the strike of stratification averages north-northwest, and is almost twice as wide at the southeast end where the strike changes to east-southeast. Within this strip igneous intrusions have not been found, but at many places the arenaceous Amole is devoid of stratification and contains "sedimentary autoliths."

In the southeastern part of this southwest strip, minor folds were observed, as indicated in K-7, L-6, and M-7 (Figure 2). As shown in profile 1-1' (Figure 3, above the word 'rubble'), a large syncline might exist in this part of the area.

Northeast of the strip reviewed above, and between it and the Silver Lily dike, is the upper, parallel belt which I have come to call the "zone of intrusive upheaval." In this belt the Amole Arkose exists as a network pierced by many small igneous intrusions and by blocks and rubble derived from pre-Cretaceous formations. A preliminary impression of this zone can be gained by walking up the little gully which trends up slope from Moore's red bed block.

The first exotic material, seen at the base of the saguaro in M-5 (Figure 2), is red siltstone. Contacts are not exposed and no igneous material was seen here, but a few yards to the south red siltstone is in contact with intrusive andesite. Upstream from the red exposure is Amole sandstone with faint vertical laminae and beyond this is a band, about 8 feet wide, of probable Concha Limestone rubble. The contact between the Amole Arkose and the rubble was dug out by structural geology students. The surface dips northeastward about 77 degrees.

The matrix of the rubble is sandstone, apparently identical with the Amole, and a few pebble-sized Amole and red siltstone clasts are present. By far the most of the clasts are limestone, like the Concha. A few of these pieces reach 10 inches in diameter.

Above and beyond the rubble is a 30 feet wide band of tuffisite so charged with pieces of Amole shale and siltstone as to merit the term 'trashy phase' of the Cat Mountain Rhyolite. In their arrangements the myriad sedimentary inclusions preserve the north-northwest strike and steep northeastward dip of the surrounding rocks. Apparently, a fine-grained, clastic unit of the Amole was especially favorable to invasion. The tuffisite appears to have risen into the sedimentary rocks along stratification or fissility, finally isolating the many slab-like inclusions without disturbing the stratified arrangement. In the initial stage at least, the tuffisite invasion must have been a relatively quiet, orderly process.

Northeast of the "trashy" tuffisite band is a strip of sandstone, about 20 feet wide, and beyond that more tuffisite. Seemingly, the coarse-grained clastics resisted the attack of the rising, hot, gas-glass shard system better than did the silty or shaley rocks.

North of the small gully sits the Concha block (L-4, Figure 2). The relations of this limestone mass to its immediate surroundings are so critical that a special map and two profiles were prepared (Figure 4-C). Eight feet south-southwest of the southernmost corner of the block is a poorly exposed intrusive mass with lenses of red siltstone marginal to it. Examination of the southeast end of this small intrusion discloses the remains of a dark, fine-grained outer shell which has been almost completely disrupted by lighter-colored material of the core. The core material breaks across the shell and encloses small, round, dark pieces of the shell.

A thin section of the shell material reveals hundreds of small parallel-oriented plagioclase tablets in a "sooty" (iron oxide rich?) groundmass. Minute gas pores are abundantly present; most of these are filled with calcite, a few with chlorite. A very few much altered phenocrysts were seen which might have been olivine.

The core material looks at first like a very coarse-grained brown sandstone, but the hand lens reveals quartz which is obviously phenocrysts, not detrital grains. The lens also reveals sharply angular, broken pieces of feldspar and six-sided biotite plates, all in a very fine-grained, brownish-gray matrix. In thin section, under high power, with crossed nicols the matrix is mostly isotropic with scattered, faintly birefringent blades or patches. In plane polarized light, colorless, lath-shaped microlites are seen and there are many ill-defined, minute, flaky crystals of a mica-like substance, perhaps a clay mineral. Under low power, the flow structure of the rock is obvious. Shattered, broken phenocrysts of plagioclase, a little quartz, and thin plates and splinters of oxidized biotite are arranged with longest dimensions approximately parallel. The groundmass elements stream and eddy between and around the pieces of this crystal debris. Adding to and emphasizing the parallel structure are conformable lenses or drawn-out wisps, rich in silt-sized, or even finer, debris. These may be remnants of fine-grained sedimentary inclusions. Some of these streamers have recrystallized to form minute sheaf-like or radiating aggregates, perhaps of feldspar. A few silt-sized grains persist, even in this fibrous material. Microfissures, formed approximately at right angles to the flow structure, contain calcite, hematite dust and sharp-edged splinters of feldspar. A few discrete grains of Amole (?) siltstone, red siltstone and andesite were seen. Brown sphene, a little apatite and some minute zircons are accessories.

The shattered, broken condition of all larger crystals and the complete oxidation of biotite suggest thorough churning of these crystals in a rising stream of hot fluid. Apparently, the motion became more orderly as the material stiffened.

The small exposure of intrusive Cat Mountain Rhyolite about 8 feet east of the saguaro (Figure 4-C) suggests that the core of the above-discussed intrusion may be underlain by rhyolitic tuffisite which furnished the activating fluid, presumably gas.

Judged from the above observations, a small "fingertip" apophysis of gas-rich, probable olivine andesite magma rose through Amole sandstone, dragging upward an incomplete collar of Recreation Red Beds. A basic marginal shell of the intrusion chilled and solidified, but the core, increasingly gas-rich and charged with more siliceous igneous materials as well as elements from the sedimentary rocks, continued to rise. The "boiling up" of the core appears to have eliminated all but a few grains of the andesite, and to have almost erased the solidified basic rim. Even the few remaining andesite grains might be volcanic constituents from the Recreation Red Beds. Finally, a small mass of rhyolitic tuffisite, probable supplier of gas, and of the siliceous igneous materials, reached the present level of exposures.

If gas was able to escape into the weakly consolidated sedimentary walls of this intrusion, a partial or complete erasure of stratification might have taken place. Except on the northeast side, where laminae in sandstone dip toward the intrusion and its red siltstone collar, strata in the enclosing Amole are elusive or absent. Moreover, the just-mentioned sandstone laminae are abruptly truncated by "massive" Amole (Figure 4-C, south of the Concha block). In the directionless Amole there are a few small remnants of laminated sandstone which suggest that the stratified rock was broken up and incorporated into a seething, arenaceous mass (ex., profile A-A', Figure 4-C).

Further, flat, pale gray, wafer-like inclusions with silky luster, and reaching an inch in diameter, are present in the directionless sandstone. These objects are thought to be pieces of altered pumice. If the identification is correct the inference is plain that the energy which caused the sand to boil was furnished by hot, gas-charged magma emplaced not far below the present surface. Accordingly, the above-described intrusion is probably a mere offshoot from a much larger, concealed mass. Even without the above evidence, the very appearance of the sandstone outcrop in the southern reentrant of the Concha block suggests emphatically that the mobilized sand did indeed boil upward past the limestone.

A hand specimen from this directionless sandstone is almost white, with light cinnamon flecks. The coarse grains are angular to subrounded. A few subangular chert granules are present. Quartz is very abundant and the rest of the visible grains are white feldspar.

In thin section, the rather sparse matrix is seen to consist of minute, sharply angular splinters of quartz and feldspar set in sericite, a little secondary calcite and "limonite." This matrix forms a web, or network, around "islands" of coarser grains ---quartz, plagioclase, microcline, chert, siltstone, calcite, and muscovite. The quartz and feldspar grains are so cracked and shattered that there can be little doubt as to the origin of the micro-splinters in the matrix. The cracks in some of the quartz grains are filled with matrix. One quartz grain was seen with a corona of quartz micro-rubble embedded in sericite. The twin lamellae of some plagioclase grains are faulted and the faults are filled with matrix. All of the feldspars are somewhat sericitized.

The general impression is that the sandstone has been at least partly disaggregated and churned. The grains of chert and of calcite might have been derived from the adjacent limestone. A few partly resorbed quartz crystals are present which might have been carried up from underlying magma. In short, the thin section accords with the field observations.

In view of the above, examination of the margin of the Concha block is important. The contact surface is stained black, probably by manganese oxide, and is rough and pitted as though by solution, by abrasion, or both. On the limestone side of the contact there is a marginal shell, from one or two inches to perhaps two feet thick, in which the limestone appears to have been brecciated and re-healed. The chert nodules, so common within the block, are reduced to angular crumbs in the marginal shell. One small piece of Amole Arkose (profile A-A', Figure 4-C) was found in this carapace. Apparently there has been at least limited intermixing of materials from both sides of the contact. Accordingly, at the time when the adjacent Amole was mobilized an outer film of the Concha block was also activated.

On the east side of the big block a thin selvage of Cat Mountain Rhyolite (Tuffisite) is inserted along part of the contact, and here chips and small, loose slabs of Pinal Schist suggest the presence of this rock immediately beneath. Intrusive fragmental andesite is probably in direct contact with limestone at the northeast corner, where the internal structure of the Concha is disturbed and twisted northward. In this entire corner much of the nodular chert has been reduced to angular crumbs. The adjacent andesite is thought to be part of an elongate mass which extends north-northwest some 70 feet (Figure 4-C).

Along its northeastern contact the Concha is overlain by silicified, brecciated Amole Arkose. The limited exposure suffices to reveal that both silicification and brecciation diminish northward, away from the big block. In the northwest corner of the northeast reentrant of the limestone contact, the Concha strata diverge outward as though the strata had been forced apart by the arkose. Additional evidence of the activity of the Amole is in the small embayment at the northwest end of the block where Amole, now silicified and brecciated, has entered fissures in the Concha. Profile B-B' (Figure 4-C) shows some of the structure in this embayment. Apparently, after the Amole became silicified and thereby stiffened, the Concha continued to be forced upward, shattering the brittle Amole and flowing viscously past it. The energy to drive these adjustments could with reason be ascribed to an underlying magma now represented by the intrusive cupolas north and south of the Concha block.

The relatively straight western edge of the Concha block is a peculiar thing, for which there is no obvious explanation. Talus west of the block precludes exposures. Chips of red siltstone in debris near the southwest corner of the Concha suggest that the small red exposures to the south may be continuous with similar ones to the north. If this is indeed the case, then the small intrusion south of the limestone might be continuous with the feature to be discussed next.

Northwest of the Concha block is the mass indicated as "andesitic conglomerate" (K, L-3, 4, Figure 2). This fragmental body appears to be elongated north-northwest; its southern end is buried beneath debris. At the northwest end is a small block of laminated Amole, and south of this, on the western side of the "andesitic conglomerate," is a ten foot slab of limestone breccia with scattered quartzite clasts and a few pieces of fine-grained sandstone. On the eastern side is red siltstone, and at the northeast corner is a block of andesite. The arrangements of these rocks -- red siltstone, andesite, laminated Amole and limestone breccia -- concentric to the northern end of the "andesitic conglomerate," suggest that the "conglomerate" rose from depth, forcing the marginal blocks aside and/or dragging them upward. The concentric strikes of internal structures of these peripheral blocks (Figure 4-C) reinforce this suggestion.

The andesite block, at the north end of the fragmental core, consists of a partial, dense, dark, smoke-gray rim and a dense, reddish-brown inner shell. Both rim and inner shell are faintly flow banded. Measurements of this structure are plotted (Figure 4-C). In thin section the groundmass of the smoke-gray rim appears to be shattered, devitrified glass with aligned plagioclase microlites and flattened micro-amygdules filled with calcite and an apple-green clay (?) mineral. The few altered phenocrysts may once have been olivine, now changed to "iddingsite." The cracks in the groundmass are filled with calcite, a little shattered secondary quartz and the apple-green mineral. Because of shattering the groundmass is divided into micro-blocks each with a slightly different orientation of microlites and amygdules. The brittle outer rim seems to have been strained by the continued rise of the still plastic inner shell.

A thin section of the reddish brown inner shell reveals a sponge-like mass with myriads of minute, irregular, calcite-filled amygdules in a mesostasis of devitrified glass charged with hematite dust. Under medium power, plagioclase microlites can be made out in the dark mesostasis. With low power the flow banding is revealed as alternating darker and lighter streaks, but with medium power the structure is seen to be swirled on a minute scale within the streaks. Perhaps the structure was formed as increasing viscosity brought about the transition from turbulent to laminar flow. The inner shell appears to have been emplaced as a fine froth. Most of the amygdules are 0.1 mm or less in length and very few reach 3 mm.

The rock of the fragmental core of this structure does not merit the term andesitic conglomerate. The material is a rubbly mass of mostly pebble- and granule-sized clasts in what appears to have been a sandy-muddy matrix. Identified pebbles are andesite of several kinds, chert, red siltstone and rhyolite. There are many angular white grains that may be pieces of altered tuff or pumice, and many broken grains of quartz. Near the contact with red siltstone, the matrix of this core rock is red and contains red grains and granules. At one place (Figure 4-C) a contact was seen between slightly different kinds of core material, and at another place (at the east dip measurement 79) what appears to be stratification was recorded.

The only thin section made of the core rock was cut from a specimen of coarse, directionless rubble collected near the east dip value 79. The slide shows no true matrix. The clasts are held together by calcite cement. All of the quartz grains are cracked and several stages are preserved of disintegration and strew of these grains. One grain retains two crystal faces, so this quartz probably crystallized as phenocrysts in a cooling rhyolite or tuffisite. This is obviously not detrital quartz. Small, mostly angular grains of plagioclase are present, but are not abundant. Rock grains, granules and pebbles include chert, limestone, red siltstone and several kinds of andesite. Some of the andesite is similar to the rock of the smoke gray rim, discussed above. None were seen which resemble the inner shell. Most andesite grains are like no rock exposed near-by; they might have been derived from volcanic conglomerate in the Recreation Red Beds (Figure 5, A, B, C, and D). The chert clasts are partly carbonatized, and the patterns of calcite in one of them vaguely suggest microorganisms. Most of the larger clasts and some of the smallest ones are well rounded.

The general appearance of the slide, as well as that of the outcrop, suggests that the core was once a seething mass in which the various constituents became thoroughly mixed. The apparent stratification at the east-dip value 79 might be a preserved relic, but more probably it is flow banding resulting from entrainment. Judged from the abundance of calcite and the paucity of hydration effects (very little sericite or chlorite) the activating agent might have been carbon dioxide, perhaps with a very limited amount of steam (Mayo, 1967, p. 212). Here again, the presence of shattered quartz phenocrysts, and the possible presence of altered pumice, suggest a hidden tuffisite intrusion as energy source.

For a few feet beyond the northern end of the above-discussed structure, very coarse-grained sandstone in the Amole Arkose is devoid of stratification. About seven feet northwest of the andesite block a faint stratiform arrangement of granules and pebbles first becomes visible and even this ordering is extremely local. In addition to dominant quartz and feldspar, grains of chert and of andesite, flakes that appear to be altered pumice, and grains seemingly of the same apple-green mineral present in the andesite block, are present in the directionless sandstone. Apparently the sandstone was once in the condition termed by Leva (1959, p. 2) a "turbulent fluidized bed," in which the solids mix readily. This boiling, abrasive sand appears to have attacked the andesite block, for the internal structure of this remnant is truncated at the northern contact.

In view of the apparent mobilization of the Amole, the presence, about 13 feet northeast of the andesite block, of a small, poor exposure of tuffisite (Cat Mountain Rhyolite) is no surprise. This energy-bringer probably underlies much of the area of "boiling sand."

The structural relations of andesite (or dacite ?), red siltstone, Amole Arkose, Cat Mountain Rhyolite and Pinal Schist north of the Concha block are indicated (Figure 4-C) in so far as they have been observed or inferred. The east-northeast trends in arkose and red siltstone are surprising and the reason for them is not known. Perhaps an east-northeast trending eruptive channel lies to the northwest, just beyond the limit of outcrops. If this is the case, then the measurements of attitude were probably made, not on strata, but on flow or shear banding generated in mobilized sediments. A similar, but better exposed case in which flow bands crosscut sedimentary laminae, has been described (Mayo, 1961, p.5, Figure 2, sketch 4).

In the far northwest (Figure 4-C) is a flask-shaped mass of tuffisite with its broader southern end nested within a chalice of red siltstone. The northern, narrow part of the tuffisite is bordered on northeast and southwest by what at first appears to be fragmental andesite. With the hand lens this is seen to be a graywacke, or microbreccia, with abundant brown grains, probably derived from andesite, and with many quartz grains. As far as revealed by the limited outcrops, the entire system is enclosed in Amole Arkose. On the southwest side of the tuffisite the Amole is devoid of stratification and contains grains of red siltstone and of probable altered pumice.

Once again the tuffisite (or an andesitic predecessor, destroyed by the tuffisite ?) seems to have dragged up into the Amole Arkose a partial shell of red siltstone. The brown graywacke may be a sedimentary unit, dragged upward, or it may represent shattered andesite, disaggregated and mixed with Amole by rising fluids. Even if the supposed altered pumice is misidentified, the Amole southwest of the tuffisite must have been rendered mobile in order to receive the grains of red siltstone.

Two more features need to be mentioned in the zone of intrusive upheaval.

First is the large mass of andesite (N, 0-5, 6, Figure 2) about 100 feet southeast of the Concha block. This andesitic mass is composite. The northern two thirds is porphyritic with very small feldspars; the southern part is coarsely prophyritic with plagioclases that may reach half an inch in length. Although the exposures do not furnish proof, this andesite is probably a remnant of two impulses of intrusion into the Amole Arkose. The Cat Mountain Rhyolite, which is in contact with the andesite on the northeast, and locally on the southwest, may have destroyed parts of the composite block. The andesite may have been lifted somewhat, or it might have sunken into the tuffisite. Perhaps it is best to assume that the block is essentially in situ.

Second, as mentioned before, the initial entry of the tuffisite into shaley units of the Amole seems to have been a gentle, orderly process. The examples discussed above and illustrated in figure 4-C, however, suggest a more forceful entry, with lifting or dragging upward and pressing aside of the enclosing rocks. That some of the upsurges of tuffisite were vigorous enough to create pipes with autonomous internal structure is shown by the round tuffisite mass with the curved dike extending southwestward from it (Figure 2, N-6) and by the probable tuffisite pipe with concentric foliation (Figure 4-D; P-7, Figure 2).

The observations and inferences presented above appear to establish the zone of intrusive upheaval as a zone, or belt, in which magmas and other fluids, welling up from depth, have lifted, penetrated, and locally fluidized the sedimentary cover. Parts of the pre-Cretaceous floor, and including even a few small pieces of the Precambrian basement, were lifted or dragged from below and emplaced among Cretaceous strata. This upheaved strip forms the outer border between the eruptive center to the northeast and the relatively intrusion-free Amole Arkose on the southwest.

Silver Lily Dike and Martin (?) Block

In the Tucson Mountains the Silver Lily dikes usually trend a few degrees north of west and transect the strikes of Amole strata (Mayo, 1967, pl. 1 and p. 26-28). On the southwest side of Bren Mountain the only known Silver Lily dike (Figure 2) conforms roughly with the general southeast strike and steep northeast dip of the enclosing rocks. Some readers may prefer to call this "dike" a sill.

In the mapped area the Silver Lily dike exists in three pieces, or segments, and the south end of a fourth segment is on the northern border above K-1 (Figure 2). The two middle segments, from K, L-1 to Q-6, are definitely elongated, but the third, southeasternmost one, is a mere fragment. A fifth, elongated segment, is southeast of the mapped area. It may be significant that the segments are offset with relation to one another in the same sense as the apparent movement on fault α. The dike is faintly but obviously flow-banded. Measurements of this structure are plotted and the flow pattern is suggested by the broken lines (Figure 2).

The Martin (?) block (Figure 4-D) is between the two middle segments of the Silver Lily dike. There is no exposure immediately north, west or south of the block, but the eastern margin, partly exhumed by erosion, dips 79 degrees east, and the block is in contact with the "trashy" tuffisite phase of the Cat Mountain. This contact, exposed to a depth of about 12 feet, is bordered by a marginal breccia, perhaps 6 to 10 or 12 inches thick, in which nut-sized pieces of the carbonate are set in a tuffisite matrix. The inner margin of this breccia shell against the carbonate is quite irregular. The configuration of the southern end of the block, as seen in the wall of a small gully, suggests that the steep eastern contact may reverse its dip and flatten at slight depth, so that the block is probably flat-bottomed. In spite of this, and in spite of the lack of exposures on three sides, there can be little doubt that the carbonate mass is nested in, not resting on the tuffisite.

The carbonate rock was originally a vaguely stratified breccia or rubble, such as might be found in a fore reef talus. This clastic deposit is now very firmly cemented. The elusive stratification dips about 74 degrees eastward, approximately parallel to the dip of flow layers in the tuffisite east of the contact. Obviously then, the initial dip of the carbonate has been greatly steepened, most probably during transport from depth. Perhaps a slab, pried loose along stratification, was turned into dynamic equilibrium with the steep upward flow of the enclosing magma.

About 20 feet east of the Martin (?) block (Figure 4-D) is a mass of peculiar brown graywacke. Marginal portions of this mass are laminated and the laminae are parallel to the converging sides as though these thin layers are the result of friction at the contacts with rising tuffisite. In addition to abundant brown grains, presumably derived from andesite, the graywacke contains pebbles of andesite, Amole Arkose and red siltstone, as well as pebbles and cobbles of itself. This seemingly inexplicable mixture may be the result of a sequence of intrusive events. Perhaps an apophysis of andesitic magma rose through the Recreation Red Beds, from which it derived inclusions, and was emplaced in the Amole Arkose, which also contributed inclusions. Suppose now that the postulated intrusion cools, shatters, and is fluidized to the state known as the "quiescent fluidized bed" (Leva, 1959, p. 2) or a similar state in which the mixing of particles is limited. Most of the andesite might be slowly reduced to sand, and the larger pieces rounded to form "pebbles." The foreign inclusions could be similarly rounded. "Dead" or stagnant parts of the system might be broken up and incorporated into still active, or reactivated, parts as authigenic "pebbles" and "cobbles." Finally, the system, perhaps only weakly consolidated, was invaded by the tuffisite.

The above interpretation is admittedly unusual, perhaps even outrageous, yet in view of the phenomena exposed in this area, the suggestion may merit serious consideration. I would welcome a better explanation.

Belt Between Silver Lily Dike and Base of Cliff

Except that no upheaved pre-Cretaceous blocks have been found in it, the north-northwest trending belt between dike and cliffs resembles somewhat the zone of intrusive upheaval. The "trashy phase" of the Cat Mountain Rhyolite occupies most of the area and seems to become progressively more cleared of foreign material as the cliff is approached. Rather large remnants of Amole Arkose are present and most of these are in the southwestern half of the belt (Figure 2). In a majority of the Amole remnants stratification dips steeply east or northeast, i.e., the over-all west-northwest strike and steep northeasterly dip have been disturbed but not eliminated.

The other large enclosures in the Cat Mountain (the tuffisite) include andesite of several kinds and brown graywacke that was probably derived from andesite. Near the base of the cliff are several large, round inclusions that appear to be coarse-grained air fall tuff or tuff-breccia.

Continuing up the small gully that runs past the southern end of the Martin (?) block, there is found on the south wall, and on the northeast contact of the Silver Lily dike segment, a mass of firmly-indurated andesitic rubble (O-5, Figure 2). This material consists of densely packed, round, purplish brown, cobble-sized clasts, set in a sparse matrix that appears to have been sand derived from the andesite. The structural relations of this rubble to the tuffisite are well exposed in the south wall of the gully (Figure 3, profile 2-2', left of the symbol Dm ?). Here the tuffisite underlies the rubble and sends small apophyses up into the overlying rock. Perhaps the intrusive and fluidizing action of the tuffisite has reduced to rubble a formerly shattered but essentially coherent mass of andesite. Obviously, this same process, operating on slabs of limestone, might have engendered limestone rubble, as at M-5 (Figure 2).

Still farther up the gully (O, P-4, Figure 2) large masses of brown graywacke, very like that already described east of the Martin (?) block, are intruded by the tuffisite. Steep east- or northeast-dipping laminae are locally present in the graywacke. Other masses of this brown sandstone are present at M-3 and L, M-2, 3 (Figure 2).

East of the graywacke, in the gully being followed, are more exposures of the tuffisite and one partially revealed mass of Amole Arkose (Q-4, Figure 2). Two blocks of the previously mentioned apparent air fall tuff lie, one on each side of the gully, below the cliff, and several blocks of andesite are exposed near by.

Some 75 feet east-southeast of the Martin (?) block, where the Cat Mountain Rhyolite truncates strata in the Amole Arkose (P-5, Figure 2) there is in the tuffisite a small, vaguely outlined, roughly circular area rich in pebble-sized clasts similar to the Concha Limestone, and small chips of Pinal Schist. Why older Precambrian the Permian clasts should be associated, to the exclusion of pieces from other formations, is not clear, but this same association has already been noted at the east end of the Concha block.

Seventy-feet north-northeast of the Martin (?) block (O-2, 3, Figure 2) there is incompletely exposed a huge slab of Amole sandstone in which the strata dip moderately south or southwest. Cross-strata, found near the southeast edge of the outcrop (Figure 4-F) show these sedimentary layers to be inverted. Within this large exposure is an irregularly-shaped mass of coarse rubble in which again "cobbles" and "pebbles" of apparent Concha Limestone and chips of Pinal Schist are set in a matrix of quartz sandstone with sparse grains that appear to be altered pumice. No obvious stratification could be found in the rubble, but a few measurements were made of a steep, planar preferred orientation of the clasts. These measurements reveal no regular pattern in plan, but the steep dips suggest an upwelling of the rubbly mass.

The contact between rubble core and enclosing sandstone is mostly concealed or gradational but in at least two places (Figure 4-F) can be seen to dip moderately away from the core. On the north side the contact is sharp and truncates the sandstone strata. On the southeast this surface is again sharp and the relation of rubble to sandstone resembles a disconformity. Where the boundary is gradational a few clasts, like those in the rubble, are present in the sandstone immediately above. The arenite which encloses these clasts is nearly or quite devoid of laminae, and is rich in white mica (derived from the Pinal Schist ?). Apparently, pieces from the core have locally been stirred into a weakly consolidated sandstone cover.

On the northern margin of the mapped area (Figure 2) at the place which should be occupied by the letter 'O', there is in the Cat Mountain Rhyolite at the base of the cliff a large round inclusion of fragmental andesite. On the south side of the inclusion the fragments are indistinct and are scarcely separated, but toward the north side the pieces have much more obviously been separated and cemented together. In this gradation there seem to be recorded early stages in the disintegration of the andesite by the enclosing tuffisite.

South of the andesite inclusion (at O-1, 2, Figure 2) there is an elliptical area occupied by a phase of the tuffisite somewhat lighter in color than the surrounding rock. The contact between the contrasting types is not exposed. At first the light-colored mass might appear to be a pipe, intruded into the surrounding Cat Mountain Rhyolite, but if this were true the internal structure should box the compass around the center of the supposed pipe. That such is not the case seems obvious from the measurements plotted on the map. Perhaps this light-colored tuffiste solidified somewhat earlier than its surroundings and is to be regarded as a large inclusion.

Bordering on the north the two southernmost mapped Silver Lily dike segments (P, Q-5, 6, Figure 2) is a sequence of intrusive surges of the Cat Mountain Rhyolite. The "trashy phase" tuffisite in P-5 is cut off at the southeast by a somewhat more inclusion-free intrusive tuff, and this in turn is transected by an elliptical pipe of pale tuffisite which fills the gap between the southernmost dike segments and is almost devoid of inclusions. These examples, which could probably be multiplied if exposures were better, suggest that the rhyolitic invasion of the Amole Arkose and the intrusive andesite was not one continuous, uniform process, but an activity which progressed by many separate and successive increments. Further, each successive impulse appears to have been "cleaner," and perhaps more vigorous, than earlier ones.

The strip between the Silver Lily dike and the cliff, plus the "zone of intrusive upheaval" forms a broad, injected mantle bordering what seems to be a major locus of rhyolitic upwelling and outpouring. Within this mantle the "wall rock," mostly Amole Arkose, is progressively more disturbed, injected and eliminated as the base of the cliff is approached. I have seen analogous injection zones, some of them many hundreds of feet in width, marginal to concordant plutonic intrusions. In the mapped area on Bren Mountain the injected border is some 200 to 250 feet wide.

Cliff Exposures

Perhaps the most surprising feature of the cliff exposures is the steepness of the planar flow, or eutaxitic, structure. The recorded measurements (Figure 2) are, from southeast to northwest, 70, 69, 51, 61, 68, 58, 64, 70, 58, 80, and 49 degrees. The sketch (Figure 3, inset) does not prepare the observer for these steep dips.

A second surprising feature is the uniformity of general strike from southwest to northeast across the mapped area. On field trips, students have been asked to make strike and dip measurements along the trail in the central part of the area, at several places on the way to the base of the cliff, and at the base of the cliff itself. Excluding the obvious local departures, the general strike and dip is essentially the same throughout. Therefore, the Cat Mountain Rhyolite, at least in the lower part of the cliff, is a concordant part of the larger structure. This seemingly incredible fact can be demonstrated to any one able to traverse the section and observe the internal arrangement.

As already indicated, to the extent that the above limited observations permit a comparison, the site of most active tuffisite upwelling appears to be related to the sedimentary wall rocks essentially as a concordant plutonic intrusion is related to its metamorphosed walls. This must mean that near the surface the weakly consolidated Amole Arkose was able to react much as do metamorphosed sedimentary rocks at greater depth.

A single reconnaissance structure profile (Mayo, 1963, Figure 4, p. 70) traverses the southwest slope and summit of Bren Mountain. A northeast dip of 62 degrees was measured at the summit and the following comment (idem., p. 77) was made regarding the northeast slope. "Judged from surface forms, without supporting measurements, these steep inclinations on the northeastern slope may flatten gradually toward the base." A rather abrupt northeastward flattening of steep northeast dips has been observed at Gates Pass and at several places north of there (Mayo, 1967, Pl. 1 and p. 25-26). These observations suggest that the tuffisite reached the surface on the lip, or rim, of some large depression, lying to the northeast, into which the resulting ash flows moved.

DISCUSSION

General Statement

In the area studied certain rather unfamiliar geological processes appear to have operated. When the results are seen at a few places only, the reality of the processes appears highly questionable, but when all of the evidence is considered, the probability becomes very impressive that the observed features are direct or indirect results of intrusive and extrusive igneous action.

Intrusive Sequence

On the slope above the trail, and to a very limited extent below the trail, is exposed an intrusive sequence which begins with andesites and terminates with a dike of probable quartz latite porphyry. Some of the small andesite intrusions in the "zone of intrusive upheaval" have basic rims and more siliceous, quartz-bearing, dacite (?) cores. Moreover, some of these cores are fragmental and contain admixed foreign clasts. The close association of rhyolitic tuffisite with these small structures suggests an almost continuous sequence of emplacement ranging from andesite to rhyolite. Elsewhere, blocks of andesite "float" in tuffisite, suggesting a more definite time interval between emplacement of intermediate and siliceous magmas.

The apparently quiet permeation of certain shale units of the Amole Arkose by tuffisite, and the relative resistance of sandy layers were mentioned above. Presumably the sand was fairly firmly cemented at the time. Seemingly then, the initial mild tuffisite invasion sought out every minute channel in fissile shale and siltstone, avoiding the less porous rocks. Eventually, however, even the sandstones were broken up so that the over-all structure pattern became strongly disturbed but not completely destroyed. Finally, near the base of the present cliff, where upward expulsion of the tuffisite should have been most active, Amole Arkose and andesite are represented only by boulder- and cobble-like inclusions. The presence among these inclusions of rounded blocks of apparent air fall tuff suggests that the magma, on reaching the Cretaceous surface, incorporated some of its own tuff cover.

Mobilization of Clastic Materials

The emplacement of the magmatic sequence must have raised the temperature of the sedimentary walls. The magmas may also have given off fluids, or fluids may have been expelled from the invaded formations--CO_2 from limestone, H_2O from any moisture-containing rock that became heated. No evidence presently at hand precludes either possibility.

The effects of the passage of fluids, especially gases, through particulate solids have been known to industry for a long time (Leva, 1959) but the significance of this process for geology has only recently been appreciated (Reynolds, 1954). The passage of fluids through aggregates of solid particles gives rise, under appropriate conditions, to the phenomenon of <u>fluidization</u>, by which the fluid-solids system acquires the properties of a liquid. I have been reminded that the term fluidization applies only to the "rendering fluid" of such a system and not to any subsequent stage, such as the transport of solids in the fluid stream. Leva, (1959) uses the term "fluidized state spectrum" for the several stages leading from the onset of fluidization to pneumatic transport.

Reynolds (1954) calls attention to two very important properties of fluidized systems. First, if very fine solid particles, or liquid droplets, are entrained in a gas, they can be injected into the minutest cracks. Thus, the planes of fissility in shale units of the Amole Arkose could have provided channels of ingress for a gas-solid or gas-molten droplet mixture -- the rhyolitic tuffisite. Second, a fluidized gas-solid mixture, at any but the dense fluidized stage, can be very abrasive. Minute entryways become enlarged, support is worn away, promoting collapse and the opening of further cracks to the attack. An included block, if perfectly sound, would merely have the surface smoothed. If the block had even the minutest peripheral fractures, an outer shell might be reduced to rubble, as in the case of the Concha block and the eastern margin of the Martin (?) block. If the included mass were deeply fractured, it might be doomed to become a group of "boulders," a lens of rubble, or possibly sand. As Hans Cloos (1941) found, this kind of action tends to convert, or <u>tuffisize</u>, any pre-existing rock. Coe (1966) has described instructive examples from Ireland.

A peculiar phenomenon associated with the fluidized state is through channeling (Leva, 1959, p. 23). With relatively low gas flow the solids bed (geologically a weakly consolidated stratified sequence) may not fluidize uniformly, but a pipe-like fluidized channel will form through the bed (or stratified sequence). Leva states that with increasing rate of fluid flow the tendency to through channeling diminishes. In nature, perhaps the incipient lithification of a detrital layer would promote through channeling. In a well indurated rock, channeling would be expected to start along fractures or at fracture intersections. Perhaps the limestone rubble at F, G-5, the tuffisite pipe at N-6 (Figure 2) and the structures shown in Figure 4-D and F, are results of through channeling.

The composite intrusions of andesite, etc., in the "zone of intrusive upheaval" are difficult to interpret. They appear to be only in part explainable as results of fluidization. The initial, basic phases were no doubt emplaced as andesitic magma, but the successive, more siliceous cores show increasing evidence of the former abundance of gas. In the small intrusion south of the Concha block the matrix of the core contains what are thought to be elusive shard textures which, together with the broken quartz and feldspar crystals and the very few grains of andesite, suggest that the original intrusion was attacked from within and almost destroyed by a more siliceous fluidized system.

The core of the same (?) mass northwest of the Concha block is now obviously fragmental and the clasts, derived from various sources, appear to have become mixed through some boiling or swirling action. This core seems to have broken up, incorporated and almost eliminated the initial andesite of which only a single small marginal block remains.

In the case of the structure in the northwest corner of Figure 4-C, if there was ever an initial andesite, it was destroyed and the succeeding fragmental core was all but eliminated. The present core is rhyolitic tuffisite. Perhaps the succession, andesite-rubble-rhyolitic tuffisite, follows because the glassy andesite on cooling was prone to shatter, thus falling victim to destruction by streaming gas-solid mixtures. In this way the rhyolitic tuffisite might have had channels of easy ascent prepared in advance.

The adjacent sandstones show, by loss of stratification, by brecciation, development of "sedimentary autoliths," intermixing with foreign elements, and at some places by bleaching and loss of the finer grades, that they have probably attained some of the stages in Levas' "fluidized-state spectrum." Apparently the magmas, as they were emplaced at depth and as they rose into the Cretaceous section, emitted and/or generated fluids which noticeably modified the structure of the sedimentary rocks. Further, through channeling of overlying sediments might have provided avenues of ascent for rising magma. By this mechanism, some apophyses of andesite, or of other magma types, could have been emplaced with minimum disturbance of the enclosing structure.

Emplacement of Exotic Blocks

The lifting of red siltstone into the Amole sequence is thought to have been accomplished by rising cupolas, or apophyses of andesite magma. The magma is visualized as having spread as sills, or perhaps as phacoliths, between the strata of the Recreation Red Beds, and to have lifted the overlying layers laccolith-or bysmalith-fashion (Figure 5, A to C). With further growth, the bysmalith is thought to have risen higher into the Amole sequence as a slender, appressed dispir, its red siltstone mantle becoming thinned and disrupted in the process. This mechanism should yield geometrical relations between red siltstone and intrusive cores like those shown in Figure 4-C. Perhaps Moore's red bed block (Figure 4-B) is the very tip of such a diapir.

As the andesite core cools, it shrinks, shatters, and is attacked from below by fluids rising in advance of the rhyolitic tuffisite. The place of the andesite is then taken, first by rubble, then by tuffisite (Figure 5, A-D).

The emplacement of Paleozoic limestones within the Cretaceous section would seem at first to be a more difficult problem, yet the principle is the same. The magma is supposed to have spread between Paleozoic strata, and to have domed upward the overlying layers, as before (Figure 5, E-F). The more brittle limestone, however, probably would not thin and stretch as the red siltstone is supposed to have done; instead, the limestone might break into blocks, some of which could be lifted high into the Amole section by the andesite, by fluidized and mobilized rubble, or by the rhyolitic tuffisite.

The idea of lifting huge blocks by any of the above means may seem preposterous, and yet the lifting power of magma is abundantly attested by laccoliths. For example, according to Weed and Pirsson (1898) the laccoliths of the Judith Mountains, Montana rise above Cretaceous surroundings, but near the intrusions upturned and upheaved Jurassic and Paleozoic, including Cambrian, are exposed. Many other examples could be cited. There is little difficulty in imagining such lifting of the cover, but can individual blocks be lifted? Mayo (1967, Figure 3-D) has shown that, in the Tucson Mountains, blocks of Paleozoic limestone have been carried upward from depth by intrusive Amole Latite. Comparison of elevations of the blocks shows that the minimum vertical distance through which some of these inclusions were lifted exceeds 1600 feet. That huge masses can be lifted by viscous magma seems beyond question.

If viscous magma can lift large blocks, can the same work be performed by mobilized rubble? Reynolds (1954) pointed out that the coarser the grade-size in a fluidized system, the higher the viscosity. If most material of the finer sizes could be elutriated from the system, the result might be a viscous, coarse-grained, slowly rising mush, or sludge. A large block might sink into such a mixture, but if the rate of sinking were less than the rate of rise of the mixture, the block would be lifted.

J. E. Richey (1937, p. 20), writing about the Tertiary volcanicity of Scotland and Ireland, commented as follows: "We know that the Tertiary explosion-volcanoes were capable of transporting material broken off from their walls upward from great depth. An especially remarkable example from Mull itself is a large boulder of schist 200 yards in length, which lies in vent agglomerate almost 2,000 feet above the highest point from which it could have come." Could an explosion, or a series of explosions, have lifted intact so great a mass nearly 2,000 feet? It seems much more probable that the huge inclusion was slowly upheaved by the rising, mobilized agglomerate.

In his description of the intrusive breccias at Bisbee, Arizona, D. G. Bryant (1968, p. 6) wrote: "The largest rounded fragment observed during this study is an elliptical boulder measuring 11 feet along the major axis and 7 feet along the minor axis. This boulder, which is approximately 1,500 feet from its closest known possible source, weighs 80 tons."

According to P. S. Freemen (1968, p. 174) blocks and boulders, ranging in size up to a volume of 4,500 cubic feet, and lifted from underlying formations, are present in the Middle

Tertiary mud diapirs in south Texas. In this case, the finer grade sizes, reducers of viscosity, were abundantly present, but in spite of this the heavy inclusions were lifted.

About half a mile north-northwest of Gates Pass, in the Tucson Mountains, a round inclusion of red siltstone 17 feet in diameter rests in an ash flow unit of the Cat Mountain Rhyolite. About 700 feet west of this inclusion, a "boulder" of limestone some 20 feet across also rests in the ash flow. Both inclusions might have been lifted into place by andesite, since destroyed by rhyolite, but the impression received is that the tuffisite accomplished some part of the lifting and that the inclusions were transported a short distance laterally in the ash flow.

In view of the above discussion there seems to be no reasonable doubt that on the southwest side of Bren Mountain parts of the Recreation Red Beds, and two limestone blocks, were emplaced by intrusive igneous action and attendant processes. Of course, the local fluidization of overlying materials would have greatly facilitated the lifting of underlying blocks into the Amole Arkose.

Depth, Pressure, and Temperature

Inspection of Assadi's (1964) columnar sections makes it seem probable that at the time of the intrusive activity the thickness of the Amole Arkose above the present erosion surface at this locality was not less than 1,000 feet or greater than 2,000 feet. The amount by which folding and contemporaneous erosion might affect this estimate is unknown, so the figures are very rough approximations. A measurement made on a structure profile (Mayo, 1963, p. 70, and Figure 5-H, this paper) makes it seem unlikely that the ancient surface was more than 1,000 feet above the present one.

Assuming an overburden of 1,000 feet, and an average density of 2.1 (Russell, 1955, p. 223; Carey, 1954, p. 79) the pressure would have been approximately 63 kg./cm^2 or about 69 bars, neglecting atmospheric pressure. This value might have been much lower near fissures.

Except in the igneous rocks themselves, evidence of high temperature seems to be lacking. As was found to be the case at Geiser's wash, northwest of Gates Pass (Mayo, 1967, p. 212) the fluidized detrital materials were probably not heated much above 250°C. If this estimate is too low, it may be because in order to crystallize those minerals indicative of a higher temperature, more time, a higher pressure and perhaps a higher vapor pressure are required than were available.

Origin of the Tuffisite

Obviously the process which converted the rhyolite magma into a fluidized system operated at some depth below the present surface. There is little to suggest where in the rock section this process was active. The fact that, so far as this writer is aware, all pieces of the Pinal Schist are found in and marginal to the tuffisite, and apparently never in the andesite, might suggest that tuffisitization began in the Precambrian basement. An alternative is to suppose that the process started in the Paleozoic section, where CO_2 from the limestones might have become dissolved in the magma and exsolved on further ascent.

Wherever the level was, the magma did not flash explosively into glowing clouds at or very near the surface of that time. In fact, there may have been no "level" of tuffisitization at all. Perhaps the slowly rising magma, exsolving gas, gradually swelled into a molten froth in which the threads of glass finally lost coherence. At the surface this fluidized system might merely "boil over" and rush as ash flows down any available slope.

The Folding

In a previous report I wrote (Mayo, 1967, p. 30) . . . "the burden of proof rests on any geologist who glibly speaks of the 'compressional phase of the Laramide orogeny' in these mountains." As was concluded from a study of folds in gneiss (Mayo, 1964, p. 142) no evidence at hand actually precludes the possibility that regional compression, operating at some unrevealed depth, has squeezed the rocks and melts upwards to form the observed structures. On the other hand, no observation made at the present surface renders mandatory the acceptance of such a possibility. Even the inferred strike-slip movements on faults α and γ might have been caused by vertical uplift (Reeves, 1946).

That the folding resulted from essentially vertical uplift is suggested by the broad, horst-like hinge (or double hinge) of the main anticlinal box-fold (Figure 3), as well as by the associated normal faults. Structures described above, in and under the sandstone unit of the Amole Arkose, suggest that on the eastern flank of the fold the sandstone has slipped and settled off the hinge. As is common knowledge, uplift must be balanced by marginal sinking.

As cause of the uplift the local observations point to the tendency for hot, gas charged and therefore relatively less dense materials to rise. In addition to the observations presented above, Assadi's geological map (1964) shows that south of the study area andesite rose along the projection of the hinge zone of the main anticline. This flat-topped fold, therefore, might have been upheaved as magma was emplaced below.

In view of the low density (2.1) assumed above for the sedimentary cover at this place the principle mentioned in the last paragraph might at first seem not to apply. However, as pointed out by Carey (1954, p. 80) in the case of salt domes the column continues to rise, even after it enters sediments with a density lower than that of the salt, because the weight of the salt column down to the source is still less than the weight of the corresponding column of sediments. Presumably the same would apply to rising magma.

If, as was inferred under 'OBSERVATIONS AND INFERENCES,' the "zone of intrusive upheaval" is a narrow, steep-flanked anticlinal welt, then the presence of a synclinal axis somewhere above and near the trail (Figure 3, profile 1-1') even though inadequately supported by evidence from the limited outcrops, is theoretically demanded. Moreover, a second structural trough should be present between the Silver Lily dike and the cliff, as suggested in Figure 5-H. The chances of demonstrating the presence of this second trough seem to be nil, but if present the syncline might explain the absence of exotic blocks in the belt between Silver Lily dike and cliff--i.e., no upfolding of the floor, no emplacement of older sedimentary blocks at a higher level.

Although observations accumulated in so small an area cannot be regarded as compelling, there is no doubt that they are highly suggestive. The data appear to reveal a genetic relation between folding and igneous action, and they say nothing about regional compression.

Volcano-Tectonic Situation

That the folded sedimentary rocks of the study area are marginal to a locus of tuffisite eruption seems sufficiently clear, but the nature of the eruptive orifice is not fully revealed by data obtained at this place alone. As mentioned above, under "Cliff Exposures," there is evidence in the surrounding region which suggests that the ash flows of the Cat Mountain Rhyolite issued, at least in part, from rim intrusions marginal to an extensive sunken area to the northeast. The ash flows may have largely filled this depression, but subsequent erosion has, in places, revealed a floor on which is a network of large and small tuffisite-filled fissures. The dimensions of this ancient cauldron, if cauldron it was, are unknown, but they might have been vast. Apparently, the Cat Mountain Rhyolite was no exception to the rule that ash-flow tuffs are usually associated with volcano-tectonic depressions.

CONCLUSIONS

As a result of the survey of the above-described area it is obvious that a distant view (Figure 3, inset) gives a false impression. The foliation of the Cat Mountain Rhyolite at the base of the cliff on Bren Mountain is a concordant part of the folded structure of the Amole Arkose. As a corollary, it should follow that folding of the sedimentary rocks and foliation of the tuffisite were genetically related. In other words, folds in the sedimentary rocks appear to have resulted from intrusion and extrusion of magma.

The sequence of emplacement of the magmas begins with olivine bearing (?) andesite, progresses through dacite and rhyodacite or quartz latite to rhyolitic tuffisite and ends with the Silver Lily quartz latite porphyry which was injected into a jagged, discontinuous fissure. The andesites appear to have lifted the pre-Cretaceous floor as diapirs which tore or broke apart as they rose. Most large pieces of the floor occupy the "zone of intrusive upheaval" which is regarded as a narrow, steep-walled anticline, or diapir complex. The synclinal (?) zone, adjacent on the northeast, is devoid of large blocks derived from the floor.

The initial entry of the rhyolitic tuffisite, a gas-particle system, into the shales of the Amole Arkose appears to have been a quiet, orderly process. The myriads of platy shale fragments in the "trashy phase" preserve in their attitudes the pre-tuffisite strike and dip of the shale. The more resistant sandstones, on the contrary, appear to have been invaded more forcibly; yet the pre-intrusive arrangement, although considerably damaged, is still recognizable. Successive surges of tuffisite form pipes and variously-shaped intrusions which crosscut the foliation of earlier surges. Each following intrusive impulse is cleaner of sedimentary and other inclusions than its predecessor.

The above activity took place at a depth of perhaps 1,000 feet, at a pressure of some 69 bars, or less, and except in the magmas themselves the temperature may nowhere have much exceeded 250°C. The tuffisite did not form explosively at or near the surface, but at some unknown, possibly great, depth. The formative process might have been gradual.

The center of tuffisite eruption is related to its highly disturbed sedimentary walls much as a concordant plutonic intrusion is related to its metamorphosed walls. Emphasizing this analogy still further, at Gates Pass and at two localities farther northwest, a nearly vertical septum of Amole Arkose divides tuffisites with very steep foliation. Analogous septa are well known in composite granitoid plutons. The fact that such a comparison is possible is thought to mean that at the time of the Cretaceous igneous activity in the Tucson Mountains the Mesozoic sediments were still only partly indurated.

The ash flows of the Cat Mountain Rhyolite appear to have issued from rim tuffisite intrusions on the margin of an extensive caldera or cauldron. To some extent the ash flows were fed also from fissures on the basin floor.

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