STRATIGRAPHY AND STRUCTURE OF THE NORTHEASTERN PART OF THE TUCSON MOUNTAINS

by

Richard L. Whitney

A Thesis Submitted to the Faculty of the

DEPARTMENT OF GEOLOGY

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

UNIVERSITY OF ARIZONA

1957

UNIVERSITY OF ARIZONA LIBRARY

E9791
1957
52

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at the University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in their judgement the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Richard L. Whitney
Richard L. Whitney

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Donald L. Bryant
D. L. Bryant
Professor of Geology

May 7, 1957
Date

CONTENTS

ILLUSTRATIONS

ABSTRACT

The northeastern foothills of the Tucson Mountains include a number of klippen of Paleozoic sediments, remnants of a thrust sheet which over-rode Cretaceous sedimentary and igneous rocks during a period of intense compressive deformation that occurred sometime between late Cretaceous and Miocene (?). A period of high angle faulting preceded and another followed the emplacement of the thrust sheet.

No stratigraphic sequence could be established, but rocks ranging in age from Devonian to Permian were identified in the various klippen. A definite conformity exists in the attitudes of the major Paleozoic blocks, as their strikes fall into a general east-west alignment.

Several Laramide intrusive bodies and volcanics of Tertiary and Cretaceous (?) age are present in this area.

LOCATION

On the northeast side of the Tucson Mountains are numerous limestone and quartzite blocks, mostly Permian, that appear to be remnants of an extensive thrust sheet. They maintain a rather uniform east-west strike, as do many of the Cretaceous sedimentary and volcanic rocks that surround them.

As a thesis problem, an area in Sections 33, 34, and 35, T13S R12E about 10 miles northwest of Tucson was mapped (Figure 1). The area is accessible by auto via Silverbell Road to Sweetwater Drive, then west 3.5 miles to an access road leading to an abandoned quarry situated within the area.

TOPOGRAPHY, CLIMATE, AND DRAINAGE

The area is situated on the north slope of a southeasterly-trending ridge of the Tucson Mountains. Many small exposures of resistant limestone form hills which are scattered over the slope. The more prominent of these hills have been numbered to facilitate location and description. The local relief, including the ridge, is roughly 1800 feet, but the study is restricted to the lower portions of the slope and

INDEX MAP OF ARIZONA
AND OF THESIS AREA IN T13S R12E
IN THE NORTHEASTERN TUCSON MOUNTAINS,
PIMA COUNTY

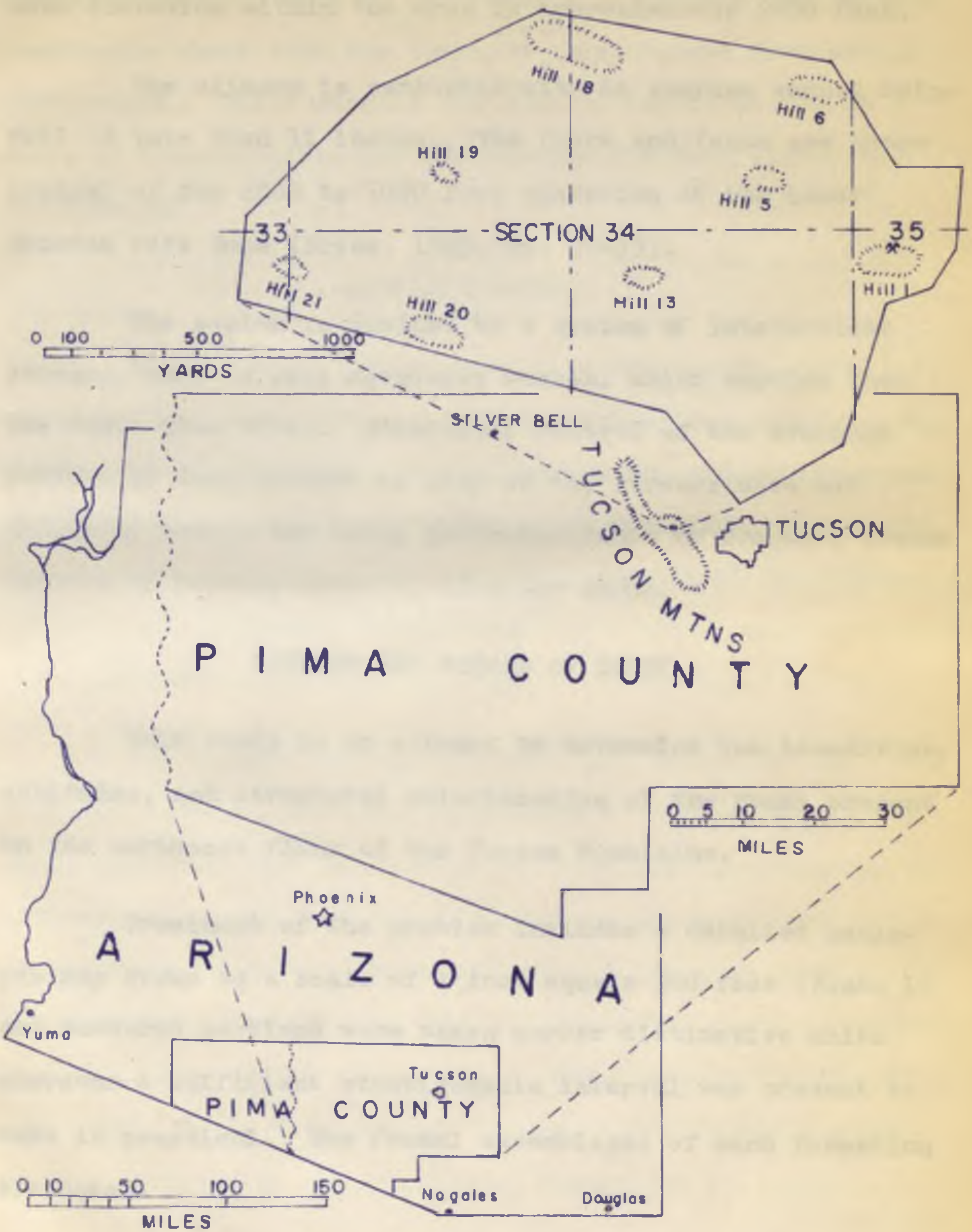

FIGURE 1

the relief within the thesis area is about 450 feet. The mean elevation within the area is approximately 2950 feet.

The climate is semi-arid with an average annual rainfall of less than 11 inches. The flora and fauna are those typical of the 2000 to 5000 foot elevation of the Lower Sonoran Life Zone (Bryan, 1925, pp. 29-53).

The region is drained by a system of intermittent streams, many in well developed washes, which empties into the Santa Cruz River. Structural control of the drainage pattern is very evident as many of the streams have cut obliquely across the slope following fault or fracture traces instead of running directly down the slope.

PURPOSE AND METHOD OF STUDY

This study is an attempt to determine the identities, attitudes, and structural relationships of the rocks present on the northeast flank of the Tucson Mountains.

Treatment of the problem includes a detailed geologic map drawn to a scale of 1 inch equals 300 feet (Plate 1) and measured sections were taken across distinctive units wherever a sufficient stratigraphic interval was present to make it practical. The faunal assemblages of each formation are noted.

The topographic map which serves as a base for the geologic data was made by enlargement of part of the Cortaro Quadrangle sheet with the drainage superimposed from aerial photographs. Field mapping was done on aerial photos on a scale of 1 inch equals 300 feet during the Fall and Winter of 1956-1957.

ACKNOWLEDGEMENTS

The writer is grateful to F. W. Galbraith and to other members of the faculty of the Geology Department at the University of Arizona for their cooperation and patience and especially to D. L. Bryant under whose direction this thesis was written.

STRATIGRAPHY

General

Portions of several formations, ranging in age from Devonian to Cretaceous, crop out within the problem area. Their fragmented nature complicates identification and makes recognition of some of the smaller exposures almost impossible. No stratigraphic sequence was determined as the only contacts seen in the area are fault, intrusive or flow contacts, and the arrangement of the Paleozoic exposures could not be related to their relative stratigraphic position. The small size of the limestone blocks also precluded measurement of extensive stratigraphic sections, though sections were measured across marker zones.

The oldest rock units identified belong to the Devonian Martin limestone, recognized by the presence of index fossils. The Mississippian Escabrosa limestone may be present; two small patches of limestone are tentatively assigned to it on the basis of their lithology. Rocks of the Horquilla formation of Pennsylvanian age were identified through their faunal assemblage. Three Permian formations are represented; the Scherrer is identified by its distinctive lithology and the Concha and Rainvalley by their lithology and faunal assemblages. The Recreation red beds and Amole arkose of Cretaceous age are recognized by their distinctive rock types.

In some cases marker beds were found which permit accurate correlation of the exposure to the type section of the formation. In other cases lithologic and faunal similarities allow correlations to be made among the rocks within the area.

In view of the age range of the recognized formations, it is possible that fragments of other Paleozoic units may be present in this general area, but others, if present, were not identified as any characteristics by which they might be distinguished were not recognized.

DEVONIAN SYSTEM

Martin limestone

The Martin limestone was defined by Ransome in 1904. At its type area at Mount Martin on Escabrosa Ridge west of Bisbee it is characteristically a dark gray, hard, compact limestone, generally fossiliferous. It overlies the Cambrian Abrigo limestone and is overlain by the Mississippian Escabrosa limestone with both relations being those of apparent conformity (Ransome, 1904, pp. 33-35).

At two places within the thesis area are rocks definitely identified as Martin limestone on the basis of two coral genera -- *Eridophyllum*, a Devonian index fossil, and *Coenites*, which became extinct during Devonian time. Another coral genus present is *Aulopora*, but it is not diagnostic.

The two exposures are in Hills 17 and 19. In both places the rock is dark gray, aphanitic, silty dolomite which weathers to a yellowish brown. The fossils are coated, and in some cases completely replaced, by brown secondary chert. The attitude is not determinable at Hill 19, but in the outcrop at Hill 17 the beds strike N70W and dip 50N. The section exposed is only about 15 feet thick, mostly covered.

Similar appearing but unfossiliferous rocks found at Hill 14 and at other places within the thesis area are mapped as Martin (?) on lithologic evidence. They are gray dolomites which weather to an uneven tan or yellowish brown. Secondary chert is scattered on the weathered surface but no primary chert nodules were found.

MISSISSIPPIAN SYSTEM

Escabrosa limestone

The Escabrosa limestone was defined by Ransome in 1904. As described at its type area on Escabrosa Ridge west of Bisbee it is a thick-bedded, nearly white to dark gray, granular limestone. It lies conformably above the Devonian Martin limestone and with apparent conformity below the Pennsylvanian Naco limestone (Ransome, 1904, pp. 42-43).

Two small exposures of rock within the problem area are identified as Escabrosa (?). These outcrops are not located on any of the hills, but are found at Location "E" south of Hill 3. They are tentatively assigned to this formation because of their lithology, being light -- almost white -- dense limestone. No fossils were found in the small, broken outcrops.

PENNSYLVANIAN SYSTEM

Horquilla limestone

The Horquilla limestone was named by Gilluly, Cooper and Williams in 1954. Its type area is on the eastern spur of Horquilla Peak in the Tombstone Hills, where it is largely a series of thin-bedded, blue-gray limestones. The base of the formation rests on an obscure surface of disconformity over Mississippian rocks and its contact with the overlying Earp formation is not ordinarily well-defined (Gilluly, Cooper and Williams, 1954, pp. 16-18).

The Horquilla was recognized at Hill 17. Here, the age of the rocks was established by two coral genera -- Syringopora, which ranged from Silurian to Pennsylvanian, and Lophophyllidium, which ranged from Pennsylvanian to Permian. Lithologically, the exposure consists of light gray limestone in which stringers of white calcite are common; the bedding is indistinct and the attitude is probably not constant as the outcrop is broken into rubble. The corals mentioned are numerous but are too scattered to be considered a faunal zone. The fossils are coated with rusty-brown chert and scattered, discontinuous bands and nodules of black chert are present.

PERMIAN SYSTEM

General

Three formations of Permian age were recognized in these northeastern foothills of the Tucson Mountains; the Scherrer, Concha and Rainvalley formations. They can be quite readily distinguished from the older Paleozoic formations, but the Concha and Rainvalley are sometimes difficult to tell apart, especially if the outcrop is small.

The Scherrer formation is easily recognized by its distinctive lithology, being a light colored quartzite. The Concha and Rainvalley formations are both limestones, dark gray to black on fresh surfaces and weathering to lighter shades of gray. They commonly emit a fetid odor when broken and are quite fossiliferous with the fossils distinctive and usually replaced, or at least coated, with brownish chert. To differentiate the Concha from the Rainvalley, several criteria were noted. The Concha formation is typically more massively bedded and more uniform in color, while the beds in the Rainvalley are less massive, more varicolored and more dolomitic. The Concha contains distinctive lithologic and faunal units -- specifically, a zone of abundant chert which weathers gray to reddish brown and was assigned the field name "tan chert zone" by Bryant (1955, p. 148), and a faunal zone characterized by Neospirifer. The Rainvalley contains one very distinctive faunal unit -- a richly fossiliferous zone characterized by the presence of the bryozoan Fenestrellina (Plate 2A). This unit is not recognized as a guide in Rainvalley exposures elsewhere in southern Arizona, but is useful within the limited area of the thesis. Chert within the Rainvalley is more apt to occur in bed-like lenses, while that in the Concha is more common as unaligned nodules.

Scherrer formation

The Scherrer formation was defined by Gilluly, Cooper and Williams in 1954. Its type area is on Scherrer Ridge in the Gunnison Hills, where it is described as consisting principally of two major sandstone members with a limestone member between them. The sandstones are nearly white, but weather to a rusty brown. No evidence of unconformity was detected along the sharp contact which separates it from the underlying limestone, which was tentatively identified as the Colina limestone, also of Permian age. The Scherrer grades into the overlying Concha limestone (Gilluly, Cooper and Williams, 1954, pp. 27-29).

In the northeastern foothills of the Tucson Mountains, the Scherrer is a light colored, clean, quartzose rock which weathers reddish brown. Unevenly cemented with silica, it is typically quartzitic, but is locally a quartzose sandstone.

All the orthoquartzites within the thesis area are included in the Scherrer. No fossils were found in them, but the lithology is sufficiently distinctive to allow identification. As noted above, the type Scherrer is composed of two lithologically similar sandstone members separated by a limestone member. However, the limestone member is not recognized in the problem area and the quartzitic sandstones may be equivalent to either the upper or lower sandstone member of the type Scherrer.

These quartzites occur throughout the area but are especially well displayed in Hill 6, Hill 19 and off the northeast side of Hill 1. Inherently brittle, they are usually broken and rubbled. Only at Hill 19 could an attitude be determined from their exposures, but traces of thin bedding and crossbeddding can be observed elsewhere. At Hill 19 the Scherrer strikes N75W and dips 25-30N, conforming well with the general alignment of the major Paleozoic outcrops.

Concha limestone

The Concha limestone was named by Gilluly, Cooper and Williams in 1954. At its type area in the Gunnison Hills it is typically a gray, medium-grained, highly fossiliferous limestone with abundant irregular nodules of light-colored chert weathering pale brown. It gradationally overlies the Scherrer formation and is unconformably overlain by the Cretaceous Glance conglomerate (Gilluly, Cooper and Williams, 1954, pp. 29-30).

In the problem area the Concha is characteristically a dark gray to black limestone which weathers to a somewhat lighter shade of gray. Its exposures are massive, bedding planes are obscure or absent and the color is usually a uniform medium to dark gray. When broken, the rocks commonly emit a fetid odor. Scattered chert is present, usually occurring as black nodules, but one zone includes light gray nodules and layers. In both types of occurrence the chert weathers to shades of brown.

Fossils are more widely scattered and less numerous than in the Rainvalley formation. Those identified within the various Concha exposures include _Dictyoclostus_, _Composita_, _Neospirifer_, _Meekella_, _Astartella_, _Plagioglypta_, _Glabrocingulum_, _Euphemites_, _Amphiscapha_, _Pharkidonotus_, Meekospira, Orthonema and Straparolus. Zaphrentids, bellerophontids, bryozoans, crinoid stems and echinoid plates and spines are commonly encountered. Most of the fossils are replaced or coated with brown chert, though some, especially noted at Hill 7, are replaced with white to tan chert and exhibit an unusual weathering pattern of fine, concentric striae. Most of the gastropod genera mentioned above were found in a concentration on the northwest face of Hill 1.

Two distinctive marker zones within this formation permit long range correlation. One is a faunal zone characterized by the presence of Neospirifer and the other is a thick zone of light-colored chert, in pseudobeds and nodules which weathers to a light brown and is given the field name "tan chert zone." Both of these units were reported and recognized throughout southern Arizona by Bryant (1955, pp. 47, 148). Within the thesis area, the "Neospirifer zone" is not conspicuous, but crops out at Location "D" along the north side near the center of Hill 6. The "tan chert zone" is especially well developed along the south face of Hill 9, and is present elsewhere. Measured section 3 includes this zone at Hill 9.

The Concha is a relatively pure limestone and has been quarried from three places in the area. Above the "tan chert zone" in Hills 7 and 9 the limestone is almost lithographic, being very dense and breaking with a subconchoidal fracture. The weathered surface of these dense limestones is characterized by an unusual pattern of small, closely spaced, sinuous grooves.

Also observed on the northwest extremity of Hill 9 and at the top of Hill 7 is a zone of oolitic limestone. On the weathering surface the oolites are coated with chert and resemble sand grains, but thin section shows that they have a nucleus of calcite crystals surrounded by nearly cryptocrystalline calcite grains. This zone is apparently about 25 feet above the "tan chert zone," but could not be traced laterally and may be a lenticular feature.

Hill 1 is the largest single exposure of Concha limestone in the area, but Concha outcrops are quite widespread and include Hills 4, 7, 9 and some of the rocks at Hill 6.

<u>Rainvalley formation</u>

The Rainvalley formation was defined by Bryant in 1955. Its type locality is on the Rain Valley Ranch in the Mustang Mountains, where it is principally made up of varicolored limestones and dolomites with some sandstone beds.

The lower contact is gradational from the underlying Concha limestone and the upper limit of the Rainvalley is a post-Permian erosion surface which may be overlain by Cretaceous (?) sediments. This formation includes the youngest known Permian rocks in southern Arizona (Bryant, 1955, pp. 48-51).

Both dolomitic and calcareous units are present in the thesis area. These rocks are generally dark gray to black on fresh surfaces and weather to lighter grays with the dolomites weathering to the lightest shades and giving the exposures a varicolored appearance of different shades of gray. When broken, these rocks commonly give off a fetid odor. The surface of the dolomitic exposures is very uneven or jagged. Chert in these units occurs as thin bands or nodules, usually black and weathering to browns.

Fossils are abundant, though localized. They are usually coated or replaced with brown chert, though some are white, calcareous cross-sections in the rock. Those identified in the various Rainvalley exposures include *Dictyoclostus*, *Composita*, *Phricodothyris*, *Juresania*, *Aviculopecten*, *Fenestrellina*, *Meekopora*, and small rhynchonellid brachiopods. Echinoid spines and plates of varying sizes and shapes are common, and crinoid stems are found.

Two distinctive marker units permit correlation among the Rainvalley exposures within the area. One is a faunal horizon of abundant Fenestrellina (Plate 2A), the other is a sedimentary feature distinguished by a zone of highly contorted, thin-bedded, silty limestone layers which are interpreted as a primary feature due to flowage while in a semi-liquid state before consolidation (Plate 2B). These marker units are described in greater detail in measured sections 1 and 2 respectively. Both index zones can be observed on the south face of Hill 5. There, the contorted bedding is a striking pink color.

Neither of the two marker units can be used for correlation with Rainvalley occurrences outside the problem area, but it is suggested that they may occur just above some major break within the formation. This is suggested by the fact that, where found, they occur near the base of the exposure including them, and could indicate that their stratigraphic position is just above some lithologic unit that might have served as a glide plane during thrusting.

Rainvalley exposures are numerous throughout the entire area with typical outcrops in Hills 2 and 5.

CRETACEOUS SYSTEM

General

Three Cretaceous units were recognized in these northeastern foothills of the Tucson Mountains, the Amole arkose, the Recreation red beds and an unnamed volcanic series. All were identified solely on the basis of lithology, as no fossils were found in any of the exposures. The volcanic sequence at the base of the system is composed of purple porphyritic andesites and latites which will be described more fully in the section of this report dealing with igneous rocks. The Recreation red beds are uniformly brick-red siltstones with some arkosic members near their base and are quite difficult to distinguish from the Amole arkose which is made up of a variety of lithologies including similar-appearing, fine-grained, red sandstones.

These three units are relatively less resistant to erosion than the Paleozoic rocks and tend to form slopes which are largely covered with talus and later volcanic flows. Consequently, the Cretaceous outcrops are usually in stream cuts and include a few patches of rubble on some of the divides. As the streams usually make their courses along fault zones, it is often difficult to determine accurately the attitudes and relationships of the rocks exposed in them.

In his general survey of the Tucson Mountains, Brown did not map Recreation red beds anywhere outside of their type area, but noted that they were present in small, poorly-exposed outcrops in the zone of the great thrust with numerous exposures east of Amole Peak (Brown, 1939, p. 716). The thesis area is about 3 miles southeast of Amole Peak and the formation is represented there. Distinguishing the Recreation red beds from the Amole arkose for mapping purposes was quite difficult as almost every large exposure of Cretaceous rocks included both arkoses and red siltstones. In general, those outcrops dominantly composed of brick-red siltstones in which purple arkosic units are minor or lacking were mapped as Recreation red beds. Outcrops mapped as Amole arkose include those which contain shales, limy beds, arkoses of various colors and minor amounts of red siltstones.

Recreation red beds

The Recreation red beds were named by Brown in 1939. At the type locality in the Tucson Recreational Area they are a series of uniformly brick-red, fine-grained sandstones with beds of purple arkose in the lower part. The base of the unit is nowhere observed, though a Cretaceous volcanic series probably lies below it. It is conformably overlain by the Amole arkose with the contact gradational through a zone about 75 feet thick (Brown, 1939, pp. 715-716).

In the thesis area, the Recreation red beds are typically fine, dark red siltstones. In thin section they are very fine-grained and slightly arkosic, though predominantly composed of angular to subrounded quartz particles. The color is due to the abundance of ferruginous cementing material. It was noted that low degrees of metamorphic activity are sufficient to change the color of the rock, usually to a bleached shade of yellow, through altéraation of the iron minerals. This type of alteration is common along fractures, faults and flow contacts. Bedding planes were not observed in the massive, uniform, brick-red exposures but jointing is well developed. The attitudes of the exposures were determined, where possible, from arkosic members.

At Location "B" -- west of Hill 13 -- is a section approximately 50 feet thick of purple arkosic units interbedded with red siltstones. The lower contacts of the siltstone layers are gradational with the arkose, but the upper contacts are quite abrupt. Some thin conglomeratic layers within the arkose include subrounded fragments, up to 3 inches, of andesitic volcanic rock and red beds. This sequence may represent part of the gradational contact between the Recreation red beds and the Amole arkose.

Outcrops of the Recreation red beds are common throughout the problem area, especially around Hill 22, just west of Hill 15 and along the southeast flank of Hill 6.

Amole arkose

The Amole arkose was defined by Brown in 1939 from outcrops in the southwest part of the Tucson Mountains. It is typically a series of gray to pink, coarse-grained arkoses, interbedded with shales and a few limestone beds and is characterized by frequent repeated changes in rock type. The contact of the Amole arkose with the underlying Recreation red beds is gradational. The top of the Amole is not exposed, having been cut off by erosion or by the "great" thrust, or buried under later alluvium or volcanics (Brown, 1939, pp. 716-718).

In the problem area, rocks assigned to this formation include purple, green and red arkoses, dark shales, siltstones of various colors and a limy unit. The siltstones are similar to those of the Recreation red beds in that they are commonly altered to bleached yellows and greens along fractures and faults. Crossbedding was observed in some of the outcrops. In many places the arkoses are conglomeratic with rounded pebbles of red beds, volcanic rocks and earlier arkose.

The shales within the Amole arkose are commonly micaceous from metamorphic activity. This can be observed at Location "F", where they are in contact with a granitic intrusion, and along the northwest side of Hill 5, where they are situated along a fault. The shales are nearly always folded. Some of the folds can be identified as drag folds and provide information on the direction of movement in some of the deformations, though none could be related to the main thrusting.

One unit of Cretaceous limestone was found and is assigned to the Amole arkose as Brown noted no limy members in the Recreation red beds. This limestone is at Location "A", to the south of Hill 11. The exposure is in a stream cut and is limited in areal extent, consisting of a 10 foot thick unit of reddish, silty limestone within a sequence of red siltstones. A 2 foot thick zone of rounded pebbles of pure limestone up to 3 inches in diameter is included in the silty limestone. Aslo included were lenses up to 5 inches thick which contained a mixture of siltstone and limestone particles up to 0.3 inches in size.

Other exposures of Amole arkose include a sequence about 160 feet thick of steeply dipping green arkoses between Hills 5 and 6; purple arkoses and arkosic conglomerates to the east from Hill 20; and a largely metamorphosed unit of green siltstones and dark shales to the south of Hill 23.

STRUCTURE

General

The dominant structural features of the northeastern foothills of the Tucson Mountains are the large blocks of Paleozoic sedimentary rocks which clearly overlie Cretaceous sedimentary and volcanic units. These blocks are apparently klippen, remaining from a period of Late Cretaceous or Tertiary thrusting.

In his general survey of the Tucson Mountains in 1939, Brown recognized these blocks as klippen, but their tectonic origin could only be inferred, as the scattered remnants of the postulated thrust sheet provided little actual evidence other than their physical presence above the younger rocks to support his ideas. No works dealing with this problem have been published since Brown's study and, in the absence of definite proof of the origin of the blocks, alternative concepts have been suggested to explain their presence.

In general, the newer ideas are attempts to account for the blocks without resorting to tectonism, and are based on movements due to gravity. Three explanations are noted:

(1) that the blocks fell by landsliding from a now-eroded highland, (2) that the blocks slid into their present position on mud flows, (3) that the blocks may represent remnants of a plateau rim which slumped downward as a unit in a form of nonorogenic normal faulting.

The new evidence brought to light in the course of this study seems to verify Brown's original contention that the blocks are klippen. It is now known that rocks which range in age from Devonian to Permian are included in this area and that a definite east-west alignment is shown by the general uniformity in the strikes of the major outcrops (Table 1). This alignment indicates that the blocks are not randomly distributed, but were brought into the region by some orderly process, and the formations recognized indicate that an extensive Paleozoic sequence must have been available in the source area. These two existing conditions could be met by the introduction of the blocks as parts of a thrust plate, but gravity movements almost certainly could not yield such orderliness.

Though the problem of the thrust sheet dominates the structural aspect of the thesis, it is by no means the only deformation to which the region has been subjected. There is abundant evidence that the area has been badly

TABLE 1 - STRIKE ALIGNMENT IN THE MAJOR EXPOSURES

Hill Number	Strike	Dip	Deviation of the Strike From an E-W Line
1*	N65E	35N	25°
2	N65W	45N	25°
3	E-W	55N	0°
4	N85W	65N	5°
5	N85E	30N	5°
8	N80W	45N	10°
9**	N80W	55N	10°
19	N75W	35N	15°
20	N80W	40S	10°

Graphic Representation of the Deviation of the Strike From an E-W Line

0°-5°	Hill 3	Hill 4	Hill 5
10°	Hill 8	Hill 9**	Hill 20
15°	Hill 19		
20°			
25°	Hill 1*	Hill 2	

* Average of four measurements
** Average of two measurements

shattered by faulting and extensively intruded. Folds, except on a very small scale in some of the shale sequences, were not observed, suggesting that the deformations may have taken place near the surface under relatively light confining pressure.

Faults

The extensive mantle of talus and volcanic rock covering the thesis area effectively obscures the traces, and in some cases probably conceals the existence, of many of the high angle faults which have shattered the region. In general, the presence of such a fault is indicated either by a visible break in the rock, by an abrupt change in the lithology of an outcrop (Plate 3A) or by a sharp turn in the course of a stream. In few of these occurrences can the fault be traced for any appreciable distance, but it was discovered that the trace could frequently be projected, on the aerial photographs, along the color variations or along lineations in the vegetation. This procedure permitted the formulation of fault patterns, but gave no information regarding the dips of the fault planes, the directions of movement, or the relationship of one fault to another. Such data could be observed only in isolated cases.

Most of these faults seem to fall into two general sets. A majority of them form a trend striking roughly N20W, and many of the remaining faults conform to a less well defined trend striking about N15-25E. Drag folds and discernable offsets suggest that the east side of the northeast trending faults has moved to the north. No information was obtained regarding movement along the northwest trend. This fault pattern could be indicative of compressive forces acting from the north or the south, but the area is too small to permit inference of regional structure. It is more logical to try to explain the observed features in the light of attempts by other authors to establish regional patterns.

The age of the faults cannot be definitely ascertained from evidence within the thesis area, and there may have been more than one period of movement along the same, or parallel, fault planes. The Cretaceous sedimentary and volcanic rocks in this region are, in general, steeply dipping and were apparently subjected to severe deformation before the thrust plate was introduced. The variation in the directions of strike at the different Cretaceous outcrops indicates that their deformation included severe faulting. These faults were probably developed during the Laramide orogeny.

The age of the thrusting is open to question. The lower (?) Cretaceous Amole arkose is the youngest datable formation in the Tucson Mountains, and it predated the thrusting, which, thus, must have occurred as a Laramide or later movement. Brown (1939, p. 758) considered the thrust fault to have been associated with the Laramide orogenesis, but Wilson (1949, p. 13) points out evidences of later Cenozoic compressive stresses in southern and western Arizona and Brennan (1957, thesis in preparation) was able to date thrusting in the Empire Mountains as Miocene (?). Accordingly, there is ample evidence of mid-Tertiary thrust faulting in southern Arizona, which could have included the thrusting in the Tucson Mountains.

Within the thesis area are high angle faults which probably occurred after the thrust sheet was emplaced. Noted especially at Hill 1 are faults which can be traced across the klippe and projected into the underlying Cretaceous section. Their projection into Cretaceous rocks indicates that they are not tear faults associated with the thrusting, and the alignment with the previously noted northeast trend of faults suggests that they were formed along pre-existing zones of weakness.

The thrust sheet may have over-ridden a surface of considerable relief. Along the south sides of Hills 9 and 2 are elongate limestone exposures, separated slightly from the main hill, that could be explained as debris accumulations in a stream channel of the pre-thrusting surface. In this regard, it is noted that the direction of their elongation roughly corresponds to the present drainage pattern, and could indicate that the streams on the pre-thrusting surface were subject to the same structural control as the modern streams.

Other features probably related to the thrusting are scattered outcrops of limestone breccias and conglomerates (Plate 4A). These occur in small, apparently random patches throughout the area. The mode of formation of these breccias is problematical. They may represent fragments broken off during movement of the thrust block and indurated as a thrust breccia underneath or in front of the advancing sheet. Two objections to this method of formation are that many of the limestone pieces in these rocks are subrounded to rounded and, though they are not uniform in size, they do not exhibit the extreme size variation that should be expected of breccias formed in that manner. It seems more logical to explain them as a pediment-like feature formed in front of the thrust sheet by erosion during periods of quiescence, and then perhaps over-ridden when the sheet began to move again.

Though the limestone conglomerates are considered erosional phenomena, the cut leading into the quarry on the north face of Hill 1 exposes a jumble of debris that probably represents a true thrust breccia (Plate 4B). This cut reveals an accumulation of material ranging from flour-sized gouge up to boulders several feet across. Though most are limestone, some of the boulders are of Cretaceous sedimentary rock. The breccia appears to have been formed by the plowing and grinding movement of the thrust plate, pushing debris before its advancing front. Upon the cessation of movement, the breccia remained draped across the leading edge of the thrust block which had been shoving it.

In any large scale thrusting movement, the question of imbrication arises. Such a telescoping of the thrust sheet can be neither proved nor disproved in this instance, but its occurrence is not considered essential to an interpretation of the structure in the area. The fact that rock units of diverse ages have accumulated in the same limited area might suggest imbrication, but could also be explained as portions of the thrust plate slumping off into topographic lows on the underlying surface and then being over-ridden as the moving sheet brought different rocks into the region. It was noted that the larger, more regularly aligned blocks belonged to the Permian system, and it is possible that they might represent that portion of the thrust plate which came to rest in this area, with the older Paleozoic exposures representing blocks broken from the sheet and left behind while it was in motion. Another suggestion of possible imbrication is the occurrence of Cretaceous sedimentary rocks lying against and apparently above the south side of the Hill 20 klippe; but this could be attributed to the post-thrust, high angle faulting already postulated for the area.

The direction from which the thrust plate moved was probably the southwest or west. Brown (1939, p. 750) considers the movement to have been from the west. Wilson (1949, pp. 11-12) suggests a northwest to northward trend for the compressive structures developed during the Laramide orogeny and (1949, p. 13) that the later Cenozoic deformations represent a continuance of the Laramide activity. The present alignment of the klippen and the occurrence of thrust breccia north of Hill 1 would be indicative of a more southerly force, but Brown (1939, p. 748) includes regional tilting as part of the formation of the basin-range structures, and, if this tilting had been toward the southeast, it could have rotated the north to northwest trending features into the presently observed west to northwest pattern.

Folds

The shale sequences of the Amole arkose exhibit the only well-developed folding observed in the area; this, however, is on a very small scale. Wilson (1949, p. 11) suggests the development of broad, open folding as part of the Laramide deformation, but no evidence of large scale folding was discernable in this locality. The steeply dipping attitudes of the Cretaceous rocks underlying the thrust sheet are interpreted as being due to faulting as their directions of strike are too variable to be fitted into a fold pattern. Viewed from the east, the northeast face of Hill 5 appears to be gently warped, and a small flexure exists in a limestone outcrop in the stream cut to the west of Hill 1 (Plate 3B); neither of these occurrences is deemed significant, and no other folds were noted in the klippen. The only information derived from folds in the area related to directions of movement along faults and intrusions as interpreted from small scale drag folds.

Joints

Many of the outcrops of Cretaceous rocks throughout the area are jointed, but at only one location were the joints sufficiently well developed to be described in detail. An elaborate system of steeply dipping joints in Recreation red beds is exposed in the stream cut west of Hill 15 (Plate 5A). The main feature of this exposure is a vertical fault which trends N40E. The predominant joint set is characterized by a gently curving trace, fanning out from the shear zone of the fault and straightening into a N75E strike. Four other directions of jointing were noted, striking N25W, N20E, N85W and N40E, parallel to the fault.

The main joint set may be a tensional feature resulting from movement of the southern side of the fault toward the east. This cannot be proven, but fits the regional pattern previously suggested by drag folds elsewhere in the area.

INTRUSIVE ROCKS

Two igneous bodies within the thesis area are definitely intrusions; one is a small granite stock intruded against a shale unit of the Amole arkose, the other is a latite dike set, fragmented by faulting, which forms a linear outcrop in the southeastern portion of the area. In addition there are scattered exposures of andesite and latite which cannot be traced laterally and may represent small intrusives, though they could also be interpreted as exotic blocks pushed into the area by the thrust sheet.

Granite stock

The small granite stock is exposed in a stream cut at Location "F", just north of Hill 15, where it has intruded and metamorphosed a sequence of Cretaceous shales (Plate 5B). The outcrop is deeply weathered, but on the fresh surface it is coarse-grained and light colored. In hand specimen the rock consists of quartz and orthoclase with some mica that has largely altered to chlorite. In thin section its texture is xenomorphic granular and it is composed of approximately equal amounts of quartz and orthoclase with traces of plagioclase, hornblende and biotite which is altering to chlorite. The composition of the plagioclase is An_{25}--An_{30}. The orthoclase is altering to sericite and magnetite grains are visible in the hornblende and biotite crystals. This granite is probably equivalent to the Amole granite described by Brown (1939, p. 721).

Drag folds within the steeply dipping shale section indicate that the granite was forcibly intruded from an easterly direction. A shale xenolith was observed just inside the border of the stock. The shales adjacent to the stock exhibit a micaceous texture and thin silty layers interbedded with the shales have been altered to dense meta-quartzites by the metamorphic effects of the intrusion. The contact between the shales and the granite has served as a zone of weakness for later movements. A minor fault plane along the contact has small drag folds just below it indicating that the granite hanging wall has moved downward toward the east for an indeterminate, but probably short, distance.

Latite dikes

Segments of tabular latite intrusives strike southwesterly over approximately 1/3 of a mile in the southeastern part of the area. The pattern of the outcrop indicates that there are probably at least two dikes present, though their lithology is identical.

The dikes appear in the field as 4 to 10 foot wide, nearly vertical, elongate exposures of light brown to tan colored rock with partings parallel to the strike of the outcrop (Plate 6A). In hand specimen, the fresh surface is brown to grayish brown and aphanitic with phenocrysts few and indistinct. Flow lineation can be detected. In thin section, the phenocrysts are euhedral to subhedral orthoclase and plagioclase crystals in a ground mass of quartz and kaolinized orthoclase. The flow structure can be observed only under low power. Epidote is present as an alteration product, and some of the plagioclase crystals contain magnetite inclusions.

These dikes may possibly be part of the Silver Lily dike system exposed to the south and west of the thesis area (Brown, 1939, Pl. 1). The attitude of these dikes parallels the trend of the Silver Lily system and they are lithologically like the Silver Lily rocks described by Brown (1939, pp. 741-742).

Other Intrusives

An irregularly shaped, apparently intrusive body of rhyolite is present north of Hill 22. The rock is light colored with phenocrysts of orthoclase and quartz. In thin section, approximately 40% of the phenocrysts are quartz with the remainder orthoclase; the phenocrysts exhibit subangular outlines, and the orthoclase is altering to kaolin; the ground mass is cryptocrystalline and its components were not identified. The northern side of the intrusion is in contact with shales of the Amole arkose and has altered them, giving a micaceous texture to the shales and forming metaquartzites from silty layers interbedded with the shales.

Several other exposures of igneous rock may represent small plugs or stocks, though their contacts with adjacent units cannot be observed. The outcrop of andesite to the west of Hill 5 is typical. This exposure is surrounded by rubbled limestone blocks which, with later volcanic and talus accumulations, effectively mask its relationships to the rocks postulated to have been intruded. The intrusive nature of the andesite is implied by its limited areal extent and the lack of identical or similar rocks nearby.

A similar occurrence is noted at Hill 10, where an isolated exposure of rock, identified in hand specimen as rhyolite, crops out and is surrounded by rubble of a later volcanic flow. An identical rock exposed in the stream cut to the southwest is close enough to the larger exposure to have been part of the same intrusion.

Scattered throughout the area, but concentrated in the eastern third, are small, isolated exposures of a very distinctive andesite, characterized by large, white, oval to lath-like crystals of plagioclase up to 0.4 inches in length, set in a uniformly dark, purplish-gray ground mass (Plate 6B). This rock is lithologically like outcrops noted and given the field name "Silver Bell andesite" by geologists at the American Smelting and Refining Company's mine at Silver Bell, some 25 miles northwest of the thesis area, and recognized elsewhere in the Papago Indian Reservation by parties of the United States Geological Survey. At Silver Bell, this rock is identified as an intrusive and it seems logical to consider the exposures in the thesis area as representing a series of small intrusive bodies, or, perhaps, somewhat larger intrusions broken by faulting.

Age of Intrusions

No relationships were observed within the thesis area to permit dating of the intrusives more accurately than to call them Upper Cretaceous or Tertiary. Brown (1939, p. 722) considers the Amole granite to have been associated with the Laramide orogeny, and the Silver Lily dikes (1939, p. 742) to be Tertiary and the latest rocks in their vicinity, though younger volcanics may be present elsewhere in the Tucson Mountains. Richard and Courtright (1954, pp. 1095-1096) date the intrusion of the andesite porphyry as Laramide, but recognize that Tertiary intrusive activity has occurred with the emplacement of monzonite stocks and dikes and andesite dikes.

EXTRUSIVE ROCKS

In the Tucson Mountains an exceedingly diversified assemblage of volcanic rocks is exposed. Brown (1939, Pl. 1) differentiated 8 units of Tertiary volcanics and recognized an older sequence of volcanic rocks which he assigned to the Cretaceous system and placed stratigraphically below the Recreation red beds. Rocks from both the Tertiary and the older sequence crop out in the thesis area.

Cretaceous (?) volcanics

A series of volcanic rocks is considered by Brown to be the oldest Cretaceous unit in the Tucson Mountains. Nearly all the members of this series have one common characteristic--they are dark, purplish-gray to purplish-black on the weathered surface. Lithologically, they include porphyritic andesites and latites, usually appearing as flows but which may be locally intrusive, and coarse volcanic breccias that appear to be flow breccias and consist chiefly of fragments of rocks similar to the flows themselves (Brown, 1939, pp. 713-715).

The evidence for dating these volcanics is weak. Their contact with the Recreation red beds was nowhere observed, but Brown (1939, p. 714) noted that the upper part of the volcanic sequence was interbedded with red beds, and that the lower member of the Recreation red beds included arkosic units with andesitic fragments. On this basis, he postulated the volcanics to be beneath the red beds and gradational with them. In studies at Silver Bell, Richard and Courtright (1954, pp. 1095-1096) recognize a series of volcanics which they have dated as occurring in the Tertiary portion of the Laramide orogeny; they note no pre-Laramide volcanism. For the purpose of this study, these volcanics are considered to be Cretaceous (?).

The exposures of Cretaceous (?) volcanic rock within the thesis area are generally small and scattered and no relationships were observed to clarify the age of the sequence. Brown's description of the rocks of this series is not detailed and their identification in the northeastern foothills of the Tucson Mountains is based on their apparent position as part of the surface originally beneath the thrust sheet. These rocks exhibit a diverse lithology and there are variations within each rock type. In view of this fact, and the lack of good descriptions of their supposed correlatives in the type area, no detailed petrographic studies were made. As identified in hand specimen, the Cretaceous (?)

volcanics of the thesis area are predominantly of andesitic to latitic composition. Textures range from coarsely porphyritic to almost completely aphanitic and colors from grays and purples to almost black.

The rocks of Hill 18 are considered to be part of the Cretaceous (?) volcanic sequence, though this assignment is questionable. Brown (1939, Pl. 1) mapped the hill as Amole latite, which he considers to be a Laramide intrusive unit, but the field appearance of this exposure shows no intrusive characteristics. The rock is a quartz latite and, though its relationships to nearby outcrops are obscure, an extrusive origin is suggested by two features, (1) the base and lower slope of the eastern side of the exposure is made up of an apparent flow breccia, while the top of the exposure is relatively free of fragmental material and (2) thin section reveals abundant irregular spherulites, probably formed by the filling of gas cavities. Neither of these criteria is conclusive, but are suggestive of a volcanic origin.

<u>Tertiary volcanics</u>

Of the many units of Tertiary effusive rocks noted throughout the Tucson Mountains, only the Cat Mountain rhyolite is found in area studied. The hills to the east and the high ridge to the south of the area are made up of rocks from this formation, but only the small exposure at Location "G" south of Hill 1 includes rocks of this type within the thesis area. Here the rock is a reddish-pink rhyolite with phenocrysts of quartz and orthoclase, flow structure is indistinct and few inclusions are noted.

The debris which covers the lower slope of the main ridge is characterized by the presence of fragments of a very distinctive rhyolite, with well developed flow lineation and abundant inclusions of foreign rock (Plate 7A). These pieces are apparently part of the Cat Mountain sequence, but are dissimilar to the rocks of the main ridge and probably represent a separate flow, rather than a talus accumulation. This flow was probably quite thin as the present occurrences of the rock are only residual rubble from the eroded sheet. In thin section this rock includes quartz, kaolinized orthoclase and minor plagioclase as phenocrysts. The flow structure is very distinct and is delineated by bands of unidentified green globulites. The matrix of the rock is largely glassy.

Justification for mapping these rocks as a formational unit, rather than considering them to be merely covering debris, lies in their ubiquitous occurrence throughout the area, their dissimilarity to the rocks found on the ridge and the occurrences at Locations "C" and "J" of apparent contacts with Cretaceous rocks and the limestone klippen (Plate 8A and B).

Brown (1939, p. 731) states that the source of the Cat Mountain rhyolite is not known. The apparently local nature of this unit in the thesis area could suggest that the Cat Mountain was formed by the approximately simultaneous extrusion of volcanic material of similar composition from a number of sites throughout the Tucson Mountains. This concept could also explain the variations noted by Brown in the character of the unit at different localities. At Location "J" just beside Hill 17, this volcanic rock displays a flow structure conforming to the shape of its contact with a limestone klippe which forms one side of a stream cut (Plate 8B). This may represent a fissure that served as a local passage for lava, though it could also be interpreted as a normal flow contact, a remnant of the main mass of the flow which has been eroded away on the other side of the fault which marks the present stream course.

ECONOMIC GEOLOGY

The Tucson Mountains, in general, have been extensively mineralized, and there have been several attempts to discover economically valuable deposits within the area of this study. Exploratory shafts have revealed copper mineralization along fault traces south of Hill 1 (Plate 7B) and between Hills 21 and 22. Other prospects south of Hill 18 and northeast of Hill 19 disclosed nothing. At none of the locations was sufficient ore present to warrant mining operations.

Limestone has been quarried from several of the klippen. The largest quarry is in the Concha limestone on the north face of Hill 1. Other sites, also in Concha exposures, are the south face of Hill 7 and the northeast corner of Hill 9. Across the stream to the northeast of Hill 9 is a limestone kiln, apparently built about 1940. The workings at Hill 1 are visible on aerial photos flown in 1936.

At the present time there is no work being done on the limestone properties or in exploration for copper, though one new claim marker dated December 1, 1956 was found beside the old working south of Hill 1, and a similarly new marker is located inside the quarry on the north face of Hill 1.

MEASURED SECTIONS

Section 1

Section across the Fenestrellina faunal horizon within the Rainvalley formation at the southeast extremity of Hill 2.

Top of section is a fault.

Permian:

Rainvalley formation: 60 feet.

Unit		Feet
	(Strike N10E, dip 75W)	
11.	Limestone: thin-bedded; pink; contorted by slumping while semi-consolidated; silty	3 est.
10.	Limestone: massive; black, weathering gray; scattered chert nodules and chert-coated fossils including Dictyoclostus	9
9.	Limestone (Fenestrellina marker zone): black, weathering gray; richly fossiliferous with abundant Fenestrellina, Meekopora, large echinoid spines, crinoid stems and fragments of brachiopods; fossils are coated with rusty-brown chert	1
8.	Limestone: same as unit 10	7
7.	Limestone (Fenestrellina marker zone): black, weathering gray; richly fossiliferous with abundant Fenestrellina, Meekopora, Phricodothyris and scattered echinoid spines.	1.5
6.	Limestone: black, weathering gray; some dark chert bands; tan and silty near the top; fossils are scattered and include Dictyoclostus, Fenestrellina, crinoid stems and echinoid spines; Phricodothyris near the top	4

Unit		Feet
5.	Limestone (Fenestrellina marker zone): black, weathering gray; richly fossiliferous with abundant Fenestrellina, Meekopora, Dictyoclostus, Composita, crinoid stems and echinoid spines	.5
4.	Limestone: black, weathering gray; irregular dark chert nodules; abundant large Dictyoclostus and scattered Fenestrellina	1.5
3.	Limestone: black, weathering gray to tan; black chert nodules weathering brown; fragments of fossils including Dictyoclostus and a few Fenestrellina.	4
2.	Limestone: massive; black, weathering gray; weathers tan in silty zones; scattered dark chert nodules and tiny quartz geodes; contains echinoid spines and a few Fenestrellina.	14
1.	Limestone: obscure, largely covered with rubble; black and fetid, weathering gray to tan; silty in places; scattered nodules of dark chert; few Fenestrellina	15 est.

Bottom of section is at broken, andesitic, Cretaceous volcanic rock.

Section 2

Section within the Rainvalley formation up the south face of Hill 5.

Top of section is erosion surface at top of south slope of Hill 5.

Permian:

Rainvalley formation: 37 feet.

Unit		Feet
	(Strike N85E, dip 30N)	
14.	Limestone: black, weathering gray; few fossils coated with brown chert include Composita and Fenestrellina	4
Break, possible bedding-plane fault.		
13.	Limestone: black, weathering gray; fetid; chert coated echinoid spines and plates; scattered bellerophontids and productids as white, calcite cross-sections; few Fenestrellina	7
Break, possible bedding-plane fault.		
12.	Limestone: same as unit 13 but lacking Fenestrellina	3
11.	Limestone: pinkish; indistinct, contorted thin bedding; somewhat silty.	.5
10.	Limestone: black, weathering gray; fetid; dolomitic near top; indistinct fossil fragments including outlines of gastropods.	1.5
9.	Limestone: black, weathering dark brown to tan; very sandy; fetid	2.5
8.	Limestone: dark gray, weathering lighter gray; fetid; quite sandy; indistinct fossil fragments including crinoid stem.	3.5
Break, possible bedding-plane fault.		
7.	Limestone: black, weathering gray; sandy; fetid; scattered chert nodules; includes 5 rather evenly spaced bands of indistinct, pinkish, contorted bedding; numerous fracture fillings of white calcite	3
Units 6, 5, 4, and 3 comprise the "contorted bedding marker zone.		
6.	Limestone; black, weathering gray; many small chert granules; unidentified fragments of fossils	.5

Unit		Feet
5.	Limestone and chert: gray; sandy; mixed with pieces of pinkish, contorted limestone.	1
4.	Limestone: pinkish; thin-bedded; contorted due to slumping while semi-consolidated; some fracturing with the thin beds slightly offset . . .	1.5
3.	Chert: black; thin-bedded with layers 1/4 to 2 inches thick.	.5
2.	Dolomite: dark gray, weathering light gray; sandy; fetid.	4
1.	Slope, covered with limestone rubble.	5

Bottom of section is greenish, Cretaceous, sedimentary rocks.

Section 3

Section across the "tan chert zone" within the Concha limestone, measured up the south face of Hill 9.

Top of section is erosion surface at top of south slope of Hill 9.

Permian:

Concha limestone: 26 feet.

Unit		Feet
	(Strike E-W, dip 70N)	
3.	Limestone: black, weathering gray; dense, with subconchoidal fracture; weathered surface has tiny, closely spaced, sinuous grooves, scattered chert nodules in lower part	10

Units 2 and 1 comprise the "tan chert" marker zone.

Unit		Feet
2.	Limestone and chert: alternating bands; limestone is gray and weathers lighter gray, in bands 2 to 4 inches thick; chert is dark and weathers brown, in layers 2 to 3 inches thick .	3.5
1.	Limestone: dark gray, weathering light gray; fetid; very cherty with chert light gray and weathering brown to give the outcrop a tan color	13

Bottom of section is covered with alluvium.

REFERENCES CITED

Brennan, D. J., 1957, "Geological Reconnaissance of Cienega Gap, Pima County, Arizona," Arizona Univ. Ph. D. thesis in preparation.

Brown, W. H., 1939, "Tucson Mountains, an Arizona Basin Range Type," Bull. Geol. Soc. America, Vol. 50, No. 5, pp. 697-760.

Bryan, K., 1925, "The Papago Country, Arizona," U. S. Geol. Survey Water-Supply Paper 499.

Bryant, D. L., 1955, "Stratigraphy of the Permian System in Southern Arizona," Arizona Univ. Ph. D. thesis.

Gilluly, J., Cooper, J. R., and Williams, J. S., 1954, "Late Paleozoic Stratigraphy of Central Cochise County, Arizona," U. S. Geol. Survey Prof. Paper 266.

Ransome, F. L., 1904, "The Geology and Ore Deposits of the Bisbee Quadrangle, Arizona," U. S. Geol. Survey Prof. Paper 21.

Richard, K. E., and Courtright, J. H., 1954, "Structure and Mineralization at Silver Bell, Arizona," Mining Engineering, November, 1954, pp. 1095-1096.

Wilson, E. D., 1949, "Structure in Arizona", paper read at Geol. Soc. America meeting in El Paso, Texas, Nov. 10, 1949.

PLATE 2

A. General appearance of Fenestrellina marker zone in the Rainvalley formation at Hill 5.

B. Contorted bedding marker zone in the Rainvalley formation at Hill 5.

PLATE 3

A. Fault near west end of Hill 4 klippe.

B. Small flexure in limestone west of Hill 1.

PLATE 4

A. Conglomerate composed of subrounded limestone cobbles.

B. Thrust breccia exposed in cut at north face of Hill 1. Line marks leading edge of klippe.

PLATE 5

A. Joint pattern in Recreation red beds west of Hill 15. Looking N75E along the principal joint set.

B. Contact of Amole granite stock (above) with a folded and metamorphosed shale sequence of the Amole arkose.

PLATE 6

A. Latite dike in the southeastern portion of the thesis area.

B. Silver Bell andesite, showing prominence of plagioclase phenocrysts.

Univ. of Arizona Library

PLATE 7

A. Cat Mountain rhyolite, showing well-developed flow lineation and typical occurrence as rubble on the slope.

B. Abandoned copper prospect south of Hill 1.

PLATE 8

A. Flow contact at Location "C". Volcanic rock to left of line, Recreation red beds to right.

B. Fissure trace or flow contact at Location "J". Flow lines in volcanic rock at left reflect configuration of contact with limestone at right.

GEOLOGIC MAP OF THE NORTHEASTERN PART OF THE TUCSON MOUNTAINS