CENOZOIC DEPOSITS IN THE SOUTHERN FOOTHILLS OF THE SANTA CATALINA MOUNTAINS NEAR TUCSON, ARIZONA

by

Klaus Voelger

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The research on which this thesis is based was completed by Mr. Klaus Voelger of Berlin, Germany, while he was studying at the University of Arizona under the program of the Institute of International Education. The final draft was written after Mr. Voelger's return to his home in the Russian-occupied zone of Berlin. Difficulties such as a shortage of typing paper of uniform grade and the impossibility of adequate supervision and advice on matters of terminology, punctuation, and English usage account for certain details in which this thesis may depart from standards of the Graduate College of the University of Arizona. These details are largely mechanical, and it is felt that they do not detract appreciably from the quality of the research nor the clarity of presentation of the results.

John F. Lance
Director of Thesis

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Abstract

Fluviatile-lacustrine deposits are exposed on the southern bajada of the Santa Catalina Mountains north of Tucson, Arizona. The name "Rillito formation" is proposed for these sediments. Their base is not exposed but they overlie in part Oracle granite and Cretaceous? sediments. Alluvial fan deposits are resting upon the formation.

The conglomeratic parts of the Rillito formation contain exotic constituents possibly derived from rocks which once rested on the gneissic-granitic complex of the Catalinas. Three members of the formation can be distinguished by differences in composition of the conglomerates. These gradual changes are believed to reflect the structural history of the area. Deformation, possibly thrusting occurred after the lower member. The granite core of the Catalinas probably became exposed to erosion by those movements as indicated by pebbles in the middle member. Another uplift of the mountain block after the middle member is inferred from appearance of gneissic particles in the upper member and from numerous faults in the middle one. They suggest tension probably incidental to movements of the mountain block. Volcanic activity preceded deposition of the Rillito formation as indicated by sedimentary particles therein.

The lower member may be older than late mid-Tertiary diastrophism although an age close to the lowest parts of the Gila conglomerate is not impossible. The middle and upper member are considered equivalent to the Gila conglomerate (Upper Pliocene and Pleistocene) of Southeastern Arizona. No fossils have been found in the Rillito formation.

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INTRODUCTION

Location of the area

The area studied is located in the northern part of the valley in which the city of Tucson,Arizona is situated.

The natural boundary in the north is formed by the base of the Santa Catalina Mountains.In the south,the Rillito Creek runs parallel to the base of the Santa Catalinas in a distance of about six miles and forms the natural boundary to the valley side.The western limit of the area studied is North Campbell avenue,the eastern boundary is formed by Agua Caliente Hill,a part of the Santa Catalina complex in the wider sense.

The region just described is about 60 square miles;in addition to it further research had to be undertaken in the vicinity of Bellota Ranch,lying on the mountain pass from Tucson to Redington.Loma Verde mine and Twin Hills,both in the eastern corner of the Tucson valley were studied on several reconnaissance trips.Another area visited is sited around a roadcut of the highway from Tucson to Benson,near the Pantano railroad station.

Outline of the geography

Relief. The Santa Catalina Mountains determine the picture of the area.They are a range of lofty and rugged mountains with their highest elevation at Mt.Lemmon(9150 ft.) and Mt. Rice (92225 ft.). Their extension in northwest-southeast direction follows the general pattern of most mountain ranges of southern Arizona. At the bold southwestern front of the Catalinas, the peaks generally have an elevation of 5-7000 feet above sea level. With a very steep slope the mountains border on the broad basin in which the city of Tucson is situated at an elevation of 2450 ft. The slope from the mountain front to the valley center is formed by a "slope" (Tolman, C.F., 1909a), "pediment" (Bryan, K., 1925, p.93), "bajada" (Blackwelder, E., 1931), or "alluvial piedmont" (Twenhoefel, W.H., 1951). The angle of surface slope flattens out to the southwest towards the center of the Tucson basin. The greatest and most conspicuous part of the Tucson valley is formed by an almost flat plain with hardly recognizable northwest slope.

The area of pronounced slope between the mountain front of the Santa Catalinas on the northern side and the Rillito Creek in the south is often referred to as the foot-hills of the Santa Catalina Mountains. The difference in elevation between the northern and southern parts of the foot-hills amounts to about 600 feet. The hilly character of the area is due to heavy dissection by washes heading in the Santa Catalina Mountains. Most of the investigations were undertaken on this dissected southern bajada of the Santa Catalina Mountains.

The width of the bajada is about four miles, measured perpendicularly to the mountain front. The length of the belt of piedmont slope corresponds to the length of the southwestern front of the Catalinas,about 15-20 miles.There is a difference in elevation between the western and eastern part of the bajada: points in the western part are at roughly one hundred feet higher elevation than corresponding points,that is those with equal distance from the mountain front,in the eastern part of the bajada.It is possible that this difference in altitude is due to heavier erosion in the east with the dividing line following approximately Sabino Creek.Another difference can be noted In the east the wash beds are shallow and the few hills are well-rounded,which suggests that erosion of the piedmont slope is more advanced here.In the west,steep walled washes are dissecting the bajada,this process is still going on.Thus,the eastern bajada shows features of a mature or post-mature morphology.In contrast to it,the west is in a more youthful stage of erosion.

Drainage. The Santa Catalina Mountains are elongated in northwest-southeast direction.The drainage of the southwestern part is to the Santa Cruz river,the main tributaries being the Pantano Wash and Rillito Creek.The northeastern part of the range is drained to the San Pedro river.All rivers mentioned belong to the drainage system of the Gila River,a stream that drains central Arizona and western New Mexico,flowing in a westerly direction towards the Colorado River.

The streams are of the intermittent type.They flow only during the rainy season which is from July to September.At other times very few washes carry water,Sabino Creek being one of them.

Climate. Tucson is situated in the semi-arid parts of the western United States;the annual precipitation on average is twelve to fifteen inches.The climate is controlled more or less by differences in altitude.In the region around Tucson the elevation is low and the summers are hot,the winters mild and sunny.Rain falls only in the rainy time from July to September, otherwise precipitation is scarce. At higher elevation,such as on Mt.Lemmon,the summers are cooler and snow in the winter is the rule.

Plant and animal life. The vegetation as well as the animal life depends on the climate and varies tremendously,the main factor being the altitude.In the foothills the vegetation is like that of the Tucson basin:cactus and desert shrub.Among many species, the saguaro(*Cereus giganteus*) is the most characteristic,the Teddy Bear cactus is for the geologist the most troublesome plant(*Opuntia bigelovii*).In higher elevation on the Catalinas, pine and oak forests are predominant.

Animal life in the foothills is inconspicuous but manifold. Birds are seen most often but reptiles(snakes,Gila-monster)and mammals(rodents,deer,mountain lion) can be encountered too.

Outline of the geology

Within Arizona,two larger units may be distinguished.The Plateau province covers roughly the northeastern half of the state and the Basin and Range province covers the rest. Several authors have pointed out that this geomorphologic separation reflects structural differences (Ransome,1915; Butler,B.S.,1929; Wilson,E.D.,1949).

The Plateau province is much better known. Its rocks, particularly Paleozoic and later ones,are exposed over wide areas,their age being fairly definite. Deformation is never intense, in sharp contrast to the strong deformation of the Basin Range province. The latter term is used here only as no better term is available to designate the non-Plateau province. This does not necessarily imply that block faulting has been the sole acting force as propounded by Gilbert for the area of the Great Basin (Gilbert,G.K.,1875).

The area of investigation lies within the Arizonan part of the Basin Range province. To the north this province includes the Great Basin of Utah,Nevada, and California; to the south it reaches as far as Sonora and Chihuahua,Mexico.

Characteristic features of the Basin Range province are the roughly parallel mountain ranges and the rather flat desert plains which isolate the mountains. Most rocks are of doubtful age and, as Wilson(1949,p.2) remarks, important features are often obscured especially in the valleys or basins. In comparison with other areas very little is known about the general structural trends in this region of which the area of study is a part. The basin and range forming diastrophism is generally understood as of Cenozoic age.

The rocks known from southern Arizona include sediments, igneous, and metamorphic rocks ranging in age from Pre-Cambrian to recent. Some formations like Ordovician, Silurian, Triassic, and Jurassic are generally lacking and suggest that diastrophism and erosion interrupted the normal sequence.

Most of the area of investigation lies on the southern bajada of the Santa Catalina Mountains, north of Tucson, Arizona. The Catalinas have been described only in parts. They belong to a complex of gneissic and granitic rocks which extends northwest-southeast over more than thirty miles and includes the Santa Catalinas, the Rincon Mountains and in the angle betwe both, the Tanque Verde Mountains. This extensive block of metamorphosed sediments and igneous rocks is assumed by Hernon (1933) to be produced by an intrusion of considerable extent in post-or late Cretaceous time.

The intrusives vary from granodiorite to alkaline granite according to the same author. These granitic rocks are known more or less only from the middle parts of the entire complex. In the southern parts, especially of the Catalinas, alteration rocks prevail. The type of alteration is rather unusual; according to B.S. Butler (oral comm.), the Catalinas may be even considered as an example of granitization. Injection metamorphosis resulted in two kinds of alteration rocks: One is an oligoclase-biotite-quartz injection rock, the other being sill-like pegmatites high in potash, soda, and silica. These two alteration rocks have the appearance,in the order described,of an augen-gneiss on the one hand and of a sheared granite on the other. These latter two rocks occur especially in the southern parts of the Catalinas.The dividing line between granite and gneiss is rather vague and was first suggested by Tolman(unpub.manuscr.) as to run east-southeast starting at Romero Canyon which is on the western front of the Catalinas.

The northern slope of the Catalinas is formed by igneous and sedimentary rocks of Pre-Cambrian,Paleozoic,and less frequently,younger age.Due to some mining activity,this area is better known than the southern parts of the Santa Catalina Mountains.

While in the north the Catalinas dip under the bolson deposits of the San Pedro River valley without a distinct line of displacement,their southern front is more or less determined by the course of one or several faults.The fault is assumed to continue from west of Sabino Canyon to the east and then to the south by swinging around Agua Caliente Hill and running along the base of the Tanque Verde Mountains towards the Rincon Mountains,according to Moore(unpubl.manuscr.).

In the region of the southern bajada of the Catalinas, south of the fault,no gneiss is exposed.Here extensive alluvial fans cover the area and most often obscure the"Catalina-fault" as the fault will be referred to.The material of the fan deposits is derived from the present Santa Catalina Mountains and therefore it consists mainly of little or non-solidified gravel of"Catalina gneiss" and schist.Individual fans usually start in the mouth of the canyons and they spread out towards the Tucson valley.After a short distance from the mountain front,two or more fans coalesce thus forming the inclined plain encountered so frequently in this part of the country and often referred to as bajada.

Different elevations of the surface level of the fans indicate several stages of erosion and deposition.Remnants of more extensive fans can be observed in many places;they can be correlated by elevation and angle of slope of their surfaces as shown by Blissenbach(1951).This author has made investigations of fan deposits in this particular area and he was able to define several distinct stages in their deposition and erosion.The age of the fans is more or less recent;none of them was found to be involved in deformation.

The central part of the Tucson valley is a large flat area formed by loose or little solidified gravel and sand. In the eastern part of the valley,occurrences of older formations are known from Twin Hills,Loma Verde mine,and Saguaro National Park.

On its westside,the Tucson basin is confined by the Tucson Mountains,consisting of Tertiary and probably younger volcanic rocks and a few sediments,furthermore Cretaceous sedimentary and volcanic rocks and intrusives of uncertain age,probably early Tertiary(Brown,W.H.,1939,p.713-718).

The southern border of the valley is formed by the Sierrita and Santa Rita Mountains which contain pre-Tertiary igneous and sedimentary rocks(Darton,1925).In the southeastern corner of the Tucson valley the Empire Mountains are situated;they consist chiefly of sedimentary rocks of younger Paleozoic and Cretaceous age.The Rincon Mountains are a continuation of the metamorphic complex of the Catalinas to the southeast.

The valley fill underlying the central parts of the Tucson valley can be assumed to be of considerable thickness as no wells have penetrated the alluvial blanket.As mentioned above,only in a few cases rocks different from the valley fill can be seen and these occurrences altogether are distributed over few square miles only.Except for these outcrops,fluviatile-lacustrine sediments are exposed in the area of the southern bajada of the Catalinas.These deposits are not very conspicuous as they are frequently overwashed by alluvium.They are the subject proper of this paper.

Tolman,one of the first authors on the area,had correlated these sediments with deposits of similar appearance exposed south of the Rincon Mountains,particularly in the headwaters of Pantano Wash.As the term "Pantano formation" has not been defined sufficiently by Tolman or Moore,[1./] who also applied it, the present author will not use the name for the fluviatile-lacustrine rocks in the southern foothills of the Santa Catalinas.In accordance to a suggestion by Dr.Stoyanow(oral comm.)

1./Both authors have written unpub.reports on the geology of Tucson quadrangle.Available for study was only that by B.N.Moore.

the term "Rillito formation" is proposed in order to designate those rocks in the Catalina foothills.

Previous works

Literature provides only little information about Cenozoic rocks of the area. The unpublished manuscript on the Tucson quadrangle by Tolman in which the name "Pantano formation" was used first, could not be obtained. In another paper, the same author writes:

> "...bottom layers of the Tucson outwash deposits, south of the Santa Catalinas, contain fragments of porphyries and lavas which do not appear in place on the South side of the range. The conclusion is evident that this layer represents a portion of the mountains entirely washed away..."
> (Tolman, 1909 a, p. 157)

First mention of structural relations seems to be made by Kirk Bryan:

> "Red and partly cemented older alluvium is exposed near the base of the Santa Catalina Mountains aat the mouth of Sabino Canyon. It is tilted and eroded, and on it rests the younger alluvium."
> (Bryan, K., 1923, p. 29)

Although B.N.Moore's unpublished report on the Tucson quadrangle is rather elaborate, his investigations appear to be more intensely concerned with older rocks and a description of Cenozoic rocks of the Tucson valley remains brief. Moore applies the name "Pantano formation" to rocks described as a "thick series of continental deposits and interbedded volcanic rocks typically exposed in Pantano Wash in the southeast corner of the Tucson quadrangle. It is not clear on which criteria Moore distinguished the formation from younger, alluvial rocks.His description of lithology and structure is rather general.Therefore,a critical attitude towards the all including use of the designation "Pantano formation" seems appropriate.

Several authors have worked in the region north of Tucson but they touch the subject of the present paper only occasionally.(Blake,W.P.,1908;Davis,W.M.,1931;Hernon,R.N.,1933; Blissenbach,E.,1951)

Problems and approaches

Detailed sedimentological studies on the southern side of the Santa Catalina Mountains were necessary to obtain criteria for the division of the Cenozoic rocks. Having secured sedimentary criteria,a division of the rocks apart from the gneiss complex into the "Rillito formation" with a lower, middle,and upper member and alluvial fan deposits was suggestive. Thereupon regional distribution and structural questions could be approached.

Exotic pebbles comprise the conglomeratic parts of the Rillito formation in many cases;thus,the problem of the contributing source area was raised.Although the fact that a few limestone cobbles had been found in the Catalina foothills gave rise to the entire investigations described in this paper,this became a secondary problem in the course of the work.

No fossils were found in the Cenozoic deposits of the area of study.Therefore,the age of the Rillito formation could be approached only by an attempt to correlate the beds with similar formations in adjacent areas.

Methods of work

Field work was started in January 1951 and done on weekend trips until summer,afterwards however over longer periods.Due to the extensive area to be investigated,the following method had to be applied.A section near Tucson was studied in detail.After criteria for recognition of the beds had been established,new outcrops were searched for in adjacent areas and investigated.

Aerial photographs. The Tucson quadrangle with a contour interval of 100 feet was not sufficient for orientation in a region so much dissected as the Catalina foothills.Therefore aerial photos were used as a base of the work.Furthermore they proved time-saving as in several cases outcrops could be identified under the stereoscope at home and trips could be planned accordingly.Stereoscopic coverage of the area was desirable especially for the purpose of detecting outcrops on sidewalls of washes.For orientation in the field,however, single photos were sufficient as long as they were taken contrary to the common procedure of photogrammetry and contained some shadow.

Sedimentary analyses. Most of the conclusions were drawn from data secured from analysis of the conglomerates of the Rillito formation.Investigations of the conglomeratic parts of the series were usually made right at the exposures.For a pebble count, an area containing roughly 75-100 pebbles and cobbles was outlined with a grease pencil. Commonly the constituents could be removed. In case of strong cementation or badly weathered state,however, they were left in place. The sedimentary particles were sorted upon a large bag which was divided into a number of fields, each for a particular rock type.

Measurements of roundness were undertaken by means of a table by Krumbein which bears images for visual roundness (Krumbein,W.C.,1941,Pl.1). The sphericity of the coarse-grained constituents was determined by computation of the ratios of the three axes (Krumbein,W.C.,1941,p.64). This latter procedure was abandoned in the course of the work as no general trends could be recognized except for one important fact concerning the Barnes conglomerate as a source rock.

Local distribution of maximal sizes was determined by taking into account all constituents of the particular outcrops and not confining the measurements to the pencil-marked parts of the outcrops.

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CENOZOIC DEPOSITS

Distribution and modes of occurrence

The Santa Catalina Mountains,Arizona,are bordered on their bold southwestern front by Cenozoic deposits.The zone of transition coincides roughly with the trend of a long fault with approximate WNW-strike.This"Catalina fault" is exposed only in extremely few cases,the best exposure being situated eastward of the north tip of Campbell avenue.

North of the border fault metamorphic rocks of the Catalina gneiss complex are the predominant type,south of it alluvial fan deposits form the slope towards the Tucson valley.In numerous cases,however,metamorphic rocks of the Santa Catalinas are overwashed by alluvium along a narrow zone.The surface of slope of fan deposits extends a short way north of the "Catalina fault" and includes a small belt of the metamorphic complex thus indicating that a narrow zone of the mountain front was subjected to a process of planation.No case is reported that gneiss occurs somewhere in the foothills,south of the border fault.

The whole area along the southern front of the Catalinas is strongly dissected by washes that head in the Catalinas.The alluvial fan deposits consist almost entirely of rocks that occur today on the southside of the Santa Catalina Mountains; therefore gneissic and pegmatitic rock fragments predominate. Different levels of the fan surfaces can be recognized,the upper one being preserved only in hill remnants and in the narrow belt of planation along the southern gneiss front of the Santa Catalina Mountains(examine Plate 1).

Where washes have cut through the alluvial fan deposits, an older formation is exposed underneath the fans;these older sediments differ from the fan deposits in color,composition, sedimentary structures,and in many places they are strongly deformed.For this older formation the name "Rillito formation is proposed.It is the subject proper of the present paper. A detailed discussion of the alluvial fan deposits of the region can be found in a paper by E.Blissenbach(1951).

The total region of distribution of the Rillito formation that was investigated,may be divided into three parts on account of the different mode of occurrence predominant in each.See Plate 1 .

A first group of exposures is situated between North Campbell avenue and Sabino Creek.Here the alluvial cover is rather thick and isolated outcrops of the Rillito formation can be found only in places of heavy cutting.Therefore,the main type of exposure is in wash bends and on the sidewalls of washes.Individual outcrops in this part of the total region are often good and high but always capped by alluvium and therefore hard to detect.The disadvantage for field work is obvious:correlation of strata over those isolated outcrops encounters difficulties as the mutual relations are obscured by alluvium.Lateral extent of individual exposures lies between fifty and five hundred feet.

A s e c o n d area of exposures is distinguished by having a thin veneer of alluvium only;it lies between Sabino Creek and Agua Caliente Hill in the northeast corner of the Tucson valley.Here the Rillito formation crops out more extensively and it covers larger parts of the surface.Dissected hills of the fan-remnant type are conspicuously absent.Deep cutting is hardly present,wash beds are shallow and the few hills are well-rounded.Good outcrops are scarce due to the lack of relief;only roadcuts along Mount Lemmon Highway permit detailed studies of stratification and structure.

In both the first and the second group of exposures the Rillito formation exhibits no relation to older formations except for the fault contact with gneiss of the Santa Catalina Mountains.The basement of the bajada beneath the Rillito formation is not known;wells have not reached the base of the Rillito formation as most groundwater is obtained from alluvium.

In a t h i r d group of exposures the Rillito formation is found in contact or at least immediate vicinity with older rocks such as granite,volcanic rocks,Cretaceous? recrystallized limestone,and gneiss of the Santa Catalina Mountains.These occurrences of the Rillito formation are very scattered and were determined by means of aerial photographs.All of them are located in the easternmost parts of the total region of study such as northeast of Bellota Ranch,at Loma Verde mine and Twin Hills.

Plate 1

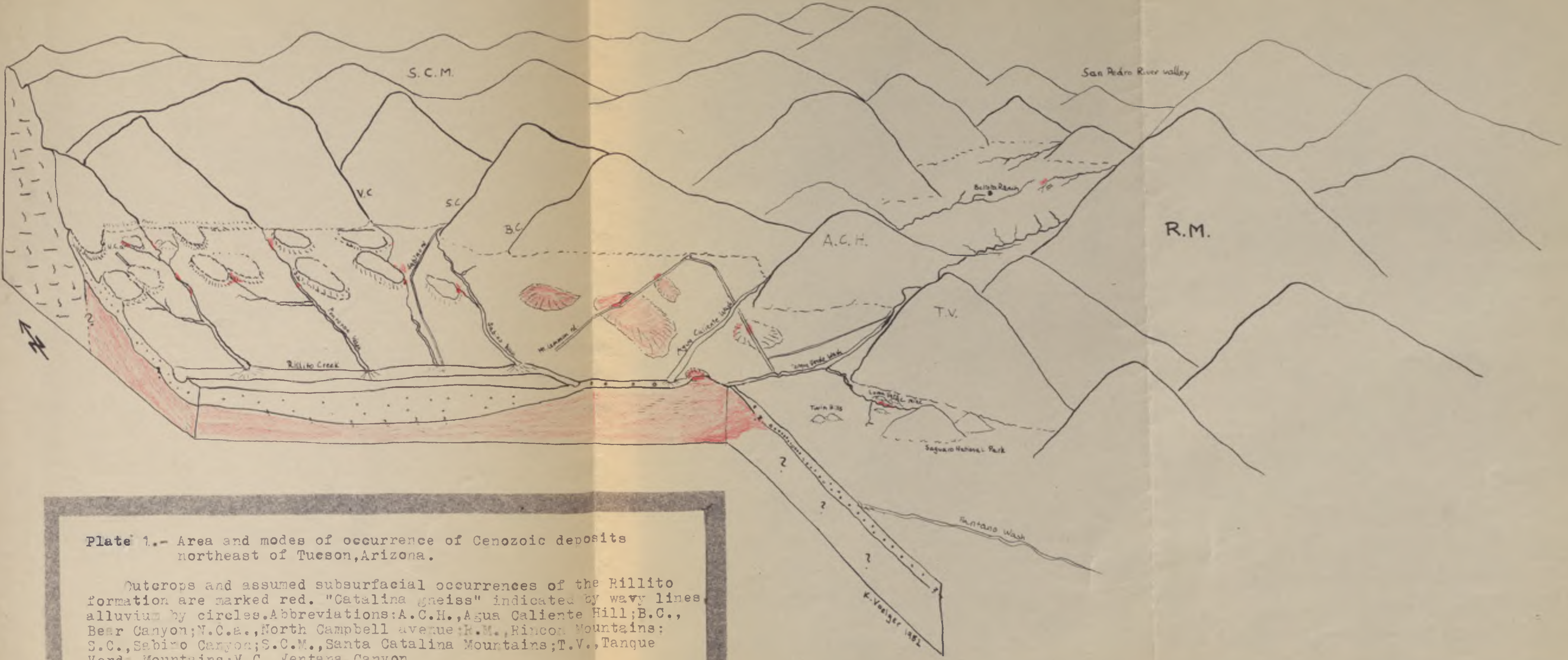

Plate 1.- Area and modes of occurrence of Cenozoic deposits northeast of Tucson, Arizona.

Outcrops and assumed subsurfacial occurrences of the Rillito formation are marked red. "Catalina gneiss" indicated by wavy lines, alluvium by circles. Abbreviations: A.C.H., Agua Caliente Hill; B.C., Bear Canyon; N.C.a., North Campbell avenue; R.M., Rincon Mountains; S.C., Sabino Canyon; S.C.M., Santa Catalina Mountains; T.V., Tanque Verde Mountains; V.C., Ventana Canyon.

Composition as basis for division of the Cenozoic

General remarks. Several methods for a differentiation of the Rillito formation from the younger fan deposits on the one hand and subdivision of the Rillito formation on the other hand were applied. Only one method, however, based on composition of coarse-grained sedimentary particles proved to be reliable. No fossil plants or animals could be detected despite intensive investigation around favourable looking exposures such as the places of transition from fine-to coarse-grained sediments. Besides establishing the stratigraphy, the composition of the different members gives clues as for the history of the erosion of the source area.

Criteria other than composition failed to help in recognition of the beds. For instance, at the beginning of the studies beds overlain by fan deposits were mistaken for Rillito formation until it became evident that there are several stages of fan deposits and all somewhat different from each other. Therefore, the fact that conglomerates, for instance, are overlain by alluvial fan deposits, does not constitute a criterion for their being Rillito in age. Color also is a doubtful criterion in distinguishing the Cenozoic. Although red colors prevail in the Rillito formation, brown and gray may be observed as well. The fan deposits are commonly white or gray, in some places they exhibit a brown color resulting from the color of the sandy matrix. For a synopsis of sedimentary features, see Table 2.

<u>Graphic presentation of composition.</u> A series of histograms shows the composition,in terms of six rock types present,of the Rillito formation and the fan deposits at various localities(Table 2).The vertical scale represents the percentage of each rock type present in a particular pebble count.On the horizontal scale six columns are plotted,each representing one particular rock type or rock group among the constituents of the Cenozoic conglomerates of the area.

From left to right,the columns represent: 1.granite of the"Oracle"type,2.limestone,3.volcanic rocks,4.quartzite and vein quartz,5.schist and phyllite,6.gneissic-granitic rocks, derived mainly from the Santa Catalina complex.This arrangement was chosen because it illustrates most clearly that the changes in composition are following a definite pattern.

Table 2 shows the four compositional types of Cenozoic conglomerates of the area. A compilation of the results of most of the pebble counts shows that the histograms in Tabl.2 were selected rather at random for each particular stratigraphic unit.This list will be found in the appendix.

In the lowest parts of the Cenozoic,granite fragments mostly or exclusively of the "Oracle"-type (see below) are the predominant constituents.These granite pebbles and cobbles are absent from the younger members of the Cenozoic. An opposite trend can be observed with particles of the sixth column: gneissic-granitic rock fragments of the"Catalina"-type are not present in strata of the older Cenozoic;they increase, however,until they form the chief part of the constituents in the youngest Cenozoic,that is in the recent alluvial fan deposits. The extreme left and right column,granite and gneiss, may therefore be understood as end members in that sense that they exclude each other in the extreme lower and upper member of the Cenozoic conglomerates of the area.The intermediary members such as limestone,volcanic rocks,quartzites,and the schist-phyllite group vary in their participation of composition throughout the stratigraphic sequence in the following way:the more to the left side the column is plotted in the histograms,the earlier(stratigraphically)this rock type ceases to contribute fragments to the Cenozoic conglomerates.The fourth and fifth group,quartzite and schist-phyllite,are not very significant probably because these groups could not be subdivided by hand specimen determination.

The petrology of the constituents was found to be significant enough to motivate a detailed description.This will be dealt with under the stratigraphic units in which the particular rock fragments make their first appearance.At this place only peculiarities of their representation in the diagrams are discussed.

G r a n i t e fragments are conspicuous especially in the lower members.Except for those particles derived in later periods of the Cenozoic history from the central Santa Catalinas, granite constituents seem to be composed of one and the same type that is referred to as "Oracle" granite.The latter ones are represented by the first column; the granite derived from the central Santa Catalina Mountains is added to the sixth column because it cannot always be distinguished from gneissic particles. L i m e s t o n e particles seem to represent only a limited number of formation which may have been in contact with each other.They are probably all of upper Paleozoic age. V o l c a n i c rock fragments in the Rillito conglomerates are assumed to be Cretaceous and younger in age,inferring this from occurrences in the southern parts of the state according to Moore(unpubl.manuscr.).Despite some variation in petrology,the volcanic rock fragments were treated as a unit because the few types usually occur together in the strata. The fourth group is composed of q u a r t z i t e s as well as of vein quartz;in the field a separation was not always possible. S c h i s t and p h y l l i t e make up the fifth group;for stratigraphic purposes they are not very useful which is true also for the fourth group.Gneissic,pegmatitic, and granitic rock fragments comprise the sixth group;these rocks were included in one column because they are exposed widely in the present Santa Catalina Mountains.Fragments of this group are hard to distinguish,it appears however that in the middle member of the Rillito formation gneissic rocks are less common than in the upper member.

Compositional types of Cenozoic deposits. Based on presence and absence of exotic fragments among the constituents,coarse-grained sediments on the southern bajada of the Santa Catalina Mountains may be divided into two groups. The adjective "exotic" is applied to those rock fragments that are not known to occur in situ in the contributing area of the drainage system which presently is resulting in deposition and erosion of recent alluvial fan deposits on the southern bajada of the Santa Catalina Mountains between the mountain front and Rillito Creek.

The group without exotic rock types among its sedimentary particles is the younger one; conglomerate of this composition will be referred to as "alluvial fan deposits". Those other sediments containing exotic particles are older and will be designated as"Rillito formation."

The Rillito formation consists of fine- and coarse-grained sedimentary rocks including evaporites. For a division of the formation,only conglomerates can be used because of the absence of determinable particles in fine-grained rocks. Within the conglomeratic parts of the formation,two types of composition are present. One type is composed of nothing but exotic rock fragments while in the other compositional type of conglomerate both exotic and non-exotic particles are present. Field evidence suggests that the beds with only exotic fragments are the older ones. Regarding the compositional development of the conglomerate,this seems logical.

The alluvial fan deposits of the area are composed exclusively of fragments derived from rocks that can be found in place in the southern parts of the Santa Catalina Mountains. These non-exotic particles are presented in the fourth, fifth, and sixth column of the histograms (Pl.2). In rare cases only,a few exotic fragments identical to those in the Rillito formation were found in the alluvial fan deposits. This is assumed to be due to a secondary deposition of fragments washed out from nearby outcrops of the Rillito formation.

RILLITO FORMATION

Lower member

General statement

The oldest member of the Rillito formation includes conglomerate,mudstone,and possibly gypsum,the latter of questionable position within the formation. The mutual relation of these rocks is evidenced by interfingering. Their relative age within the Cenozoic of the area is based on the conglomerate as the only stratigraphically determinable rock type.

Relation to older rocks. The base of the Rillito formation as well as the rocks of the subfloor are nowhere exposed in the Catalina foothills. Wells also have not reached the rock floor underneath the formation nor can well logs be employed with certainty to give clues to the subsurfacial situation of the Rillito formation due to the known difficulty of applying the driller's description to geologic purposes. To overcome this latter handicap, a simplified method of determination of the Cenozoic is suggested. It can be accomplished by determination of presence and absence of those rock types which are shown in column 1, 2, 3, and 6 of the histograms on Plate 2.

Outside of the Catalina foothills, however, lower Rillito beds were found in immediate vicinity of older rocks at two localities. Thus, at Loma Verde mine, in the northeast corner of the Tucson valley, conglomerate of the lower member was found about one hundred yards from red granite,commonly referred to as "Oracle"granite in the region north of Tucson.Although the contact is not exposed,the situation suggests that the conglomerate was deposited here upon an irregular granitic surface.Here also porphyritic basalt was observed in fault contact with the conglomerate which formed the hanging wall.The basalt is regarded as being younger than the lower member(see section: "Rillito formation and volcanism",below in this paper).

On the mountainous pass between Santa Catalinas and Rincon Mountains near the county highway from Tucson to Redington,about two miles northeast of the Bellota Ranch buildings a conglomerate can be observed that corresponds very closely to the lower Rillito conglomerate in the valley as far as composition,color,particle size,sorting,stratification,and cementation is concerned.The conglomerate lies at an elevation of 4500 feet above sea level;this is in contrast to all other occurrences in the Tucson valley which lie usually at 2500 to 2900 feet elevation.

Gneiss of the Catalina complex surrounds the isolated occurrence and underlies it probably.Rillito beds form only a part of this lense of one mile in diameter which rests on gneiss.From southwest to northeast the following rocks are exposed in this unusual as well as very isolated occurrence: recrystallized limestone(forming a small hill) of Cretaceous? age;reddish shale,perhaps also Cretaceous?;lower Rillito conglomerate;shale or mudstone intruded and altered by adjacent volcanic rocks which are composed,at least in part, of porphyritic basalt.The altered mudstone or shale may belong to the Cretaceous? or to the lower Rillito member, distinct indications for a relation were not observed by the author.The volcanic rocks occur along a northeast trending strip of more or less continuous exposures;a dike is probable.Features suggesting a dike can be seen on Plate 9. As the area around Bellota Ranch was visited only on reconnaissance trips,more detailed studies seem necessary before statements about the relation of the lense of sedimentary and volcanic rocks on the gneiss can be made.

In the conception of B.N.Moore(unpubl.manuscr.),it is the remnant of a block of younger deposits that was thrust upon the gneiss.It can be assumed that Moore did not observe the volcanic rocks in the vicinity nor the altered mudstone or shale.

A large number of coarse constituents of the lower Rillito conglomerate in this particular area are shattered and appear uncommon when compared with the generally intact constituents of occurrences in the Tucson valley.This would agree with Moore's idea of overthrusting;however,it does not necessarily imply such movement.Moore's argument is the presence of a zone of brecciation;this could not be observed by the present author which may be due to the short time of study there.

Considering the possibilities of overthrusting,the following points are noteworthy.If the occurrence near Bellota Ranch is due to an overthrust,a lateral displacements of several miles has to be postulated because the block could not have been derived from a locality within the gneiss complex.Assuming an origin from a place outside the gneiss,either northeast or southwest from Bellota Ranch, the amount of displacement must be several miles.

Another possibility of the origin of the sedimentary lense near Bellota Ranch would be their deposition at the present place with subsequent uplift or downwarp to account for the unusual elevation of the deposits.This will be discussed later in this paper.It should be added,however,that the broken and shattered character of the lower Rillito member (Plate 3,A)may be due to such deformations as during vertical movement.

Facies and distribution. The relation between conglomerate and mudstone deposits of the lower member is evidenced by their interfingering at several localities,best observed at site 6 and site 19 (map with location of sites in pocket). This feature of sidewise representation of fine and coarse material appears to be rather common among continental deposits of Cenozoic age in southern Arizona according to F.L. Ransome(1903,p.48),C.P.Ross(1925,p.29-30),J.W.Gidley(1926, p.83),Knechtel(1936),and Alexis(1949,p.58) et al.It is due to the particular environment and mode of deposition discussed later in this paper.

The present scattered and fragmentary distribution of occurrences of the lower member is mainly a feature of preservation.Mudstone deposits in particular have been subjected to strong erosion due to their softness.An example is seen in the elongated depression of one mile length southeast of site 19(map in pocket),the conglomeratic facies northwest of it was resistent and is standing out today.

As outcrops are scarce and well logs uncertain(p.29), little definite statements can be made about facies distribution. This subject is of particular interest in its relation to the areas of high relief of former and present times. It appears,however,as though in the lower Rillito member,conglomerate is more extensively developed near the present mountain front while mudstone deposits increase towards the Tucson valley.

Transition from conglomerate to mudstone can be observed at site 6,west of Pontotoc road,where both facies are interfingering.South of it for about 2000 feet mudstone deposits form high and steep walls along Pontotoc Wash until they dip under the gray conglomerate of the middle member.To the north the conglomerate,exposed already at site 6,forms larger outcrops around site 10.The inclination in both facies is the same,namely to the valley.

Another strip of rather continuous exposures of lower Rillito beds is east of the northern end of Campbell avenue.

Figure 1. Mudstone lense with fibrous gypsum,about 400 feet west of massive gypsum

Figure 2. Occurrence of mudstone at Pontotoc Wash,overlayed by middle member conglomerate

In the middle part of it, a lense of mudstone deposits is enclosed by the lower member conglomerate in north and south.The conglomerate on both sides shows synclinal dip to the mudstone.It is unlikely that the dip is initial; imbrication,best exhibited at site 11(map in pocket),indicates that the depositing stream came from the north even where the inclination is to the north.Tectonic forces,therefore,are assumed to be the cause of the situation of the conglomerate.

The mudstone deposits in the center of the syncline are of silt-size with gradations up to granules towards site 19. The stratified mudstone dips southwest with transitions to the dip of the adjoining conglomerate. Exposures around site 20 exhibit that the mudstone,dipping 25 degrees southwest and west,contains gypsum layers,one to two inches thick, on bedding planes and fissures.The gypsum on fissures cuts the one on bedding planes in places.It is not impossible that these thin gypsum layers are younger than the intercalated mudstone.Thus,they may have been derived from a nearby occurrence of massive gypsum(site 30) by circulating waters.

The relation of the massive gypsum(site 30) to the mudstone lense and thin gypsum(around site 20) is not certain. The massive gypsum is much thicker and lies flat in contrast to the thin gypsum which dips 25 degrees southwest.Indications in the field are too scarce as to permit definite interpretation.No definite solution can be offered,however,the following discussion is believed to clarify the issue at least.

Concerning the relative age of the massive gypsum (site 30), the following arguments for the two main possibilities are indicated:

1. The massive gypsum is pre-deformational and pene-contemporaneous with lower Rillito beds:

Supporting: The mudstone facies seems limited to the lower Rillito formation; no mudstone deposits of any thickness above one foot are present in the middle and upper member of the Rillito formation. Furthermore, the local coincidence is remarkable: both occurrences (site 2o and 30) are less than 500 feet apart. It should be remembered that site 20 is lower Rillito evidenced by interfingering. The mudstone both in site 20 and site 30 is rather similar in appearance.

Opposing: The fact that the massive gypsum lies horizontal disagrees with the assumption that it predates the deformation which caused the dip in conglomerate and mudstone in the immediate vicinity. Two ways of interpretation are offered for this latter feature: a. the gypsum forms the center of the structural syncline; b. the gypsum was sited in a block that was warped down without resulting tilt.

The difference in appearance between gypsum at site 20 and site 30 opposes the assumption of contemporaneity. The gypsum at site 20 is fibrous and in layers one to two inches thick; gypsum at site 30 is massive, beds are up to eighteen inches thick. The gypsum at site 20 cannot be relied upon as a criterion for the mudstone in which the gypsum is intercalated.If the gypsum is regarded as being younger than the mudstone because it had been,for instance,deposited by circulating waters,it cannot be representative in any way for the lower Rillito member at site 20 and vicinity.

2. The gypsum at site 30 is post-deformational and younger than the lower Rillito member:

Supporting: The horizontal strata of the gypsum at site 30 remind of undisturbed strata of the upper member of the Rillito formation.

If the thin gypsum layers at site 20 are assumed to be equivalent to the mudstone in which they are intercalated,the mineralogic differences between the two gypsum occurrences oppose contemtemporaneity for the following reason:the surface of the gypsum layers at site 20 is uneven and rather wavy,this suggests increase in volume after hydration.Therefore,at site 20 anhydrite possibly was deposited originally.The gypsum(!) at site 30 does not exhibit the typical signs of increase of volume;therefore it can be assumed to be deposited as gypsum,not anhydrite.

Opposing:Although a mudstone facies was not observed in the middle and upper member of the Rillito formation,this may have the following reason:The mudstone facies of the upper members may be present south of the area of study,that is underneath the alluvium of the Tucson valley because the relief during the time of deposition of the two latter members was higher.This change in relief would move the border between purely conglomeratic facies (near the mountain front) and conglomeratic and fine-grained facies (usually more in the valley) to the valley side.

The lower member of the formation is distributed over the whole area of study except for the middle part of the belt:it does not crop out in the region between Sabino Wash and Soldier's Trail.West of Sabino Wash conglomerate and mud-stone are developed equally well,east of Soldier's Trail the conglomerate facies predominates,mudstone being present only near Knagge's ranch and in a dubious occurrence north-east of Bellota Ranch where the mudstone or shale is altered by a volcanic intrusion(p.31).

Lithology of the lower member

Conglomerate

General character

The thickness of the lower Rillito conglomerate cannot be determined exactly as the base is not exposed.The thick-ness is estimated,however,to be at least 1800 feet,inferring from projection of dip along a strip 4500 feet long which is formed by a sequence of rather continuous exposures along washes east of North Campbell avenue.Similar figures were obtained from the area northeast and northwest of Del Powell's ranch,east of Pontotoc road.

The color of the conglomerate is characteristic and commonly purplish red,more rarely gray but always with a touch of red,due probably to a content of iron in the cement.

The material of the conglomerate consists chiefly of roughly sorted gravels of pebble and cobble size.Maximal particle size of around 25 inches was observed near the mountain front at site 37(map in pocket).The roundness of the rock fragments in the conglomerate ranges from .5 to .7 on average. The petrology of the constituents is discussed later.

Stratification appears distinct and is caused by layers of about equal size in diameter of particles or by non-persisting streaks and lenses of sand and granules.It appears that the thickness of individual strata is slightly proportional to the diameter of particles therein.Maximal thickness of individual strata is around 15 inches,the more common thickness is about 10 inches.

The matrix of the conglomerate consists of granules and sand;if the strata are well sorted only little interstitial material is present.The induration is variable, mostly good but often the strata are extremely solidified due to their calcareous cement.The cement is assumed to be more or less contemporaneous with the beds,at least it is not derived from the caliche-forming agents of present times.

Besides studies in the area of distribution (p.37), similar sediments were visited in the vicinity of the highway from Tucson to Benson.Here,in the region of Pantano Wash,conglomerate and mudstone of considerable thickness are exposed.Both types have reddish colors and the conglomerate in particular reminds of the lower member of the Rillito formation.Although the sedimentary particles are different from those in the lower conglomerate of the Rillito formation,the ratio of different rock types is similar to that in the lower Rillito.Near the Pantano railroad station,gypsum layers,one to four inches thick, are intercalated between mudstone.This gypsum occurrence is located some hundred feet east of a roadcut where a block of Paleozoic or older quartzite is interpreted to form a klippe,according to E.D.Wilson(oral communication).

Constituents of the lower conglomerate

Granite

In the histograms(Plate 2),granite particles are expressed by the first column.Except for that type of granite which is associated with the gneissic and pegmatitic rocks of the Santa Catalina Mountains,the granitic fragments are rather uniform.This type of granite is assigned to the "Oracle" granite,a name which has found wide recognition for the area north of Tucson.Granite from the central Catalina mountains does not appear in the lower member of the Rillito formation.

Petrology of the granitic constituents: In a groundmass of feldspar,quartz, and biotite grains up to 2 mm., large phenocrysts of orthoclase are enclosed that show Karlsbad twinning in some places. The size of the orthoclase crystals ranges from 2 to 20 mm., their flesh color determines the overall color of the granite. In some cases, large hornblende crystals darken the appearance of the rock. Thus, the color of the granite constituents ranges between red, white, and green, the latter color being infrequent. The coarse grains evidently favour the weathering observed in many granite constituents.

A comparison of granite particles in the lower conglomerate with various granites of the region suggests that the fragments were largely derived from the Oracle granite, named by Tolman(unpubl.report) after the town of Oracle, about thirty miles north of Tucson. The occurrence of this granite is described by B.N.Moore (unpubl.manuscr.) as follows:

> "The Oracle granite forms the pediment on the north spur of the Santa Catalina Mountains...The granite is part of a very large body which extends south into the Tucson quadrangle,forming much of the country west of Oracle ridge,and extends west under the cover of alluvium to the tip of Tortillita mountains. A tongue extends east into Geesman and Stratton Canyon and large bodies are exposed in Buehman and Bullock Canyon. A large body of gneissose granite crops out south and east of the Youtcy Ranch...Near the Italian Ranch is a small body of Oracle granite. A number of small masses of Oracle granite crop out near the eastern margin of Rillito valley and near Twin Hills."

Moore furthermore mentions that much of the granite is altered by post-Cretaceous injections and that the least altered occurrences are near Oracle,that is in the western part of the entire granite mass.Varieties rich in hornblende occur near Samaniego ridge,in the western part of the Catalina mountains.

Several of the granite constituents of the lower Rillito conglomerate have a gneissic appearance;these were collected in outcrops between Sabino Canyon and North Campbell avenue.They belong probably to the granite variety mentioned by Moore that has been subjected to metamorphism during the injection of the Santa Catalina central plutonic masses in post-Cretaceous time.It should be mentioned that those altered "Oracle" granite constituents are often chloritized and therefore have greenish hues.

The core of the Santa Catalina Mountains consists of fine-grained and light colored granite of post-Cretaceous, probably early Tertiary age.None of the granitic fragments in the lower member corresponds to that younger granite; in upper members of the formation this "Catalina"granite occurs,however,and it will be put into the sixth column together with gneissic and pegmatitic rocks(p.26).

The base level of erosion had probably not reached the central Catalina batholith at the time of the lower member of the Rillito formation.

Limestone

Limestone constituents are the most obvious exotic particles of the Rillito formation.No limestone outcrops are known in the Rillito valley or at the southside of the Catalina mountains .Only two minor exceptions are present, both composed of recrystallized limestone of Cretaceous? age,one being near Bellota Ranch and the other at Twin Hills.Those two outcrops exhibit unfossiliferous limestone which has little similarity to the distinctly Paleozoic limestone fragments rich in fossils which are found in the conglomerate.

A common feature among limestone fragments of the conglomerate is their constant roundness from .5 to .7. Rounding may continue even in situ as shown by limestone pebbles in the conglomerate that were half buried.The half above the surface of the exposure usually exhibited higher roundness than the buried half.Solution by water is assumed to be the cause of this phenomenon,effective particularly under the present climatic conditions. The sphericity of the limestone fragments appears to be rather persistently around .7. In harmony with those observations is the fact that there appears to be a threshhold value in minimal size: hardly any limestone constituents were found to be smaller than one or two inches in diameter.

The following types of limestone fragments were observed in the lower Rillito conglomerate:

a.dark gray limestone:fresh faces appear almost black;very cherty,color of chert is brown and when weathered,black; n o f o s s i l s

b.dark gray and similar to type a. but very f o s s i l i f e r o u s:brachiopods,gastropods,bryozoa.Preservation of fossils is too poor as to permit positive determination. Dr.Stoyanow(oral communication) assumes very tentatively Snyder Hill formation(Permian) as suggested by similarity in lithology and preservation of chert.

c.gray limestone with red stains on fresh and weathered faces;if weathered,the color is conspicuous,a rusty brown. Extremely fossiliferous:corals,brachiopods,echinodermata, and abundance of fish relics.According to Dr.Feth(oral comm.) it may be Pennsylvanian or Permian,as suggested by productidae-like shells.

d.gray limestone,composed of broken and comminuted fossils, especially crinoid stems.Age uncertain,perhaps Escabrosa (Mississippian).

The unfossiliferous type a. may belong to the group mentioned under b. It may be Abrigo limestone(Upper Cambrian) as well which is known also to contain chert in bedded form.

At the present time,Paleozoic limestones are exposed extensively on the northeastern slope of the Santa Catalina

Mountains.In canyons towards the San Pedo valley,thick sections of Devonian,Mississippian,and Pennsylvanian limestone are exposed.No Permian,however,is known from this and other areas of the Catalinas. The possible Permian age of some of the constituents therefore is noteworthy; this would suggest that in the source area of the rock fragments Permian was present.As the more central parts of the Santa Catalina Mountains are assumed to be the source area(see:"Source of the constituents"),a former veneer of Permian strata may have been present in the Catalinas.Other occurrences of Paleozoic limestone,Permian included,are exposed today south of the Rincon Mountains and in the Empire Mountains.North of Tucson,Permian and older Paleozoic limestone formations crop out at Picacho de Calera.Abrigo limestone is known from the Santa Catalina Mountains according to Moore(unpubl.manuscr.).

The implications of the source area are discussed in a later chapter of the present paper.

A unique constituent was collected from an exposure of the lower conglomerate near Bellota Ranch: a boulder of 18 inches in diameter which consisted of limestone pebbles in a limestone matrix.The individual pebbles in this fragment of an older conglomerate are about three inches in diameter and well rounded,the boulder as a whole is extremely solidified. Although most of the pebbles in this boulder are limestones,a few are of chert and quartzite. The origin of this old limestone conglomerate is uncertain. No equivalent rock has been reported from the Santa Catalina Mountains.Only from an area south of Tucson,Box Canyon in the Santa Rita Mountains,Blake(1908,p.50) describes a "conglomerate of limestone pebbles resembling a conglomerate in the Huachuca Mountains" to be situated on top of red shales of probable Cretaceous age.In the Empire Mountains similar deposits are known(Gillingham,unpubl.thesis).

No occurrence of such limestone conglomerate is known from the Santa Catalina Mountains.It is possible that this is due to lack of observation;there are numerous occurrences of Cretaceous? limestone,particularly on the pass from Tucson to Redington. The age of those occurrences was inferred by Moore(unpubl.manuscr.) to be Upper Cretaceous as Benton group fossils have been found in the Rincon valley in beds associated with recrystallized limestone.

Volcanic rocks

Throughout the entire Rillito formation,volcanic rock fragments are the most persistent of all constituents.This is indicated also by their central position on the horizontal scale of the composition diagrams.

Biotite andesite.This rock consists of a gray,dark brown, or sometimes purplish groundmass with tabular white phenocrysts of plagioclase exhibiting albite twinning striae and with black phenocrysts of biotite. Most specimens have no quartz, a few contain it, however. The latter ones have to be classified as dacite. Gradations between andesite and dacite can be observed. While the color of both types may vary, the luster remains rather constantly greasy or similar to ground glass.

The great amount of volcanic rock fragments among the constituents of the conglomerate of all members of the formation indicates that large outcrops of volcanic rocks were present during the time of deposition of the Rillito formation.

The andesite constituents in the Rillito formation must be called "exotic" as no outcrops are known in the Rillito valley. West of the Santa Cruz River, in the vicinity of Tumamoc Hill, andesite covers considerable parts of the surface according to Tolman (1909 b,p.75). Here also the feature of gradation between andesite and dacite is observed (Tolman, 1909 b,p.82).

No occurrences of volcanic rocks are present in the southern parts of the Santa Catalina Mountains. On the northern slope of the range,however, extensive outcrops of andesite are reported by Moore (unpubl.manuscr.),a more schistose facies of the same rock was found by the same author in Peppersauce Canyon, in an area east of Oracle ridge,and high in the Catalinas. In connection with the andesites,Moore(unpubl.manuscr.) makes mention of a particular variety as follows: when the andesite "intrudes the Cretaceous conglomerate,every pebble is surrounded by green andesite as a matrix." Among the constituents of the Rillito conglomerate,andesites are present which have green stained parts and ,as in a few cases, show also clastic characteristics.To these rock fragments,Moore's description quoted above would apply. These greenish varieties are an exception,the common types of andesite are of the colors described above(p.45).

As for the age of the andesite flows and intrusions, Moore(unpubl.manuscr.) assumes it to be Upper Cretaceous and is in agreement with a number of authors on southern Arizona.

Tuff. Pebbles and cobbles of a gray,porous tuff were found only at one exposure,located on the Tanque Verde road,east of the intersection with Soldier's Trail.Phenocrysts include plagioclase and pink orthoclase;both are irregularly arranged.

Recent outcrops of such rocks are known in the Tucson Mountains(Tolman,1909 b,p.81),but nowhere in the Santa Catalinas or their northern spur.

Diabase.Dark green constituents can be observed at exposures near North Campbell avenue.Small laths of plagioclase are enclosed by a green groundmass.Their ophitic arrangement can be observed only on weathered faces where the plagioclase stands out.

Dikes and sills of diabase are known from several areas of the Tucson quadrangle,for instance at the northeastern slope of the Santa Catalina Mountains,according to Moore(unpubl.manuscr.).Moore assumes Cretaceous age for the diabase. It should be noted that there is older diabase known from other parts of Arizona.This diabase (or basalt of some authors) is contained in the Apache group elsewhere,for instance near Globe.No diabase is known from the Santa Catalina Mountains whereever the Apache group is represented.It is assumed therefore that fragments of diabase in the conglomerate are derived from occurrences of Cretaceous? diabase of unknown locality.For a determination of the source area the diabase cannot be employed.

Quartzites

Heterogeneous types of quartzites and vein quartz contained in the Rillito formation are represented by the fourth column in the histograms.As a classification was not possible under field conditions,the height of the column is expressing the total amount of quartz-composed rock fragments. From the mass of those constituents,a few types can be distinguished and are described hereunder.

Redbrown quartzite. The cement of this rock often is dissolved on weathered faces and thus indications of stratification can be observed because the more resistant quartz grains stand out.Fresh faces have a vitreous luster and effervesce with hydrochloric acid.The lack of effervescence on weathered faces is due to the dissolution of the calcitic cement.

Quartzites of various colors,ranging between gray and brown, exhibit sedimentary structures such as stratification and cross-stratification.No statement can be made regarding the probable source rock and its distribution,due to the non-specific character of the fragments.

Pebbles from the Barnes conglomerate. Specimens have been collected that show a different character from all other quartzite constituents found in the Rillito formation. These pebbles and cobbles have both a high and persistent roundness(.8 to .9) and conspicuous and constant shape. In Zingg's classification of shapes(Th.Zingg,1935,as mentioned in:F.J.Pettijohn,1949,p.49),the particles would be designated as rods or rollers because they are elongated, ovoid bodies.

The pebbles and cobbles consist of a solid white to light gray mass of quartzite in which single quartz grains usually cannot be distinguished.

The constant shape and high roundness of the particles is suggestive of the Barnes conglomerate as the source rock, there being no other conglomerate in the whole region with such uniformity in shape of particles.It appears unlikely that the fragments in the Rillito conglomerate obtained their shape and particular roundness during their last transport. The constituents show very convincingly the features of being reworked in a shallow sea as it has been supposed for the Barnes conglomerate particles.

Concerning the paleogeographic distribution of the Barnes conglomerate,emphasis should be laid upon a statement by Stoyanow(1936,p.465) about the occurrence of the Apache group which includes the Barnes;according to this author,the Cambrian rests immediately on Archeozoic Pinal schist in an area limited in the south by the international boundary and in the north by a line drawn from a short distance north of Tucson(probably somewhere in the Catalinas) to the southeast corner of the state.North of that line, Cambrian is resting upon the Apache group including the Barnes conglomerate.Concluding from this statement,the nearest occurrence of Barnes must always have been in an area which is now the central part of the Catalinas.It is legitimate to assume that at no time Barnes conglomerate had been present west and south of the Rillito valley when the formation was formed.

Occurrences of Barnes conglomerate in the Catalinas were mentioned already by Blake(1908) and later by Darton

(1925),the most detailed description is given by Moore (unpubl.manuscr.):

> "the conglomerate which rests upon the Pioneer and corresponds to the Barnes is perhaps the most variable of all formations...In the region northeast of Marble Peak it is a coarse conglomerate of rusty color...it contains small to large cobbles and small boulders of quartzite and chert.Most of the pebbles are well rounded with irregular ellipsoidal to discoidal shapes. ...South of the Mount Lemmon road the thickness of conglomerate continuously decreases until in lower Geesman Canyon it has become a pebbly phase of the Dripping Spring quartzite.Southward of the creek the Barnes is represented merely by a few inches of pebbly sandy shale between the Pioneer and the Dripping Spring and is conformable with both...To the Southeast,in Buehman Canyon most of the cobbles are small to medium size and generally discoidal. The pebbles and small cobbles out of which it is formed are much flattened from squeezing but it retains its rusty color and shows no signs of leaching."

From the foregoing it can be assumed that the particular quartzite fragments are most likely derived from the Barnes conglomerate in which they were contained with almost the same roundness and shape. The indications of pinching out to the southern parts of the mountains agree with Stoyanow's statement(p.50). The Barnes pebbles, therefore,are very significant as for the source area. These pebbles and cobbles must have come from northerly or northeasterly direction before they were deposited as Rillito conglomerate.

<u>Schist and phyllite</u>

The width of variation of its petrological character is remarkable for this group. Many gradations can be observed and any subdivision of the group would be artificial and for field use purposeless. The group as a whole, expressed by the fifth column, is not useful for stratigraphic evaluation because its changes are indistinctive.

It appears that some of the constituents included in this group are derived from Pinal schist; these fragments occur more frequently in the middle member of the Rillito formation, they seem rare in the alluvial fan deposits.

Outcrops of schist and phyllite are distributed all over Southern Arizona; in the area of the Tucson quadrangle they occur especially as part of the metamorphosed complex of the Santa Catalina, Tanque Verde, and Rincon Mountains. Others such as the Archeozoic Pinal schist are also known from the Santa Catalina Mountains and vicinity.

<u>Gneissic-granitic rocks of the Catalina complex</u>

No rock fragments of this group were observed in the lower member of the Rillito formation.

Mudstone deposits

Fine-grained deposits of silt-size are exposed along the sidewalls of Pontotoc Wash and they are estimated to have a thickness in the order of magnitude of two to three hundred feet. Less conspicuous outcrops are in the area north and east of Hazienda del Sol and near North Campbell avenue around site 20.

The color of the mudstone is rather constantly a brownish to purplish red. Sieving tests were run and it was found out that the rock is composed almost exclusively of particles of silt-size,that is smaller than 1/16 mm in diameter. Crushing under the binocular affirmed the writer that the rock is a rather pure siltstone as the few larger grains from the sieving test have to be regarded as compound grains. Despite intensive leaching they could not be dissolved. The content of lime ranges from 28 % to 36 %. The rock is sometimes fissile,more commonly the strata are between 2 and 10 inches thick.

Generally the siltstone is little affected by disturbances. Only at one locality, near Knagge's ranch at the southwestern base of Agua Caliente Hill,it could be found in fault contact with Catalina gneiss. It showed signs of crumpling and moderate mineralization by green stains.Elsewhere in the Tucson valley the mudstone exhibits gently inclined strata,with 15 degrees at the maximum,on average 10 degrees,always directed to the valley side.

In the Bellota Ranch area,less than 200 yards from the nearest outcrop of lower Rillito conglomerate,intrusion by a porphyritic basalt has produced an alteration rock,evidently a former siltstone or shale. Flow structures are exhibited beautifully(Plate 3,B). The assignment of the host rock to the Rillito formation is tentative as Cretaceous? shale could be taken into consideration too.

Gypsum deposits

Two different types of gypsum are present,their mutual relation being uncertain(p.34-37).

At site 20 several gypsum layers one to two inches thick are intercalated between thicker mudstone layers and beds. A number of thin fissures are filled with gypsum too. In both cases the gypsum is fibrous with its elongated axes perpendicular to the bedding plane or fissure plane. The surface of these "planes" is often crumpled and wavy; this might be due to hydration of the evaporite. (Plate 10,A).

At site 30 gypsum beds are thicker than the intercalated mudstone layers. No fibrous gypsum is present except for one or two small fissures in the massive gypsum. Some coaly remnants in the top bed are interpreted as being very young. They may be relics of an Indian site or burnt roots of the time when the ditch now forming the exposure was being dug.(Plate 10,B).

The following section is exposed at site 30:

top:loose wash gravel

	inches
Gray gypsum as a massive bed,broken vertically, some blocks missing and the space being filled with charred wood	12
Siltstone,brown,	7.5
Gypsum,gray	3
" "	3.5
" "	11
Siltstone with gypsum layers;gypsum is solid and iron stained	3.5
Gypsum,gray	3.5
Siltstone with cracks which are filled with translucent crystals of gypsum,little fibrous gypsum	11
Gypsum,gray	8
Siltstone and gypsum,interbedded	12
(base of exposure)	Total:5 feet 5 inches

Northeast of a roadcut of the highway from Tucson to Benson,near the Pantano railroad station,the present author has observed an exposure of fibrous gypsum intercalated with thick mudstone.The gypsum fibres are strongly inclined,otherwise the outcrop is similar to that at site 20 in the Catalina foothills.It is not certain whether the inclination of the fibres is due to tectonic forces or to primary deposition;the first possibility would agree with the fact that a quartzite block exposed in the roadcut is understood as klippe of an overthrust(E.D.Wilson, oral communication).

Mode of deposition

The conditions under which the lower member of the Rillito formation was formed is suggested by the close neighborhood of fine and coarse material and evaporites. Twenhoefel has described this particular environment under the term "piedmont" as follows:

> "The piedmont environment is found over that part of the courses of streams where steep gradients of upland regions pass into the gentler gradients of bordering lowlands.The environment passes gradually into that of the valley flat....Streams flowing across growing piedmont deposits gradually fill and dam the channels in which they flow.Channels are invariably shallow...All variations of clastic sediments dovetail with each other,there is much cut-and-fillstructure."
>
> (Twenhoefel,W.H.,1951,p.69-71)

Clays,lime,silts,and possibly evaporites may be deposited in small basins formed between coarse deposits according to Twenhoefel (1951,p.71). Climatic conditions play certainly an important role particularly in regard to evaporites. The distinct stratification of the lower Rillito member suggests that streams carried more water than today where the alluvial deposits have less distinct stratification due to the intermittent type of deposition;turbulence of recent flows may add to that effect.

The fact that in recent alluvial deposits of the area no basins are observed of the type Twenhoefel mentions, is interpreted as being due to the boldness of the mountain fronts today. It can be inferred that only a moderately high relief was present during lower Rillito time.Elsewhere in this paper,indications are presented that suggest that the constituents of the Rillito formation derived from an area north or northeast of the Rillito valley.

<u>Structure of the lower member of the Rillito formation.</u> <u>Inclination of the strata</u> is found wherever the lower member is exposed. Generally the dip is steepest near the mountain front of the Catalinas and it decreases towards the Tucson valley. Steep inclination was observed around site 37 (up to 50° north and south), east of Pontotoc road(30° to 40° south) as shown on Plate 4, B, and near Loma Verde mine (around 20°) as shown on Figure 3 ; the foregoing statements concern the conglomerate facies. The dip is generally south with variations between southwest and southeast. Exceptional dip was observed near site 37 where in places near the mountain front the dip of the conglomerate is north with about 50°. In a distance of two or three miles from the mountain front the dip of the conglomerate is up to 25°, more commonly being around 20°.

The siltstone deposits lie in some distance from the present mountain front and their dip hardly exceeds 15°, it is in most places 10°. Strong inclination of the siltstone is near Knagge's ranch at a locality about 400 yards southeast of a small concrete tower belonging to Agua Caliente Ranch. Here the siltstone dips 30° to 40° east; nearer to the base of Agua Caliente Hill an altered facies of the same rock is exposed. The inclination of this latter crumpled and green stained siltstone cannot be measured due to indistinctive stratification.

The cause of the inclination is seen in tectonic movements rather than in initial dip during the deposition. Although undisturbed strata are known to exhibit primary dips of the degree found in the lower member (Lahee,F.H., 1941,p.66),this explanation cannot be applied to the lower member conglomerate for the following reasons.a.The exceptionally steep dip limited to the mountain front evidences strong movements.b.The inclination of the mudstone around site 20 (25° SW) is hard to understand as being due only to primary dip.c.The steep inclination(25° N and S) persists over several miles in the foothills and also disproves the idea of primary dip as the only cause.

Within a limited region,as for instance between site 20 and site 15 (map in pocket),the conglomerate shows a certain uniformity in dip as far as the direction is concerned and slow gradual change in degree of it.This is true for other sections as well and probably due to deformation:blocks in the order of magnitude from a half to several miles reacted differently to deformation.

Faulting. Little positive statements can be made about displacement and direction of stress because the few faults observed in the area between Campbell avenue and Pontotoc road and east of the latter are poorly exposed.Furthermore,identification of a stratum over any distance is

Figure 3. Near Loma Verde mines: Lower member conglomerate in contact with porphyritic basalt

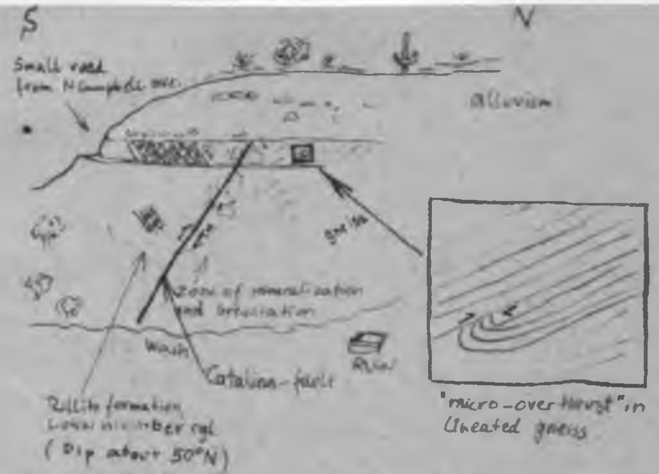

Figure 4. Exposure of Catalina fault near N Campbell avenue

extremely difficult if not impossible in the conglomerate.

At a wash bank exposure near Loma Verde mine, the lower member conglomerate is in fault contact with a porphyritic basalt, the latter forming the footwall (Fig. 3). The strata of the conglomerate on the hanging wall are turned up steeply. It can be inferred that the basalt was moved up in respect to the conglomerate.

The Catalina fault. Along the southern base of the Santa Catalina Mountains in a few places a fault is exposed which determines the contour of the mountain range here. Larger implications of this structure will be discussed later (p. 85); here field evidence of the fault and its relation to the lower Rillito member is treated only.

An arroyo has exposed a thick section of lower member conglomerate around site 37, east of North Campbell avenue. The conglomerate is in fault contact with gneiss of the Santa Catalina Mountains along a WNW striking fault which dips 30° to 40° south. Between the conglomerate on the hanging wall and the gneiss, a several feet wide zone of mineralization can be observed (Fig. 4) because of its conspicuous red and green colors. The breccia zone is poorly exposed due to alluvial cover.

The following field evidence suggests a reverse fault with the conglomerate in the hanging wall being thrust upon the gneiss or the gneiss thrust under the conglomerate.

Small structures in the footwall of the fault are visible due to the banding of the gneiss.These "Micro-overthrusts" (Fig. 4) suggest the direction of the movement.Furthermore,the fact that the conglomerate on the hanging wall dips to the fault is also suggestive of a reverse movement. While farther south,between site 35 and site 19,the conglomerate dips south,closer to the fault,around site 31 and site 37, the conglomerate has a dip up to 50° north. Thus,it appears like a drag although such a feature is not considered as conclusive evidence for the direction of the blocks.

Further indications for the Catalina fault are near an abandoned wooden hut,west of the mouth of Ventana Canyon. No exposures of the border fault are present until it reaches the eastern end of the base.Thus the easternmost exposure is located near the base of Agua Caliente Hill where mudstone deposits are bordering on gneiss;indications found(p.53) suggest a fault.

Middle member

General statement

Only conglomerate is known of the middle member of the Rillito formation.Whether other rocks,for instance siltstone and evaporites were formed during that time, cannot be stated.It is possible that the fine-grained rocks were deposited in some distance from the former mountains, thus, siltstone of the middle and upper member may be hidden under the thick alluvial blanket of the Tucson valley. This seems not impossible because changes in relief after deposition of the lower member are assumed to have steepened the gradient of the rivers. Another possibility is that some of the siltstone assigned to the lower member, actually belong to the middle or upper one. As no interfingering conglomerate was found, some isolated exposures of siltstone were assigned to the lower member for reasons of analogy.

Relation to older rocks. Middle member conglomerate rests upon siltstone of the lower member in the area between Hazienda del Sol and Pontotoc Wash. An interesting outcrop is located some hundred feet east of the gardener house of the Grace estate, south of Hazienda del Sol. Here beds of siltstone are flexed up to the north. This phenomenon may be either structural or due to deposition on a delta foreset which was strongly inclined. On this steep surface strata of the middle conglomerate were deposited and as they naturally follow the former surface, the bottom parts in particular seem to be flexed too. This irregularity of the middle conglomerate is fading out gradually to the top and to the side.

Another indication of the relative age of the middle member is shown on Plate5,A :a small boulder of lower conglomerate was found in the middle member.

It can be assumed tentatively that the middle member was deposited upon an erosional surface, partly formed by the lower member of the formation. Diastrophism took place during that interval because the middle member is less inclined; see p. 90 for other indications.

Facies and distribution. Conglomerate of the middle member crops out extensively in the area between Soldier's Trail and Sabino Wash, less frequently west of Sabino Wash.

Lithology

Conglomerate

General character

Gneiss content is the criterion on which the middle member was separated from the lower one. From the upper member, which has a similar composition, the middle member can be distinguished because it shows faulting and tilt while the upper member is undisturbed.

It appears that there are two kinds of conglomerate of similar composition present in the middle member. One is gray and hard while the other is more similar to the lower member conglomerate. At an exposure near the Grace estate gardener house the thickness of the gray conglomerate is estimated at around 150 feet; it forms a narrow zone, about 500 feet wide, which runs more or less parallel to the mountain base for three quarters of a mile.

The gray conglomerate consists of pebbles and cobbles, lenses or interlayers of fine-grained material are conspicuously rare. The induration is considerable;where washes cut into the region of outcrop of the gray conglomerate,the wash beds become narrow and the side walls higher. Although the gray conglomerate never looses a red touch,it has a somewhat dirty color in comparison with the other conglomerate of the member.

The other conglomerate, of unknown relation to the gray one, corresponds rather closely to the conglomerate of the lower member as far as stratification,sorting, particle size and color are concerned. The color,however, often lacks the striking touch of purple which is so conspicuous for the lower member. The mass of exposures of the middle member belong to this type,for instance in the region between Sabino Wash and Soldier's Trail. Any estimation of thickness must be tentative as the dip is changing over short distances and numerous faults in addition would make a computation uncertain. The present author believes that 500 feet are a minimum to be assumed.

Constituents of the middle member conglomerate

Granite

Granite of the Oracle-type has decreased to form constituents,this being expressed by the length of the first column:it is shorter than in the lower member of the Rillito formation.

Limestone

Appearingly the same types of fragments as in the lower member;percentage has decreased.

Volcanic rocks

The bulk of the volcanic rocks are of the same types as described under the lower member. Additionally two new (?) kinds of volcanic rocks appear.

Latite. The phenocrysts are white plagioclase and reddish orthoclase.They are in a purplish goundmass.Only one specimen of this type was found (site 51)

Porphyritic basalt. Two pebbles of porphyritic basalt were collected at site 51.The groundmass is dark and in it lighter phenocrysts are arranged in a manner reminding of a porphyritic basalt found near Twin Hills and Loma Verde mine. The length of the plagioclase crystals is about 20 mm.

Quartzite

No change.

Schist and phyllite

One particular rock of this group is conspicuous because of its high fissility.It shows folds and injections suggesting strong metamorphosis.The green color of the rock is distinct and Pinal Schist is assumed to be the source rock.Near the mountain base these particles reach the size of 12 inches in diameter.

Gneissic "Catalina" rocks

Rock fragments assigned to the Santa Catalina Mountains gneissic and granitic complex make their first appearance.The most common constituent of this group found in the middle member is a light gray rock that resembles an aplite rather than a granite. Numerous small garnets are conspicuous besides common minerals such as quartz, orthoclase,plagioclase ,and biotite. The rock may be coarse grained and exhibit some signs of metamorphosis,in this case it would be called a sheared granite.

An abbreviated description of the rocks of the Santa Catalina complex was found in a paper being an abstract of the results of geologic investigation in the Tucson quadrangle(B.S.Butler,R.N.Hernon,B.N.Moore,unpubl.manuscr., see"Bibliography").According to these authors,two main types may be distinguished,one being gneissic,the other being granitic.The gneissic rocks are subdivided into two varieties:one is medium coarse-grained,resembling a <u>sheared granite</u>,the other is an <u>augen gneiss</u> with crushed porphyroblasts of feldspar that are in places several inches in length, surrounded by fine-grained material rich in biotite.In lighter colored facies the biotite is replaced by feldspar and quartz. The <u>granitic rock</u>,according to the same authors, is a light gray rock varying in texture from fine to coarse in different areas and being in general of simple composition.Conspicuous is the presence of small red crystals of garnet.The authors state that in the hand specimen the rock has a typical granitic texture,in larger fresh outcrops,however,such as on road cuts,the granite has a distinct gneissic appearance.Transition from the obscure gneissic texture to the strongly foliated gneiss is reported from the outer portions of the complex.

Rock fragments in the middle conglomerate differ in their composition from the alluvial fan deposits in so far as no fragment of the augen gneiss type has been found.

A boulder of lower Rillito conglomerate

Near site 40 a boulder 35 inches in diameter was found in the middle conglomerate(Plate 5,A).By its composition it was determined to be a fragment of the lower Rillito conglomerate.

Mode of deposition

Similarity in sorting,rounding,color,and stratification suggests that the middle member was deposited under approximately the same conditions as the lower member. The relief probably had become higher as indicated by the increase in maximal size of particles.It can be assumed that it was still moderate in comparison to the present relief as the maximal sizes in the middle member compare with maximal sizes in recent alluvial fans as 1:3 .The climate must have been more humid than today because stratification is distinct in the lower and middle member.An example of channel cutting is shown in Plate 5,B.

Structure of the middle member

Inclination of the strata in the middle member is less pronounced than in the lower member. In a few places, however, the dip reaches over 60° E, for instance near Pontotoc mine. Here a limited region near the mountain base shows gradual change in dip. From over 60°E at the northernmost exposure (site 1,2) the dip decreases to 40° E (site 3) and 15° E (site 5) over a distance of 2500 feet southward. In the foothills the dip is around 5° to 10° south or southeast. Nowhere the dip of the middle member is directed to the mountains (as it can be observed in the lower member); it varies between east, south, and southwest, always directed away from the mountain base.

Faulting. Many faults are exposed in the middle member, all being of the normal type. No case of crumpling or other signs of compression are present in the middle member. The faults strike subparallel to the present mountain base; no case was observed where they lie at a right angle to it.

Several faults are exposed along Mount Lemmon Highway between Rillito Wash and the mountain base. In a few cases the southwall was thrown down, in most cases, however, the displacement could not be determined. Correlation of beds across the fault is usually uncertain, the reason being the difficulty to identify a stratum even over a short distance.

Generally the faults in the middle conglomerate suggest tension. Such indications are seen in a graben (Pl.6,B) and in several Y-shaped branching faults (Pl. 6,A; Pl.7,A).

Greatest vertical displacement can be observed at site 73b,north of Hazienda del Sol.Mudstone of the lower(?)member is thrown up against conglomerate of the middle member forming the hanging wall.The faultplane dips northeast. The displacement is assumed to be greater than 30 feet. In this case,the upthrown wall is the southern one.

Regardless the fact whether the southern or northern walls of faults have been thrown up more often,the impression of normal faulting due to tension is rather positive. It is assumed that the respective movements were incidental to diastrophism of the mountain block .This is supported by the fact that tilting and faulting - the latter one is not proven statistically - are strongest near the mountain front of the Santa Catalinas.

Upper member

General statement

Conglomerate is the only rock type of the upper member.It overlies the middle conglomerate(gray conglomerate) at two localities.At site 76 it rests upon the gray bank with what appears to be a slight angular unconformity;While the middle member dips 20° SW,the upper member dips only

10° to 15° southwest. A similar situation is present west of Sabino Canyon road(site 73 upper member,site 72 middle member). Here the upper member forms a conspicuous hill with a steep northeastern wall due to the dissection by a wash which heads in Ventana Canyon. Middle conglomerate of the "gray-bank" type crops out extensively in the immediate vicinity(site 72) southeast of the hill. Although the contact between the two members could not be found, analogy to site 76 is suggested by the situation.

Little of the upper conglomerate is exposed in the whole area,more occurrences,however,are assumed to be hidden under a thin veneer of alluvium in hills and mounds of the area around Sabino Creek and road.Great parts of the upper member were eroded thus having exposed the lower members of the Rillito formation.

<u>Lithology of the conglomerate</u>

Two chief features distinguish the upper member conglomerate from the middle one: the absence of limestone and the lack of faults and strong dips. Most of the inclination can be assumed to be primary;perhaps less conspicuous movements of the blocks have played a certain role too.

The thickness exposed west of Sabino road is about 150 feet. Great parts of the outcrop may be designated as a sandy conglomerate because sandy and granular layers prevail. Cobbles of Catalina gneiss can be observed interspersed in medium-and fine- grained material;their size being about 6 to 12 inches.

The color of the conglomerate is brown and gray with little red. Fine-grained layers are commonly brown. Within such layers mica flakes can be observed in places to be abundant. The particle size of the finer layers and lenses exceeds 1/16 of a millimeter; mudstone of the lower member is composed of particles smaller than 1/16 of a millimeter in diameter,as mentioned above(p.53). It may be assumed that no basins of the kind wherein the lower member mudstone was deposited, have been present in this area during upper Rillito time.

Although the conglomerate at site 76 is less sandy than that at site 73,both rocks correspond very closely as far as other characters are concerned,for instance,color, composition, and structure. Stratification is equally poor in both exposures. Thus, the upper member conglomerate is apt to be confused with recent or sub-recent alluvial fans if composition is not considered.

<u>Composition.</u> Oracle granite fragments are very rare and can be found only after some searching over the whole exposure. Limestone fragments are absent. Volcanic rocks form a major part of the constituents,the types being unchanged. As usual the quartzite and schist-phyllite group form a moderate part of the particles. Rock fragments of the sixth column have increased in number, particularly gneissic rocks are conspicuous. Pebbles and cobbles of white or light gray granite with small garnets are still common but less frequent

than the distinctly gneissic types. Porphyroblasts,so commonly found in gneissic rocks of the constituents of alluvial fans,seem to be missing.

The distribution of particle sizes is noteworthy. The bulk of fragments above 6 to 10 inches in diameter is comprised of Catalina gneiss;only about 10 % of these larger particles are composed of volcanic rocks and dark quartzite.The roundness of the gneissic constituents is lower than that of the other rock types.

Structure

No signs of deformation are present at exposures of the upper member.The dip is very gentle and only over short distances at site 73 it may reach as much as 25°east. (See p. 69).

The source of the constituents of the Rillito formation

Besides rock fragments derived from known outcrops, for instance the Catalina gneiss,the Rillito formation contains"exotic"(p.27) particles of an unknown source area. In absence of any direct way to determine the source area of these exotic constituents,their site of derival must be inferred from other data. In cases of obscure source area several methods have been applied by different authors and some successful solutions have been achieved by one or the other method.

As for the Rillito formation,it is attempted to determine the source area by interpretation of a number of features exhibited by the conglomerate.These features may be divided into two groups: a.Some data are resulting from mechanical action during transport and deposition. b.Other features to be interpreted are comprised of petrologic properties of the constituents.

a. Interpretation of data which are due to mechanical action.

Roundness. In a conglomerate of wide horizontal distribution measurements of roundness of particles may show that the roundness increases or decreases in a certain lateral direction. If this method can be done with sufficient statistical ampleness,the direction of transport may become evident because the roundness of the constituents is a function of, among others,the length of transport. A particle farther away from its source is apt to exhibit a higher degree of roundness than one found near the source area. A better way than taking fragments of different rock types,would be to pick out members of a certain petrologic group which thus would have probably the same resistance to wear.

Measurements of roundness were undertaken whenever pebble counts were done. The difference in roundness is small and does not exhibit a recognizable trend within anyone member. Volcanic rock fragments were used as the representative rock type and given special attention.

In the whole area of distribution of the conglomerate no change was observed. The following interpretation is offered. The area of study has the shape of a narrow belt of east-west trend. If no change could be observed in east-west direction over about 12 miles, this suggests that no streams have flowed in easterly or westerly direction.
In north-south direction the belt measures about 6 miles, determination is possible only over four miles due to lack of outcrops in one or the other section. This short distance makes it appear unlikely that a change in degree of roundness could have been observed if the depositing streams during Rillito time were actually flowing north or south. Thus,the second possibility remains undisproved. It is open,

however,whether the material came from either north or south. A derival from a source east or west of the area of study is not impossible as streams may have changed their direction in the lower courses.

Particle size. The particle size is a function of the power of the transporting agent. This power usually decreases with length of transport because it depends on the angle of slope besides other factors,for instance climatic ones. Thus,"the size is in some way an index to the proximity of the source"(Pettijohn,F.J.,1949,p.9).Application of this method would have to deal either with the median diameter or with the maximal diameter of the sedimentary particles (Krumbein,W.C.,1939,pp.559-591).

The constituents of the Rillito conglomerate show a wide variation in particle size,ranging between boulders and clay in the matrix.Lack of time forbade determination of the median diameter.Therefore,only maximal sizes have been determined and this method has,as the author believes, produced relatively fair results.

Measurements along a south-north running strip over two miles evidence an increase in diameter from 15 inches (site 15) to 21 inches(site 37).The measurements are distributed over 6 exposures with an interruption by a siltstone lense.These figures concern occurrences of the lower member conglomerate;the increase in maximal diameter towards the northern end is not very conspicuous. Studies in the middle conglomerate were yielding the following results. From 9 inches (site 78) up to 30 inches(site 2),this south-north running sequence shows a similar trend although more pronounced than the lower member.

It is obvious that results such as these have to be considered with some reservation because of a number of unknown factors(difference in stratigraphic position of beds compared,climatic changes during deposition of strata such as rainy season,freezing which produced uncommon great amount of debris etc.). It should be added that comparison of figures in east-west direction did not show any noteworthy changes in maximal sizes. Thus,it can be tentatively assumed that the source was somewhere between northwest and northeast of the present site of the constituents.

The size increase in the lower member is relatively smaller than in the middle member. This is probably not by chance as it is accompanied by other important changes, for instance in composition and structure. Steeper angle of slope during transport of the middle member does not appear unlikely therefore.

<u>Imbrication.</u> In a fluviatile environment such as this,the imbrication is always directed in stream direction. Thus, the source may be detected by tracing back the ancient

drainage pattern.

Wherever imbrication is present in the Rillito formation,it suggests that the depositing streams came from northwest,north,or northeast.

Cross-stratification. Indications of cross-stratification are too vague as to permit interpretation.

b.Interpretation of petrology of constituents

Discussing the sedimentary properties was done in order to find directions.Such direction would be instrumental in the locating of the site of derival of the constituents of the Rillito conglomerate. Petrologic data, being discussed in this section,must be interpreted in an entirely different way. Essentially,it will be attempted to correlate the rock fragments of the Rillito formation with their source by inferment from recent outcrops of the particular rock types.

The handicaps of this method are obvious.The former outcrops may have been destroyed by erosion etc. and recent outcrops of that rock type may be located elsewhere,thus misleading the investigator.

The constituents of the Rillito conglomerate are discussed in the same order in which they are arranged in the histograms.

Granite of the Oracle-type is known from areas north,northeast,and east of the site of the formation (p.40).

Limestone particles are not significant for the location of the source because outcrops of the types mentioned(p.43) are known from all directions in respect to the area of distribution of the Rillito formation.

The specimens of questionable Permian age, based on their resemblance to Snyder Hill limestone, are implying that Permian was developed in the source area. If it is agreed the source area of all constituents being in the North or Northeast and that the questionable limestone fragments are really Permian, this formation must have been present north or northeast of Tucson. However, authors who worked in that particular region, especially on the north-eastern slope of the Santa Catalina Mountains have never found Permian in situ (Dr.Stoyanow, oral communication). It appears appropriate, therefore, to consider the possibility that once Permian strata were represented in the area what is now the Santa Catalina Mountains or north or north-east of it.

Volcanic rocks. Today such rocks are distributed all over the Tucson quadrangle and outside of it. A few less common kinds among the volcanic rocks such as meta-dacite and the volcanic agglomerate of green color(p.47) suggest that the source had been sited north. Identification of these uncommon volcanic rocks is extremely doubtful. It will be shown, however, that occurrence of volcanic rock fragments in the

Rillito formation and absence of recent outcrops of volcanic rocks in situ in the area of the Santa Catalina Mountains is not contradictory to the assumption that the source area had been somewhere north or northeast of the Rillito valley. There are indications of volcanic activity in the Santa Catalinas however slight they may be(p.82).

Quartzite constituents are insignificant except for the pebbles and cobbles derived from the Barnes conglomerate. This Pre-Cambrian conglomerate has a distinctly limited distribution according to Stoyanow(1936,p.465) and Moore (unpubl.manuscr.).If despite scarceness of outcrops in Southern Arizona these authors can be relied upon,the paleogeography of the Barnes is highly suggestive of the particular fragments having been derived from a source in the North or Northeast.

Gneissic rocks and granitic rocks of the Santa Catalina complex appear late in the sequence of the constituents. As some are represented already in the middle member of the Rillito formation,it seems legitimate to assume that during that time parts of the Santa Catalina complex contributed fragments to the conglomerate.

As gneissic rock fragments of the Catalina complex are conspicuously outnumbering the granitic variety in the upper member(in the middle member gneissic fragments were practically missing),diastrophism may be assumed to have changed the topography after deposition of the middle member. The present author believes that a broad zone along the southern front of the Santa Catalinas must have been subjected to such changes then, secondary uplift not being impossible. Thus, granite was prevented to be washed into the southern valley.

Conclusions

Data gained by comparisons of maximal sizes as well as of roundness are too vague as to permit certain conclusions. Only imbrication provides fairly reliable information suggesting that the depositing streams came from north, northwest, or northeast.

Several rock types among the constituents have their outcrops only in areas north, northwest, and northeast of the foothills. Although this is suggesting approximately the same area as gained by evaluation of sedimentary features, it is not conclusive evidence. Strong indications are provided by peculiar fragments assigned to the Barnes conglomerate because of the limited occurrence of the Barnes conglomerate. This again indicates a source in the north.

In the upper member of the formation fragments of the Barnes have not been seen. Rock fragments derived from the Santa Catalina gneissic and granitic complex play already an important role. They must be considered as another strong evidence for a northern site of the source area as it is unlikely that gneissic rocks of the Catalina type could have come from southern areas.

The fact is noteworthy that the changes in composition follow a definite trend: step by step rock fragments expressed by columns on the left side of the histograms (Plate 2) decrease until they have almost disappeared in the upper member of the Rillito formation. The ultimate step in this sequence is seen in the composition of the alluvial deposits of the bajada; they are composed almost entirely of gneissic-granitic rocks. As the source area of the alluvial fanglomerates is determined by the headwaters of the particular washes and creeks in the Santa Catalina Mountains, there seems to be no obstacle to the assumption that the upper and middle member conglomerate are composed of rock fragments derived from areas adjacent or corresponding to the Santa Catalina Mountains.

Furthermore,as the constituents of the two upper members contain a number of types of which the lower member is composed exclusively,it may be inferred that the constituents of the lower member essentially are derived from about the same area. This area either was bordering on the gneissic-granitic complex of the Catalinas or the particular rocks were on top of the gneiss complex.

In conclusion it may be stated that the three members of the Rillito formation record the gradual erosion of a positive area by their changing composition. This source area is assumed to coincide locally with the Santa Catalina Mountains. Probably the source area was limited to the central or northern parts of the range in early Rillito time.

The only feature remaining problematical is the sudden disappearance of volcanic particles after deposition of the upper member; in the alluvial fan deposits of the bajada no volcanic fragments are present.

Rillito formation and volcanism

Fragments of volcanic rocks form a major part, from 20% to 40%, of the conglomerates of the Rillito formation. Therefore, volcanic activity producing andesite,dacite,and gradations between them,must have preceded the deposition of the Rillito formation. No volcanic rocks corresponding to those are known from the Santa Catalina Mountains,the inferred source area. Only on their northern spur,beyond the Tucson quadrangle,Moore(unpubl.manuscr.) observed volcanic rocks of the types mentioned. Thus,the question is raised how far to the South those volcanic rocks may have extended at the time when the Rillito formation was being formed.

Some information may be obtained from the constituents by their maximal sizes. Scattered specimens exhibit a maximal size of about two and a half feet. Due to their agglomeratic character these large constituents do not appear to be very resistant to long transport. The present author estimates that the length of transport did not exceed five miles.

Valuable information about volcanic activity in the region of the gneiss complex is obtained from Moore (unpubl. manuscr.).The author found some pipes of porphyritic rhyolite on the northern edge of the Tucson quadrangle and pipes of"porphyritic lava similar to that of Sentinel Hill" on Buehman Creek also near the northern edge of the quadrangle. It is noteworthy that by comparison with the lava of Sentinel Hill the present author would assign the porphyritic basalt of Twin Hills and Bellota Ranch to the same group. Also in gneiss Moore found a dike of porphyry on the southside of the Tanque Verde Mountains at an altitude of 4500 feet. All the above mentioned occurences are regarded as being younger than the gneiss. South of Spud Rock Ranger Station at an altitude of 5400 feet,however,Moore found an outcrop of a volcanic rock that he regarded as a part of the host rock and therefore being older than the gneiss.He assumes a relation in age to the Cretaceous andesites.

Porphyritic basalt was observed by the present author northeast of Bellota Ranch in the immediate vicinity of lower Rillito conglomerate.Besides this direct evidence, volcanism in the southern parts of the Santa Catalina Mountains is suggested by a small boulder 20 inches in diameter which was found on the gneiss pediment several hundred yards east of site 37. The location makes it appear unlikely that the rock derived from any other place than from the gneiss complex. The specimen consists of a matrix with flow structures enclosing angular fragments of the same material that is a reddish groundmass with small feldspars. The fragments in the block show some variation in color and texture. The specimen reminds of a flow breccia or a pipe fill.This find is considered as an indication that pipes are present also in the southwestern parts of the Catalinas,a section from which no pipes have been reported by Moore. This lack of observation is probably due to the inaccessibility of this region.Thus former outcrops of volcanic rocks- as indicated by the pipes - may be assumed to have extended well into the southwestern parts of the mountain range. The volcanic flows and intrusions on top of the gneiss complex have vanished by erosion as recorded by the composition of the Rillito formation.

By their relative age,the volcanic rocks of the area may be divided into two groups. As predating the deposition of the Rillito formation must be regarded the andesite and dacite because their fragments are present in the lower member of the Rillito formation.These rock fragments have the longest range of all constituents and they last until the upper member of the Rillito formation. The age of the andesite flows is inferred by Moore(unpubl.manuscr.) from other areas of Arizona as to be Upper Cretaceous. In the Tucson Mountains W.H.Brown has carried out extensivesstudies and he assignes some andesites to the Lower Cretaceous and occurrences of diopside andesite and rhyolite to the Lower Tertiary.

The age of the porphyritic lavas is less certain. They were assumed to be intercalated with sedimentary series of the"Pantano formation" by Moore(unpubl.manuscr.). Although the situation near Bellota Ranch needs further studies,it is believed that the porphyritic basalt at this locality is younger than the lower member of the Rillito formation. While no fragments of porphyritic basalt have been found in the lower member,two pieces of it were collected in the middle member(site 51,p.64).Therefore it may be concluded tentatively that the porphyritic basalt,in part at least, has been formed after deposition of the lower and before deposition of the middle member of the Rillito formation.

Structural implications

A synopsis of structural features is presented in this chapter as obtained by interpretation of the writer's field evidence and information from other workers.

The Catalina fault,the most eminent structural feature, cuts off the Santa Catalina Mountains on their southern front and is the clue to the structural history of the whole area. Although some observations are in favour of a reverse fault, for instance near North Campbell avenue(pp.59-60), several movements on it are suggestive.

West of Sabino Canyon the Catalina fault strikes WNW. Between Sabino Canyon and Agua Caliente Hill the fault is not exposed but morphology indicates that it runs parallel to the more westerly part, however, it seems displaced by one half to three quarters of a mile to the south. An aerial photograph taken in direction of the fault shows the assumed offset quite clearly (Plate 11). At the southern base of Agua Caliente Hill the fault is poorly exposed and here also WNW strike is suggestive. Thus, another offset of even greater extent may be assumed along the western base of Agua Caliente Hill. On a larger scale,the western and southern base of the Tanque Verde Mountains remind of Agua Caliente Hill.

By two dividing lines,laid in about NS direction along the assumed offsets over the southern bajada of the Catalinas, this bajada may be divided into three sections I,II, and III as shown in Fig.5. On Plate 11 only section I and II are visible.

Figure 5. Structural sketch of the southern front of the Santa Catalina Mountains.

Section I is covered by a thick blanket of (now partly dissected) alluvium;from the middle section(II) the thick alluvial cover is absent and the middle member of the Rillito formation forms larger parts of the surface. In section III finally,older rocks crop out for instance at Twin Hills, Loma Verde mines and farther south,Saguaro National Park. If these differences in geomorphology can be related with structural changes,the respective movements must have occurred rather late in the structural history of the area.

The offset near Sabino Canyon seems to be expressed in another feature visible on Plate 11. The lineation of the gneiss,probably due to bedding of the host rock, gives the impression of dipping steeper to the valley in the region bordering on section I than in the region at section II, the dividing line being again around Sabino Canyon. Such feature would be suggestive of a fault trending in direction of the assumed offset and thus separating the differently dipping gneiss sections. At the same time,the western end of the mountain base seems to dip under the basin with a remarkably steep angle. Both features mentioned should be understood very tentatively as it cannot be stated whether they are not merely due to perspective distortion.

Although there are some indications for reverse or thrust movements along the Catalina fault(p.60),at least at one time the uplift of the range must have taken place along this fault as the author believes.Gilbert's argument was brought forth by Davis already(Davis,W.M.,1931,p.290) that it is inconceivable that a much larger mass,initially extending southward well into the present valley,could have eroded back to so simple a base line as is here seen.Thus several movements on the Catalina fault are suggestive.The important question which came first,reverse or normal(that is uplifting)movement,cannot be answered readily.

Moore(unpubl.manuscr.) assumed that overthrusting had preceded uplifting in the region. His idea seems to be based upon the fact that remnants of what he considers an overthrust block (with lower Rillito member) lie at an elevation of 4000 feet above sea level near Bellota Ranch. The elevation of the block probably is assigned by him to be due to the fact that both thrust block and mountains were lifted up in later periods.

The following observations were made by the present author in this particular area. Heavy deformation is not confined to a"breccia zone"[1/] which by the way could not be observed probably due to brevity of investigation.The shattered state of fragments in the lower member of the Rillito formation would agree with that part of Moore's statement. But there are other indications of tectonic activity,especially of tension,which could account for some of the features of deformation. Thus,a number of outcrops of volcanic rocks being composed at least in part of porphyritic basalt form a more or less continuous strip. Although only small parts of it are exposed,a NE striking dike is suggested by the conspicuous line visible on the aerial photograph(Plate 9.). Future field work as it should be repeated appears necessary to clarify the situation. Parallel to the dike(?) the gneissic rocks of the Santa Catalina complex exhibit an extremely striking system of parallel joints (Plate 9.),called "chimney

1/Moore(unpubl.manuscr.)states:"The western end of this block is limestone,the eastern end Pantano and both formations are thrust upon the gneiss as shown by a breccia zone" rocks" by ranchers of the area(Plate 4,A). A study of the lineation could not be undertaken but is expected to give clues as for the direction of stress. The dike(?) and even more tentatively speaking,the joints are suggesting tension rather than compression.

Without discarding Moore's idea of overthrusting, the following possibility should be taken into consideration besides it until further evidence is secured:The lower Rillito conglomerate was forming a wide blanket over an irregular but moderate relief when blockfaulting took place and the Santa Catalinas or parts of them were lifted up. Contemporaneously with this movement or later than it,tension was present and along NE striking faults(possibly confining the Bellota plain today) a graben was thrown down thus preserving parts of the old sedimentary blanket. The present author is aware that there is an obstacle to this explanation in the fact that Rillito beds at Bellota are resting upon gneiss.

Davis(1931) also assumes two different movements basing his argumentation on geomorphologic data only. The first movement according to this author was an uplift of the southside by 6-8000 feet and by much less on the northside of the range. The amount of vertical displacement is inferred by Davis by projection of an old (Oracle-)granite peneplain on top of Samaniego ridge suggesting that the near the fault in the south the mountain block was raised 6-8000 feet(Davis,W.M., 1931,p.291). A second movement is assumed to have resulted in a minor upbending of the northwestern part of the range by about 1000 feet and in a downwarping of the southwestern areas indicated by the inclination of the surface of a young pediment along the western base of the Santa Catalina Mountains(Davis,W.M.,1931,p.295). This younger movement may be corresponding to what has caused the steep inclination of the gneiss lineation in the western end of the southern base and other late features in the history of the mountains and their bajada mentioned above.

The following attempt to correlate field observations with larger structural features should be understood very tentatively.After a period of moderate relief and quietude as recorded by conglomerate and mudstone of the lower member, considerable deformation took place:signs of crumpling and synclinal dip in the lower conglomerate east of Campbell avenue suggest compressional forces. Another indication of diastrophism must be seen in the conspicuous change of composition after thee deposition of the lower member:Fragments derived probably from the central granitic body(not Oracle) of the Catalinas appear in the middle conglomerate. At least the central part of the mass of intrusive and injection rocks had become exposed to erosion then;gneissic parts seem to be still absent from the middle member.Thus,it may be inferred that an uplift to be assumed for that time had been restricted more or less to the granitic,that is the central part of the Santa Catalina Mountains.The gneiss on the southside of the range was probably not exposed. Finally,volcanic activity producing porphyritic lavas may be assigned to that interval.

For a second time,deformation must have been active after the deposition of the middle member of the Rillito formation. No indications of compression are observed in the middle conglomerate;tear faults in the latter are indicative of tension due probably to considerable uplift of the mountain block thereafter.In the upper member of the Rillito formation more distinctly gneissic fragments start. Therefore,it may be assumed that the preceding uplift involved those parts of the range in particular that are composed of gneissic rocks.Such parts are most likely to be on the southside of the range as they are today.

Rock fragments of the augen-gneiss type extensively described by Hernon(1933) seem to be absent still from the valley fill deposited in the time of the upper member. This may be due to the following facts. Either the particular type was not exposed yet because erosion had not reached it or it may have been exposed later after the base level of erosion was changed by diastrophism.Such movement may be related to Davis' second movement(1931, p.290;this paper p.90).No faults are found in the upper member of the Rillito formation to indicate postdating movements. The strong degree of inclination in a few places is suspicious. Another striking feature is the sudden change in percentage of the volcanic constituents. From around 25% they show in the upper member, nothing is present in the alluvial fan deposits. Such statistically rapid change is not observed with any other group of constituents. These features are to be explained, so much may be said, by either structural or climatic changes.

Correlation and age

In absence of paleontologic evidence the age of the Rillito formation must be inferred from comparison of lithology and structure with other deposits.Unfortunately few occurrences of Cenozoic have yielded fossils in Southern Arizona and correlation of unfossiliferous beds faces considerable difficulties because of the wide unknown areas lying in between.The present author has attempted to extract information about the Cenozoic history and deposits from a number of papers and the result is presented in a table(Pl.12) the tentative state of which needs no emphasis.

Strong late mid-Tertiary diastrophism. It is generally assumed that considerable disturbances,chiefly in the form of block faulting affected most parts of Southern Arizona in late Miocene or early Pliocene time(Knechtel,M.M.,1936,pp.89-90; McKee,E.D.,1951,p.498;Eardley,A.J.,1951,p.420 and Fig.244). In Northern Sonora this diastrophism was probably even stronger and was connected with granitic intrusions according to R.E.King(1939). Over the entire region accumulation of lacustro-fluviatile sediments started in the lower areas due to the major change in relief. Generally a relation between facies distribution and present topograpgy can be observed in these deposits:coarse-grained sediments near the base of the mountains grade into fine-clastic rocks and evaporites in the centers of the valleys.Such deposits have been compared with the Gila conglomerate (Gilbert,G.K.,1874,p.540;Lindgren, W.,1905,p.75) and named so. In the San Pedro and San Simon valley,Gila conglomerate yielded some faunules which date it,at least in part,as Upper Pliocene and Pleistocene(Gidley, J.W.,1922,pp.119-131;Knechtel,M.M.,1936,pp.86-87).Over wide areas south of the international border simlar deposits have been recognized and named Baùcari(Dumble,E.T.,1900,pp.122-152) or Baucarit (King,R.E.,1939),the age of the formation being suggested by finds of proboscidia of late Tertiary or early Quaternary age.

Deposits older than Gila-Baucarit. Gila-type deposits rest in various places upon older lacustro-fluviatile sediments and volcanic rocks which are more or less strongly deformed. These older sediments were probably formed more or less shortly before disturbances of mountain-biulding proportions affected the area and they include: Miocene? beds at Ari-vaipa Creek(Ross,C.P.1925,pp.29-30);Whitetail conglomerate near Globe(Ransome,F.L.,1903,p.48);mid-Tertiary sediments containing tooth of a small rhinoceras(Chew,R.T.,1952,written communication) situated on the northern slope of the Rincon Mountains;parts (?) of the "Pantano" formation south of the Rincon Mountains(Moore,B.N.,unpubl.manuscr.);early Tertiary "clastics without granitic pebbles" intercalated between volcanic flows in Sonora(King,R.E.,1939,p.1692);and probably the lower member of the Rillito formation of the present author.

The Whitetail is probably older than the rest of the formations mentioned above because during its erosion a considerable part of the enrichment of the copper deposits in the Globe area took place according to F.L.Ransome(1903) and E.D.Wilson(1949).

Some of the"pre-Gila formations" exhibit already relations to the present topography.Thus,the sedimentary series including the "rhino-beds" on the northside of the Rincon Mountains was derived essentially from the same source as the sediments today(Chew,R.T.,oral communication).This is shown also by the lower member of the Rillito formation. and by the"Miocene?" strata of Ross'.

Thrusting as a time-mark. Correlation of Cenozoic formations, in Southern Arizona and Northern Sonora by means of structural boundaries seems to be uncertain because intensity and timing of crustal disturbances are not uniform although some trends are noticeable. Considering a recent review of Arizona's structural history(Eardley,J.W.,1951,Fig.244 and p.420) it appears that thrusting predates the Gila conglomerate and thus would constitute a criterion to date questionable beds.However, there are cases observed where the Gila conglomerate was subjected to overthrusting. About 40 miles southeast of the author's area of investigation,Gila conglomerate was involved in overthrusting near the Huachuca Mountains according to C.Alexis (1949,p.58).Not far east of that locality,in the Courtland-

Gleeson area,Wilson (1927,p.35) observed nearly flat thrust faulting considered by him to be younger than the vertebrate bearing strata of the San Pedro Valley.

South of the international boundary Baucarit,the equivalent of the Gila conglomerate,is very commonly overridden according to King(1939,p.1715).This feature persists until farther south the deformation again becomes weaker and finally in the plateau section of the Sierra Madre,that is about south of the 28th parallel,the Baucarit is only tilted and gently faulted.Reasons for this differentiation are seen by King in the fact that mid-Tertiary movements were the major diastrophism in northern parts of Sonora and exceeded by far the post-Cretaceous revolution which had been so effective farther south. Thus,post-Baucarit thrusting can be considered as posthumous to the strong(with granitic intrusions!) mid-Tertiary diastrophism.The area in the south had become consolidated before that already.

Turning back to the Rillito formation,the possible thrusting on the southside of the Santa Catalinas appears now under a different aspect.Thus an occurrence of young thrust faulting must be considered as the northernmost outpost in the sequence of decreasing intensity from northern parts of Sonora towards the Colorado Plateau.

As it has been shown that thrusting is not confined to predate Gila-age deposits, a dating of the Rillito members in this way is not possible.

Other means of correlation. Future investigations around Bellota Ranch are hoped to clarify the relative age of the porphyritic lava in respect to the lower member of the Rillito formation there. An andesite porphyry of similar appearance is reported by R.T.Chew (personal communication) to intrude beds of mid-Tertiary age in the vicinity of Bar LY Ranch several miles northeast of Bellota Ranch. A petrographic comparison might clarify the relationships.

From subsequent changes in composition of sedimentary particles of the two upper members of the Rillito formation and from the intensity of deformation it is assumed that the lower member of the Rillito formation has preceded the late mid-Tertiary diastrophism although an age close to the lowest parts of the Gila conglomerate is not impossible.

The middle and in particular the upper member of the Rillito formation are very similar to recent deposits as far as the composition is concerned. This in addition to the more or less gentle degree of deformation suggests that the middle and upper Rillito member are very likely to be equivalent to the Gila formation. Future comparative studies of composition may confirm this conception.

APPENDIX

Plate 3.

A, A shattered granite constituent in the conglomerate of the lower member, Rillito formation. Exposure in washbank, northeast of Bellota Ranch. Hand lense for comparison.

B, Alteration in mudstone or shale due to volcanic intrusion. Flow structures not very distinct in the photograph. Northeast of Bellota Ranch.

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Plate 3.

A. "Chimney rocks" northeast of Bellota Ranch showing parallel jointing("Catalina" gneiss).

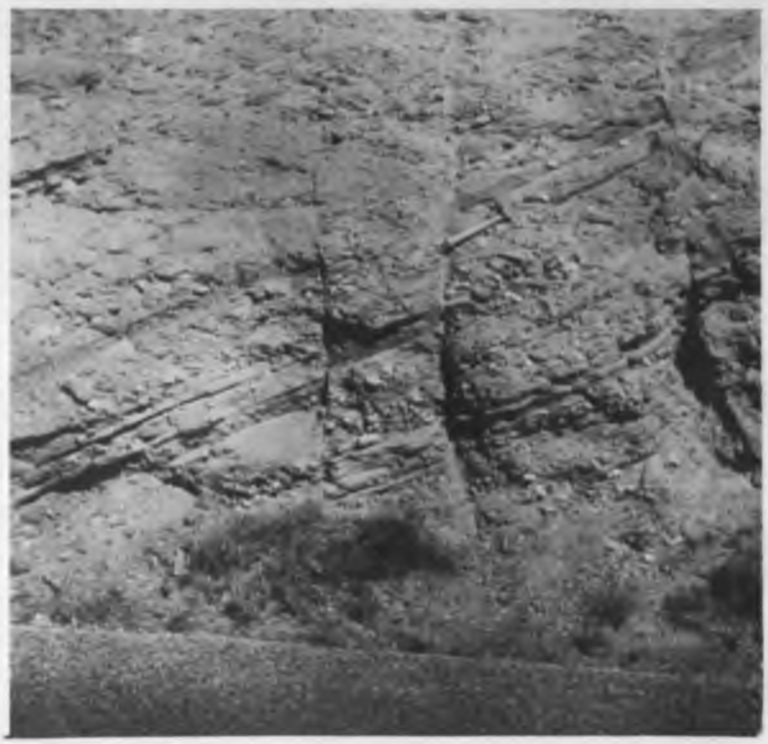
B. Conglomerate of the lower member of the Rillito formation exhibiting steep inclination, about 45° SE, east of Pontotoc road.

A. Boulder of lower Rillito member conglomerate being a constituent in the middle member of the formation(near site 40).

B. Channel cutting in the middle member of the Rillito formation.Small lense of fine sandstone intercalated between conglomerate(site 51).

SW  NE

A. Conglomerate of the middle member, Rillito formation, showing branching faults.
Mount Lemmon Highway, site 51.

SW  NE

B. Small graben in the middle member, site 51

SW  NE

A. Fault complex in the middle member,Rillito formation.East of Pontotoc Wash,near site 40.

SW  NE

B.Normal fault in the middle member,Rillito formation,southwest wall thrown down.Locality as in A.

Plate 8.

Stereo-pair (aerial photographs) showing Twin Hills, east of Tucson. Two little hills emerge from the monotonous plain of alluvium. The hills are formed by dark porphyritic basalt and a non-porphyritic variety which is capping the two hills. At the southeast base of the hills minute outcrops of other rocks are present, for instance, recrystallized limestone; light colored granite partly of aplitic appearance; conglomerate being overwashed by alluvium and therefore unidentified.

Plate 8.

Plate 8.

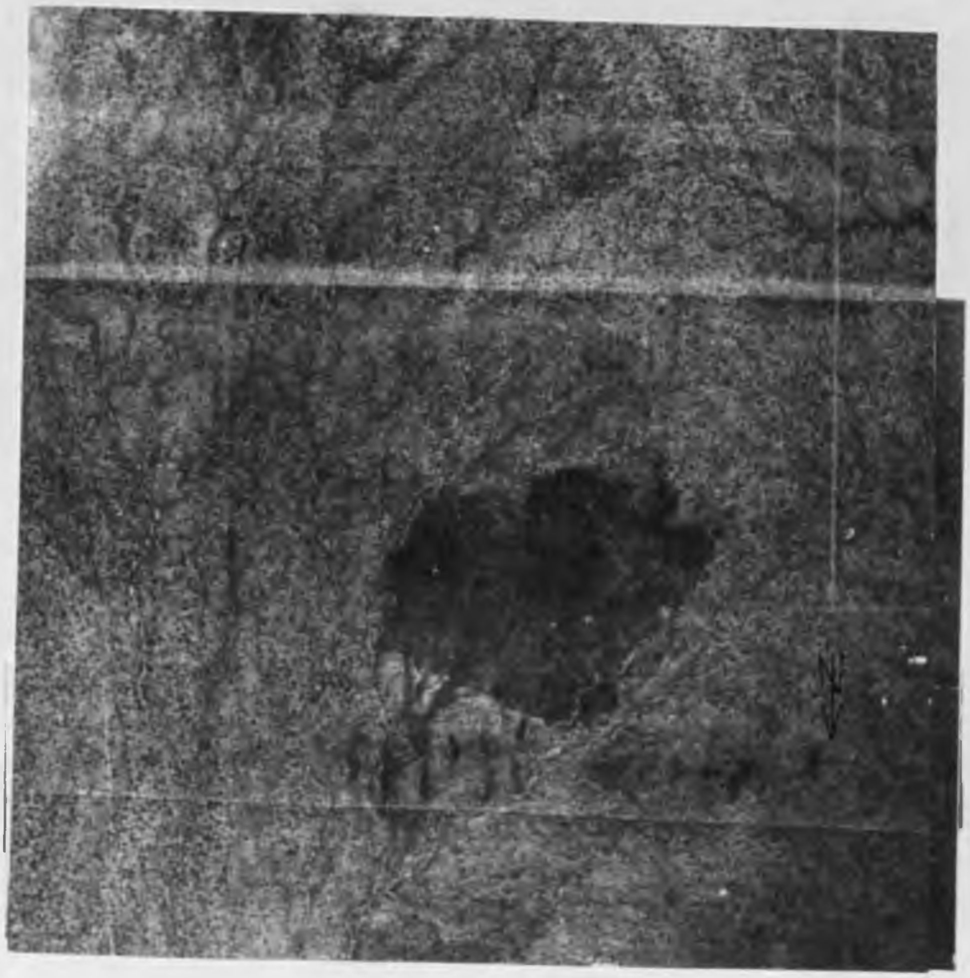
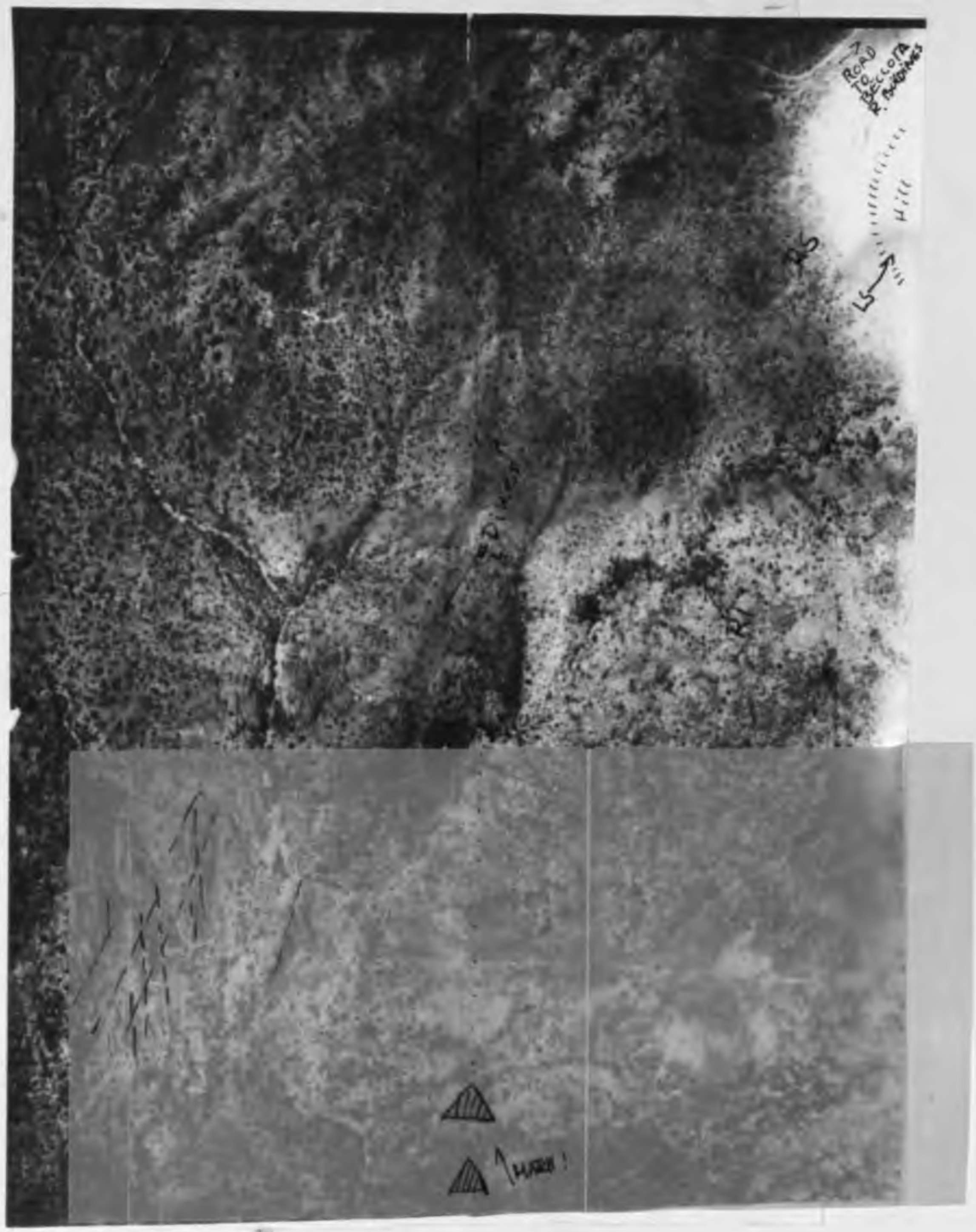


Plate 9.

Plate 9.

Stereo-pair (aerial photographs) showing "Chimney rocks" about one and a half mile northeast of Bellota Ranch. Two chief directions are to be distinguished(black broken line) among the joints which are so conspicuous because of preferred weathering. Dark streak in soil color connects outcrops of volcanic rocks,probably it is a dike. Occurrence of altered mudstone or shale is bordering on the zone of volcanic rocks which are in part porphyritic basalt;disregard dark spot(stain on original photo) beside the place of alteration,marked AS. Conglomerate of the lower member of the Rillito formation is exposed in wash bank marked RI. Reddish shale (RS) lies at the base of a hill formed by recrystallized limestone(LS).

Plate 9.


ROAD
TO
Hill
RS
LS

A. Layers of fibrous gypsum intercalated between thicker mudstone layers and beds. (site 20)

B. Massive gypsum beds with fine layers of mudstone. Coaly remnants in upper left part of picture. (site 30)

Plate 11.

Plate 11.

View along the assumed trend of the Catalina fault. Picture taken from an airplane in about 7000 feet above sea level being approximately over Agua Caliente Hill.


Plate 11.
WNW
Tucson
Rillito creek
N. Campbell ave.
assumed offset
Sabino Wash
Bear Canyon
Mt. Lemmon road

Plate 11

Table: Pebble counts in the Rillito formation

UPPER MEMBER

site, locality	Oracle granite	lime-stone	volc. rocks	quartzite	schist &phyll.	"Catalina gneiss &granite"	doubtful
	c o a r s e	c o n s t i t u e n t s (%)					
76, SE of Haz. del Sol	5	--	32	14	21	28	--
73, W of Sabino road	2	--	25	28	9	36	--

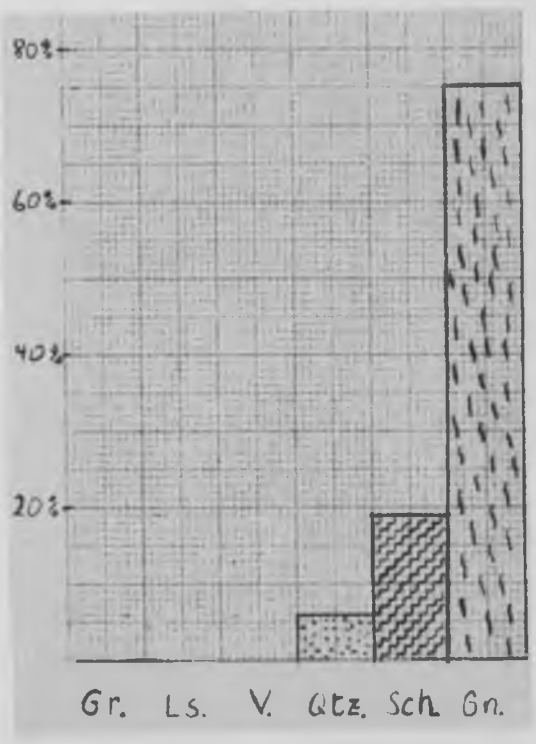
MIDDLE MEMBER

site, locality	Oracle granite	lime-stone	volc. rocks	quartzite	schist &phyll.	"Catalina gneiss &granite"	doubtful
2, W of Pontotoc mine	32	6	28	8	19	7	--
40, 1 mile S of Pont. mine	7	5	50	10	12	16	--
78, SE of Haz. del Sol	10	6	27	15	21	21	--
72, W of Sabino road	3	9	44	33	4	7	--
51, Mt. Lemmon Highway	--	14	25	22	5	34	--
54, W Snyder road	12	13	17	22	11	25	--

LOWER MEMBER

site, locality	Oracle granite	lime-stone	volc. rocks	quartzite	schist &phyll.	"Catalina gneiss &granite"	doubtful
37, E of N Campbell ave. (N)	28	16	18	31	5	--	2
11, E of N Campbell ave. (centr.)	39	6	20	18	14	--	3
15, E of N Campbell ave. (S)	40	--	28	12	20	--	--
10, E of Hazien. del Sol	17	14	51	9	9	--	--
6, SE of Haz. del Sol	10	7	39	16	26	--	2
69, W of Dell Powell's ranch	16	3	28	24	29	--	--
70, NE of Powell's ranch	12	8	35	17	28	--	--
Tanque Verde road &Soldier's Trail	50	6	26	12	6	--	--
Loma Verde mine	20	20	28	32	--	--	--
1.5 mile NE of Bellota Ranch	37	5	13	27	18	--	--

Table: Composition and other features of Cenozoic conglomerates of the area

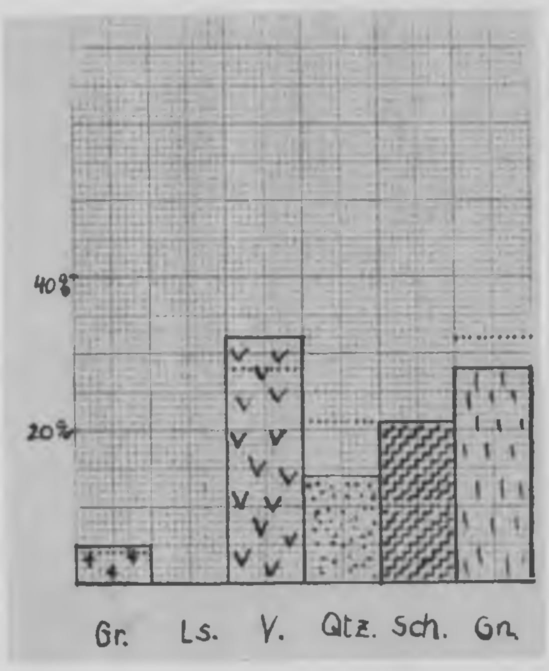


Alluvial fan deposits

Induration: little; good in several places by caliche
Color: always light; gray to brown
Matrix: often sandy or granular; wide range in particle size
Stratification: generally poor but there are exceptions
Sorting: poor in most places
Roundness: ranging from .2 to .5
Maximal particle size: depending on distance from mountain base, even sev. miles from base up to 4 feet in diameter
Types of deposits: fanglomerate predominates in higher parts, finer grained facies near Rillito Creek
Structure: no deformation
Composition: monotonous; histogram shows comp. near site 76

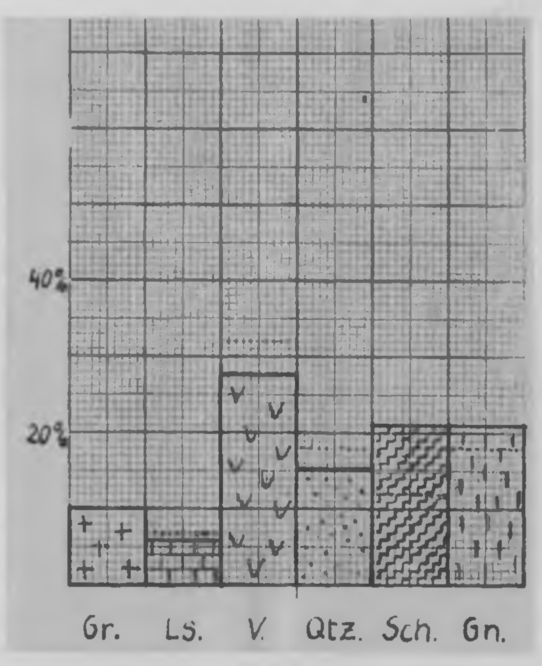
Rillito formation

Upper member



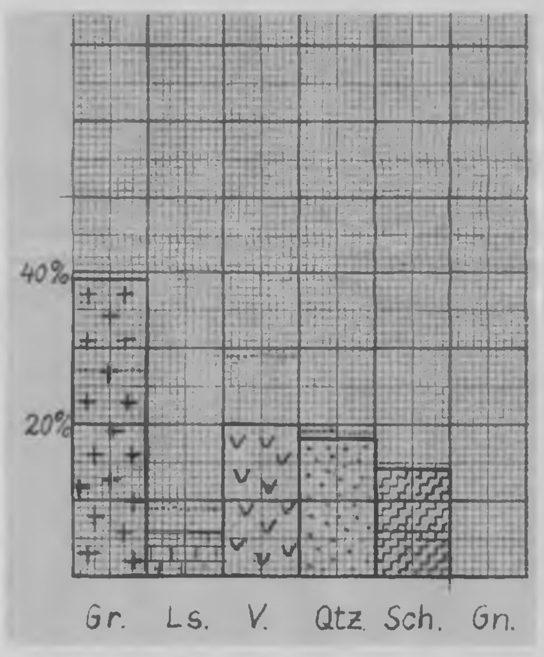
Induration: little in fine-grained, better in coarse-grained facies
Color: brown and gray, with red touch in places
Matrix: very sandy, may be called "sandy conglomerate"
Stratification: inconspicuous, partly due to poor sorting. Stratification obvious when abrupt change in particle size
Sorting: poor in the overall picture, fair in some strata
Roundness: .4 (average fig. of volc. rocks for better comparison)
Maximal particle size: about 14 inch, mostly "Catalina gneiss"
Types of deposits: only congl. was observed; compared with m. and l. member, the u. member is rare
Structure: gently inclined, dip is probably initial. No faults or strong tilt.
Composition: uniform in both exposures (dist. between them 5 miles) Histogram shows site 76

Middle member



Induration: good, partly excellent due to calcitic cement
Color: "dirty" red; redbrown, gray
Matrix: some occurrences with little interstices, others with sand and granules in matrix
Stratification: pronounced
Sorting: good in places
Roundness: .5 (only volc. fragm.)
Maximal particle size: 30 inches (volcanic chunk)
Types of deposits: only conglomerate (two kinds distinguishable)
Structure: Dip 10° to 65°. Numerous normal faults, several suspect of being reverse (in Pl.6, A?), but secure statements handicapped by indistinct strata.
Composition: histogram shows site 78

Lower member



Induration: good, partly excellent due to calcitic cement
Color: purplish red, reddish gray; gray and brown with red touch less common
Matrix: same is observed as in middle member
Stratification: distinct; not recognizable when deformed
Sorting: same as middle member
Roundness: .5 to .6 (volc. fragm. for comparison, average figure)
Maximal particle size: 12 inches is common
Types of deposits: conglomerate, mudstone, gypsum (see p.35)
Structure: Dips from 15° to 50°, most occurrences about 20°. Faulting: stronger near the mountain base, there probably thrust on gneiss
Composition: histogram shows that of site 11

Note: Dotted line indicates average percentage

PLATE 12. APPROXIMATE CORRELATION OF THE CENOZOIC IN SOUTHEASTERN ARIZONA* AND ADJACENT AREAS

	SYCAMORE CANYON PRICE	GLOBE – RAY RANSOME	BELMONT QUEEN AREA HARSHMAN	ARIVAIPA REGION AND VICINITY ROSS & KNECHTEL	MAMMOTH PETERSON	NORTHERN RINCON MTS. CHEW	SOUTH OF SANTA CATALINA MTS. VOELGER	TUCSON MTS. W.H. BROWN	SAN PEDRO VALLEY BRYAN & GIDLEY	COURTLAND - GLEESON E.D. WILSON	TOMBSTONE GILLULY	BISBEE RANSOME *)	SONORA R.E. KING
QUATERNARY	BASALT FLOWS TYPE B GRAVEL	GILA CONGL.	BASALT	GILA CONGL. TUFF	GILA CONGL.	GR. DISPLACEMENT UPPER GILA CONGL.	ALLUVIAL FAN DEPOSITS UPPER RILLITO FORM.	BASALT	FOSSILBEARING STRATA (LAKE BEDS, ETC.)	Thrusting LAKE BEDS	GILA CONGL.	BASALT GILA CONGL.	Thrusting BAUCARIT WITH BASALT
UPPER TERTIARY	BASALT LAVAS TYPE A GRAVEL	DACITE FLOWS	DACITE CONGL. DACITE FLOWS	FLUVIATILE SEDIMENTS AND LAVAS (ROSS' "MIOCENE")	BASALT LAVA AND RHYOLITE	MIDDLE GILA CONGL. LOWER GILA CONGL. ANDES. PORPHYRY Thrust & form faults SEDIM. WHITH RHINO TOOTH (THREE MEMBERS)	MIDDLE RILLITO FORM. PORPHYRITIC BASALT LOWER RILLITO FORM.	LAKE BEDS, SHALE, TUFF Blockfaulting LAVAS	SEDIMENTS AND VOLCANICS				GRANODIORITE
LOWER TERTIARY		WHITETAIL CONGL. DIABASE GRANITE ?	WHITETAIL CONGL. GRANITE				(SANTA CATALINA GNEISSIC-GRANITIC COMPLEX POSSIBLY AT THIS TIME)	EROSION INTRUSIONS ?			SCHIEFFLIN-GRANITE ? ANDESITE PORPHYRY DIKES		SEDIMENTS "WITHOUT GRANITE PEBBLES" & VOLCANIC FLOWS
OLDER ROCKS	KAIBAB, MOENKOPI	NACO	NACO	UPPER CRET. FRESHWATER DEPOSTS.		EROSION ORACLE-GRANITE	CRETACEOUS, PALEOZOIC & OLDER ROCKS	CRET. CONTI N. DEP. AND VOLC.			UNCLE SAM PORPHYRY (QTZ LATITE INTRUS.)		CRET.: CLASTICS ANDES. FLOWS CLASTICS

NOTE: ~ = tectonic activity
? = dating tentative

*) after EARDLEY. 1951, Fig.244

GEOLOGIC MAP OF

CENOZOIC DEPOSITS IN THE SOUTHERN FOOTHILLS OF THE SANTA CATALINA MOUNTAINS NEAR TUCSON, ARIZONA

TOPOGRAPHY AFTER MAP OF THE TUCSON QUADRANGLE, ENLARGED

SCALE $\frac{1}{31680}$ *

CONTOUR INTERVAL: 100 FEET

GEOLOGY BY K. VOELGER
SURVEYED IN 1951

*CORRESPONDING TO THE PHOTOGRAPHIC MOSAIC IN THE GEOLOGY DEPARTMENT, UNIVERSITY OF ARIZONA, TUCSON