GEOLOGY AND KINEMATIC ANALYSIS OF DEFORMATION IN THE REDINGTON PASS AREA, PIMA COUNTY, ARIZONA

by

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STATEMENT BY AUTHOR

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ABSTRACT

Folds in sedimentary and metasedimentary rocks on the southeastern flank of the Santa Catalina Mountains have been attributed both to drag during thrust faulting and to deformation during the forceful intrusion of a granitic pluton. Gravity gliding has also been suggested to explain the presence of Cambrian Bolsa Quartzite overlying Mississippian Escabrosa Limestone in the study area.

Geologic mapping has revealed that Bolsa Quartzite does not overlie Escabrosa Limestone in the area but is in its normal stratigraphic position. The overturned and cascade style of the folds and their eastward asymmetry suggest that folding was caused by gravity-induced slippage along bedding surfaces. The slip-line direction, as determined stereographically from the fold geometry, indicates movement in a S 60° E direction. This movement direction is further supported by an east-west lineation which is interpreted to be an "a" lineation produced by the displacement of units along bedding planes during gravity gliding.

The Pennsylvanian age of the folded sediments together with their eastward dip off the Santa Catalina Mountains and the inferred eastward movement direction indicate that gravity gliding was initiated during Tertiary uplift of the Santa Catalina Mountains.

INTRODUCTION

Purpose of Investigation

The Paleozoic rocks on the southeastern flank of the Santa Catalina Mountains have undergone one or more periods of deformation. This deformation is well expressed by folds of different styles, symmetries, and orientations. In this study the folds are analyzed in detail in order to determine the mechanisms and kinematics of deformation of these sedimentary units. The major purpose of the study is to determine whether deformational features of the rocks in the area resulted from (1) drag due to thrust faulting, (2) forceful intrusion of a large granitic body, (3) gravity-induced movement to the east-southeast off the Santa Catalina Mountains, or (4) some combination of the above.

Location and Access

The study area is located approximately 35 miles east-northeast of Tucson on the southeastern flank of the Santa Catalina Mountains in northeast Pima County, Arizona. The map area (Figure 1) is approximately six square miles and includes sections 17, 18, 19, 20, and parts of 29 and 30 of T. 12 S, R. 18 E and parts of 13, 24, and 25 of T. 12 S, R. 17 E. The area lies within the Bellota Ranch Quadrangle of the U. S. Geologic Survey topographic map series.

Access to the eastern half of the area is provided by the Tanque Verde-Redington Pass Road. This road is passable throughout the year

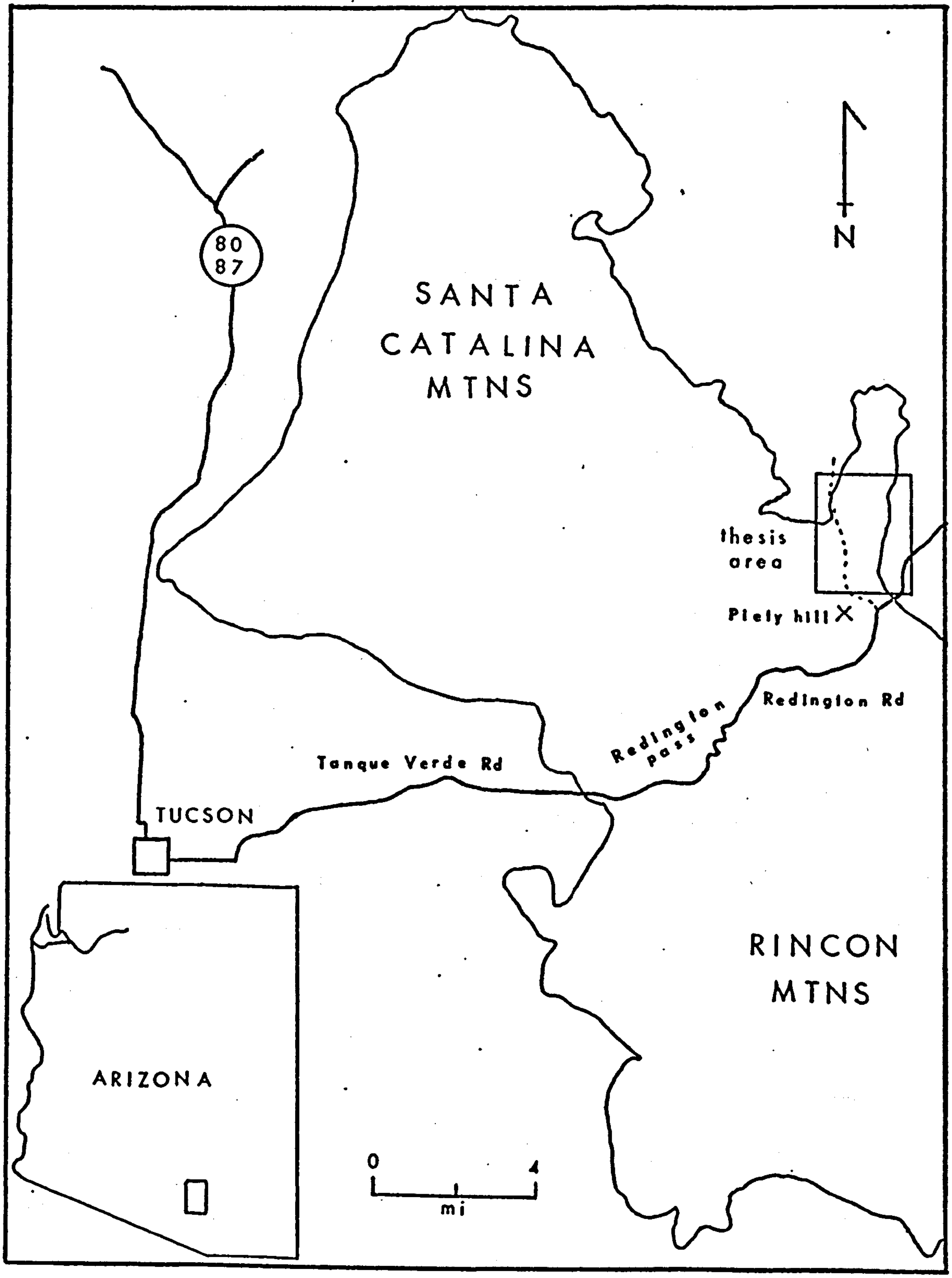

Figure 1. Map showing location of thesis area.

except during short periods of extreme runoff. A jeep trail which branches off of the Redington Pass Road near Piety Hill (Figure 1) provides access to the western half.

Topography and Climate

Low relief of approximately 350 feet with moderately steep slopes and rounded hills is typical of the eastern half of the area. The western half is characterized by rugged slopes, particularly the steep cliff area adjacent to Buehman Canyon in the northwest portion of the area. The maximum elevation in the area is 4372 feet and the minimum elevation is 3360 feet.

The washes within the area are dry throughout the year except for Buehman Canyon which during the months of February and March may contain running water from the melted snow of the Santa Catalina Mountains. The drainage pattern is rectangular in the western half of the area near Buehman Canyon, with stream orientations of north-south and east-west (Figure 2, in pocket). To the east the drainage pattern is parallel with east-west-trending washes. The patterns are a reflection of faults and the eastward dip of the bedding towards the San Pedro River. The climate is typical of the arid southwest, with extremely hot dry summers and moderate winters.

Good outcrops are generally found in the washes and along cliff faces. However, many of the low hills are capped by the more resistant units which also provide excellent exposure.

Method of Study

The field work for this study was conducted during the spring and fall of 1973. The 15-minute Bellota Ranch Quadrangle map (scale 1:66,500, CI 80 feet) was used as a base. The portion covering the thesis area was enlarged to one inch equals 500 feet by photographic methods. This together with enlargements of 1966 Forest Service aerial photographs comprised the base control. Geologic data were accumulated on tracings from these enlargements which were later transferred to a final geologic map.

A Brunton compass was used to measure the orientations of bedding and fold elements. The small size and good exposure of the folds permitted direct measurement of axes and axial surfaces. Computer programs devised by Davis (1971, 1972) were then used to convert the orientation data into lower-hemisphere equal-area net projections. Fold features such as shapes of the folded layers, interlimb angles, and hinge-zone thickening were analyzed using methods outlined by Hansen (1971), Ramsay (1967), and Hudleston (1973).

Previous Work

No previous detailed geologic studies have been made of this area which is included on the state geologic map and on the U. S. Geological Survey map of the Tucson Quadrangle, scale 1:125,000 by Moore et al. (1941). Raabe (1959) made a structural and petrographic study of rocks in the Bullock Canyon-Buehman Canyon region which lies immediately west of this study area. He was concerned chiefly with describing the petrography of the Late Precambrian Apache Group (?)

metasedimentary rocks and Paleozoic (?) metacarbonates. He concluded that the rocks were metamorphosed to a low grade during emplacement of an intrusive gneissic granite. Within his area Raabe (1959) recognized three sets of drag folds which he attributed to movement between bedding planes during the forceful intrusion of the gneissic granite. The first set trends northwest overturned to the northeast and is found in silicated rock. The other two sets are found in overlying magnesium carbonates and are overturned to the northeast and southwest. Raabe (1959, pp. 39-40) stated that

> Drag folds overturned to the northeast . . . were caused by vertical stresses during the emplacement of the gneissic granite. Drag folds, overturned to the southwest toward the intrusive, are probably due to an adjustment during cooling when the rocks tended to slide back from where they came.

McKenna (1966) studied the Paleozoic section exposed in Buehman Canyon immediately north of the area studied for this report. The rocks of Buehman Canyon range in age from Younger Precambrian to Recent, but McKenna was concerned mainly with describing the stratigraphy of the units ranging in age from Cambrian through Pennsylvanian. Several sections were measured by McKenna, but only a cursory treatment was given to the structural history of the region. Two northeast-southwest anticlinal folds and three major high angle faults trending approximately N 30° W were the major structural features recognized by McKenna. He concluded that the deformation in the area was a result of Laramide orogeny in Late Cretaceous-Early Tertiary time and was accompanied by igneous intrusion and metamorphism.

The rocks around Piety Hill, which is adjacent to the southern boundary of this study area, were mapped by Broderick (1967). He focused on the petrography of the metamorphosed Precambrian Apache Group and Paleozoic sedimentary rocks. He suggested that the Piety Hill area was affected by at least two stages of metamorphism: a regional metamorphism which took place during the formation of the Catalina Gneiss followed by a contact metamorphism during intrusion of the Catalina Gneiss. He attributed deformation in the area to thrust faulting from the east or gravity gliding from the west which caused Cambrian Bolsa Quartzite to be emplaced upon Mississippian Escabrosa Limestone. Minor folds in the Abrigo Formation were interpreted by Broderick as products of differential slip along bedding planes during thrusting.

To the west-northwest Pilkington (1962) studied in some detail the structural geology and petrology of the gneisses and sedimentary rocks in the Santa Catalina Mountains. He recognized two high angle west-northwest trending faults and on the basis of foliation orientations outlined a series of west-northwest trending anticlines and synclines within the gneiss. Pilkington attributed shear jointing within his area to vertical forces. He concluded that both the metamorphism and the deformation in his area could be explained by doming of the Santa Catalina Mountains and that the field relationships of the rocks suggest a post-Paleozoic-pre-Upper Miocene age for the metamorphism.

The position of the study area on the southeastern flank of the Santa Catalina Mountains implies that the geologic history of the Catalinas is intimately related to the history of the thesis area. The

Santa Catalina complex is composed of granitic gneiss which has been termed "Catalina Gneiss" by Du Bois (1959) and contains a well-developed foliation and a penetrative northeast trending mineral lineation. The gneiss ranges from quartz monzonite to a granodiorite. Du Bois divided the gneiss into three types: granitic gneiss, augen gneiss, and banded augen gneiss.

The age of the Catalina Gneiss as well as the age and character of the rocks from which the gneiss was derived are topics of much controversy. Moore et al. (1941) described the Catalina Gneiss as an intrusive body grading into Paleozoic and Mesozoic sedimentary rocks and therefore of post-Cretaceous age. Raabe (1959) referred to the Santa Catalina Mountains as an anticlinal structure with a gently plunging southeast axis. He attributed the structure of the mountains to forceful intrusion of granite which resulted in doming and partial granitization of the sedimentary cover. Overturned and recumbent folds can be found within the Younger Precambrian Group metasediments and lower Paleozoic rocks overlying the Catalina Gneiss near the top of the Santa Catalina Mountains. Waag (1968) explained these folds by gravitational gliding off the Catalina complex during mid-Tertiary doming. Doming of the Santa Catalina Mountains has also been suggested by Pilkington (1962) and Peterson (1968).

Du Bois (1959) believed that an older Precambrian event produced the Pinal Schist which was later converted to gneiss by a post-Cretaceous metamorphic event. Metasomatism of Pinal Schist followed by vertical uplift in Tertiary time was suggested by Mayo (1964), and has been supported by Peterson (1968) and Waag (1968). Damon, Erickson and Livingston (1963) have recorded two dates for the Catalina Gneiss. They derived a 1660 m.y. date from the lead isotope content of zircons in the gneiss and a 27 m.y. date from the micas. Therefore, it seems that although the origin of the Catalina Gneiss is still open to question, at least two metamorphic events have affected the Santa Catalina Mountains, one in Precambrian time, and one in Tertiary time.

Geologic Setting

The rock units within the study area range in age from Precambrian to Recent (Figure 2). The pre-Paleozoic rocks consist of metasedimentary equivalents of the Younger Precambrian Apache Group and Late Precambrian diabase sills which have intruded the older rocks. The Paleozoic rocks range in age from Cambrian to Pennsylvanian and are of sedimentary origin. They consist predominately of limestone, dolomite, and quartzite with minor amounts of shale and siltstone. To the north of the study area rocks of Early Cretaceous age overlie the Pennsylvanian limestones in angular unconformity and have been assigned to the Bisbee Group (McKenna 1966). The San Pedro Valley basin is located to the east of the study area and is filled with Quaternary and Tertiary gravels and alluvium.

The portion of the Santa Catalina Mountains to the west of the study area contains Precambrian rocks of the Apache Group together with the Cambrian Bolsa Quartzite and Abrigo Formation. The post-Paleozoic rocks consist of a quartz latite porphyry and Catalina Gneiss. The

Catalina Gneiss in this area consists of a banded augen gneiss and a granitic gneiss (Pilkington 1962).

ROCK UNITS

Distribution

The Paleozoic section makes up about 90 percent of the rocks exposed within the area (Figure 2). The Precambrian Apache Group and its associated diabase sills occupy a quarter-mile-wide strip which trends north-south and is bordered on the west by the Buehman Canyon fault. This strip is located in the north-central part of the map area and extends approximately 1.5 miles to the south. The Cambrian Bolsa Quartzite and Abrigo Formation, the Devonian Martin Formation, and the Mississippian Escabrosa Limestone occupy a three-quarter-mile-wide strip which trends 1.5 miles north-south through the north-central section. In the southern half of the area the Cambrian Bolsa does not crop and the Cambrian Abrigo, Devonian Martin, and Mississippian Escabrosa are restricted to a quarter-square-mile area. The eastern third and the southwest quarter is made up of Pennsylvanian Horquilla Limestone which is by far the most extensive unit. Tertiary and Recent gravels occupy the northwest quarter and southeast third and diabase intrusions are scattered throughout the eastern half of the map area.

Precambrian Apache Group

Pioneer Formation

The basal unit of the Apache Group was originally designated the Pioneer Shale by Ransome (1903) in the Ray quadrangle, Arizona. The name has since been modified by Shride (1961) and is now called the Pioneer Formation. Shride divided the Pioneer Formation into the Scanlan Conglomerate and the Pioneer Shale. The Scanlan Conglomerate, at the base of the Pioneer Shale, is characterized by light to dark gray and grayish-red quartzite pebbles in a fine to coarse grained arkosic matrix. The Pioneer lithology is composed of grayish-red siltstone or silty mudstone that commonly includes abundant grains of fine sand (Shride 1961). Shride noted that along the San Pedro Valley the Pioneer is mostly a dark-colored quartzose siltstone and that the Scanlan Conglomerate is generally very thin occupying only a few inches at the base of the formation.

In the thesis area the Scanlan Conglomerate Member is not recognized and the Pioneer is typically a hard, dark-colored quartzitic phyllite. It has a characteristic rusty appearance on the weathered surface and is often found occupying rubble-covered slopes. Diabase sills are found within the formation but rock debris from the overlying formations makes the contacts difficult to locate. The Pioneer is overlain conformably by the Barnes Conglomerate Member of the Dripping Spring Quartzite. The presence of the Barnes Conglomerate is the most conclusive evidence that the phyllitic units are part of the Pioneer Shale.

Dripping Spring Quartzite

The Dripping Spring Quartzite was first named and described by Ransome (1903). Shride (1967) included the Barnes Conglomerate as a basal bed of the Dripping Spring Quartzite. Creasey (1967), who mapped the geology in the Mammoth quadrangle, divided the Dripping Spring into three members: Barnes Conglomerate, the lowest member; a middle member of medium-grained feldspathic quartzite; and an upper member of fine-grained micaceous quartzite, and shale. Creasey (1967) also noted that the Dripping Spring Quartzite is often partially recrystallized as a result of pre-Paleozoic diabase intrusion.

In the study area the Barnes Conglomerate Member is represented as a stretched quartz-pebble conglomerate overlying the Pioneer Formation and underlying the upper quartzitic members of the Dripping Spring Quartzite. The conglomerate is composed of stretched white to gray quartzite pebbles, one-quarter to two inches in length, in a matrix of quartz and mica. The quartzite pebbles are enveloped in thin layers of biotite and sericite and are elongate in approximately a N 75° E direction. Within the map area the Barnes is best exposed in the two northernmost washes which cut east-west across the Apache Group. The Barnes Conglomerate Member grades upward into the medium-grained quartzite member. This member is composed of thin-bedded siltstones and gray quartzites which weather to a yellowish brown color. Most of the quartzites exhibit recrystallization. It is doubtful that all of the middle or upper members of the Dripping Spring are present in the thesis area because complete sections south of latitude 33° N are rare (Shride 1961).

The uppermost formation of the Apache Group, the Mescal Limestone, is not present in the area and the contact between the Precambrian and Paleozoic rocks was chosen at the boundary between the uppermost diabase sill and the base of the resistant cliffs of the Cambrian Bolsa Quartzite. The metamorphosed nature of the Apache Group and the typical rubble-covered slopes make contacts difficult to trace out in the study area. Consequently, for purposes of this investigation, units within the Apache Group were not differentiated on the geologic map (Figure 2).

Paleozoic Rocks

Cambrian Bolsa Quartzite

The Bolsa Quartzite is in the basal Cambrian unit in the greater part of southeastern Arizona and was first named by Ransome (1904) for exposures at Bisbee. The name was applied again by Ransome (1916) in the Tombstone district and by Gilluly, Cooper and Williams (1954) in the Dragoon Mountains. Stoyanow (1936) misnamed the Bolsa Quartzite in the northern Santa Catalina Mountains as the Troy Quartzite. Shride (1967) has shown that much of what Stoyanow (1936) had called Troy Quartzite is Precambrian in age. The name Troy Quartzite, therefore, is now restricted to the Precambrian (Krieger 1961). Krieger (1961) has also shown that after deposition of the Troy Quartzite, the Younger Precambrian sedimentary rocks were intruded by large sills of diabase and were eroded extensively prior to deposition of the Bolsa Quartzite.

The Bolsa Quartzite in the study area consists of medium to coarse grained quartzite with a basal conglomerate consisting of rounded, gray to white quartz pebbles. The beds range in thickness from one to four feet, and cross-stratification is present in much of the formation. The weathered surface is generally reddish brown as a result of iron staining, but parts of the formation are nearly white. On fresh surfaces, the color of Bolsa Quartzite ranges from gray to white with minor amounts of iron staining. The only fossils found in the Bolsa were Scolithus-type worm tubes which are present in the upper Bolsa near the contact with the Abrigo Formation. The Bolsa Quartzite is easily recognized in the field by its massive cliffs and steep rubbly slopes at the base of the cliffs.

Correlation of the quartzite in this area with type Bolsa Quartzite is based on its lithologic similarity to the descriptions of Bryant (1968) and Krieger (1968), and on its stratigraphic relationships to the overlying Abrigo and the underlying diabase sills and Apache Group.

Middle Cambrian fossils have been found in the lower part of the Abrigo Formation in Cochise County, the northern Santa Catalina Mountains, and the Mescal Mountains (Krieger 1968). The Bolsa Quartzite underlies the Abrigo Formation conformably and therefore is inferred to be no younger than Middle Cambrian in age. For mapping purposes, the upper contact of the Bolsa Quartzite was drawn at the position of the highest quartzite unit exposed.

Cambrian Abrigo Formation

The Bolsa Quartzite grades upward into the Abrigo Formation which ranges in age from Middle to Late Cambrian. The name Abrigo Limestone was introduced by Ransome (1904) for the Cambrian limestone overlying the Bolsa Quartzite in the Bisbee area; he used the name again in the Tombstone district (Ransome 1916). Stoyanow (1936) suggested that the name Abrigo Limestone be changed to Abrigo Formation.

Lithologically the Abrigo Formation consists of an assemblage of limestone, dolomite, shale, siltstone, and sandstone. In the study area, the Abrigo Formation is composed of mudstone, sandstone, and sandy dolomite. Massive limestone and dolomite as well as wavy or gnarly bedding, characteristic of the Abrigo Formation to the southeast, are absent. Colors are green, blue, and brown which on weathered surfaces appear very dark. The Abrigo is relatively non-resistant and is recognized in the field as the slope former between the resistant Bolsa Quartzite and the ledges of Devonian and Mississippian limestone.

Previous work on the Abrigo Formation (Stoyanow 1936, Cooper and Silver 1964) has shown that the formation is marked by a northward change in facies, from predominately carbonates in the Bisbee area to mudstones, shales, and sandstones in the north. The presence of predominately clastics in the study area supports this conclusion.

Although no fossils were found within the Abrigo Formation in the study area, fossils of Middle and Late Cambrian age have been found elsewhere in the Abrigo. Correlation of rocks labeled "Abrigo" in this area with type Abrigo Formation has been based on lithologic similarity and stratigraphic position between the Bolsa Quartzite and the Devonian-Mississippian limestones.

Devonian Martin Formation-Mississippian Escabrosa Limestone

The Devonian rocks of southeastern Arizona have an extremely varied lithology. This regional variation was shown clearly by Wright (1964) in his stratigraphic cross-sections. The Martin Formation is

Late Devonian in age and overlies the Abrigo Formation disconformably. The name Martin Limestone was proposed by Ransome (1904) for the Devonian limestones in the vicinity of Bisbee. He applied the name as well to the Devonian-Mississippian rocks in the Globe, Ray, and Tombstone areas (Ransome 1916). In this study the name Martin Formation, as defined by Bryant (1968), refers to the dolomite and clastic units underlying the Escabrosa Limestone and overlying the Abrigo Formation.

Here the Martin Formation consists of shale, siltstone, sandstone, and dolomite. Bedding ranges from about one to four feet in thickness. Fossils are generally lacking in the Martin Formation within the study area and those that were found are highly silicified. Fortunately in one outcrop two diagnostic Devonian corals were found, Coenites and Pachyphyllum. Syringopora was also found but this coral is present in much of the Paleozoic section and therefore was not helpful in providing an age for the formation. The most distinctive feature of the Martin Formation in the study area is the yellowish-brown color of its weathered surface.

The Martin Formation is capped by the more massive Escabrosa Limestone and in areas where the Escabrosa Limestone is well exposed it forms resistant cliffs. It is typically a medium to coarse grained, light-gray limestone containing abundant crinoid debris. Horn corals are found in the Escabrosa Limestone to the north (McKenna 1966), but except for crinoid debris, no fossils were found in the study area. The limestone is generally recrystallized, with metamorphism increasing towards the south as indicated by the increasing abundance of tremolite.

Some dolomite is present, but the formation is typically limestone free of clastics.

The name Escabrosa Limestone was first used by Ransome (1904) for Mississippian limestones in the Bisbee area, and he used the name again (Ransome 1916) in describing rocks in the Tombstone area. The U. S. Geological Survey has used the name Escabrosa Limestone in reference to rocks in the Dragoon quadrangle (Cooper and Silver 1964) and again in Cochise County (Gilluly et al. 1954). Armstrong (1962) studied the Escabrosa in the northern Chiricahua Mountains and elevated the Escabrosa to group rank. He considered the age range of the Escabrosa Group to be from about the middle of Lower Mississippian to middle Upper Mississippian.

Pennsylvanian Horquilla Limestone

The Escabrosa Limestone is overlain disconformably by the Pennsylvanian Horquilla Limestone. The Horquilla Limestone is the basal Pennsylvanian formation in southeastern Arizona except where the Black Prince is present. The Black Prince Limestone has been identified in the Little Dragoon Mountains, Gunnison Hills, Whetstone Mountains, and the Johnny Lyon Hills but has not been reported from other localities (Bryant 1968). The Black Prince has been assigned a Mississippian age (Gilluly et al. 1954) but Nations (1963) suggests that it might be Pennsylvanian. No Black Prince has been identified in the study area although it has been mapped in the adjacent area to the north (McKenna 1966).

Ransome (1904) proposed the name Naco Limestone for the limestone between the Mississippian Escabrosa and the Cretaceous rocks at Bisbee. Naco has also been used as a group name by the U. S. Geological Survey for all post-Mississippian Paleozoic rocks in southern Arizona. The Naco Group was subdivided by Gilluly et al. (1954) into the Pennsylvanian Horquilla Limestone, the Pennsylvanian-Permian Earp Formation, and the Colina Limestone, Epitaph Dolomite, Scherrer Formation, and Concha Limestone, all of Permian age.

The only member of the Naco Group identified in the study area is the Horquilla Limestone. However, some of what has been mapped as Horquilla Limestone may be Earp Formation because the Earp-Horquilla contact is a difficult one to place. The contact is gradational and conformable and in the original description Gilluly et al. (1954, p. 19) wrote that " . . . the base of the Earp is arbitrarily taken where the thin shaly limestones and the reddish shales become dominant over the more massive limestone of the Horquilla." The boundary therefore depends on local conditions of deposition and one's interpretation as to where thin shaly limestones and shales become dominant. One feature of the Earp which can be used for positive identification is the presence of a red chert-pebble conglomerate which lies in the middle of the formation. This conglomerate is not present in the study area. Therefore it would seem that if any Earp is present, it would be the lower half of the formation assuming that portions of sections have not been removed by faulting.

The Horquilla Limestone in this locale is composed of light-gray sandy limestone from one to three feet thick and thin beds of red and green shale and mudstone. The limestone is locally marbleized and the mudstones appear phyllitic in many places. The shale and mudstone form non-resistant interbeds and are usually exposed only in the washes. These easily weathered shaly units alternate with limestone ledges to produce a ribbed topography. No fossils were found in the Horquilla Limestone except for small fusilinids and crinoid debris. Unfortunately these fossils are also found in the Escabrosa Limestone and therefore are of little use in identifying the unit. Medium to large fusilinids, which are lacking in the Escabrosa Limestone, have been used in other areas to identify the Horquilla Limestone but no large fusilinids were found in this area. The contact between the Horquilla Limestone and the Escabrosa Limestone was placed where the red and green mudstones first appear above the more massive Escabrosa Limestone.

A diagnostic feature of the Horquilla Limestone in this area is the presence of nodules and lenses of gray to white and pink chert which weather to a rusty-brown color on exposed surfaces (Figure 3). Upon close examination of the nodules, one can see that some are folded siliceous interbeds (Figure 4). In other cases the near spherical nodules appear to have been deformed into lenticular shapes (Figure 5) and resemble a stretched pebble conglomerate as pictured in Hills (1963). In areas where the more resistant siliceous lenses are abundant, the outcrops have a distinctive ribbed surface. These relatively siliceous units occur chiefly in the eastern portion of the area where they cap

Figure 3. Photograph of Horquilla Limestone with abundant chert nodules.

Figure 4. Photograph of folded siliceous interbeds within the Horquilla Limestone, looking east-northeast.

Figure 5. Photograph of the Horquilla Limestone showing chert lenses and small rootless folds.

small hills. The red and green mudstones and the siliceous interbeds of the Horquilla Limestone also contain numerous mesoscopic folds. This penetrative deformational fabric which is common only to the Horquilla Limestone can in itself be used locally for identification of the formation within the study area.

Tertiary-Recent Rocks

Well-cemented alluvial debris unconformably overlies the Paleozoic limestones in the northeast and central portions of the area. For purposes of this study it has been mapped as a fanglomerate. Although bedding is crude, the unit strikes generally north-south and dips less than 10° to the east.

Beds in the fanglomerate vary from six inches to six feet. The fanglomerate is poorly sorted and is made up of quartzite, gneiss, schist, and diabase fragments in a fine-grained matrix. The average size of the clasts ranges from two to twelve inches with some unusually large boulders up to two feet in diameter. The composition of the clasts suggests that they were derived from the Santa Catalina Mountains to the west. The fanglomerate may have been part of a large "bajada," perhaps the one inferred by W. M. Davis (1931) in his physiographic study of the Catalina Mountains.

Alluvium

In the northwest, small amounts of Recent sand and gravel are present in the stream beds of Buehman Canyon. To the east alluvium unconformably overlies the Pennsylvanian Horquilla Limestone. This alluvial unit consists of poorly consolidated fragments of gneiss, diabase, quartzite, and limestone in a matrix of sand and clay. It is presumed to be Late Cenozoic in age.

Intrusive Rocks

Gneissic Granite

Located near the middle of the eastern boundary of the map area is a small area covered by granitic boulders and debris which have been inferred to approximate the position of a small granitic stock. The boulders are composed of quartz, feldspar and mica and range from 2 to 15 inches in diameter. They are generally grayish white and abundant biotite commonly gives them a speckled appearance.

The stock has been previously mapped and described by Raabe (1959) as a gneissic granite. Raabe related the stock genetically to a much larger gneissis granite body with lies a quarter of a mile to the west-southwest. Raabe suggested that this larger gneissic granite body may be part of the main Santa Catalina Mountain complex and has assigned it a Cretaceous (?) age based on its metamorphic effect on the surrounding Paleozoic rocks.

Diabase

The diabase in the study area occurs as sills in the Precambrian Apache Group and as dikes and plugs within the Paleozoic rocks. Diabase sills are commonly found in the Apache Group throughout Arizona and have been dated at 1200 m.y. (Damon, Livingston and Erickson 1962).

A well-developed foliation is present within the diabase sills of the Precambrian Apache Group but is lacking in the dikes and plugs in the Paleozoic units. This together with the unmetamorphosed character of the diabase within the Paleozoic units suggest that the dikes and plugs were emplaced after metamorphism. Damon et al. (1963) have dated the metamorphism between Upper Oligocene/Lower-Miocene time. The intrusion of the dikes and plugs is therefore post-Lower Miocene in age. Emplacement of the diabase during two separate time periods has been previously proposed by Moore et al. (1941) in their report on the Tucson quadrangle.

The diabase sills in the Apache Group are dark green in outcrop and appear as distinctive dark bands on aerial photographs. The diabase dikes and plugs within the Paleozoic rocks are commonly found along fault zones. They weather black to dark green and in some outcrops have a salt and pepper appearance.

Turkey-Track Porphyry

Two plugs of Turkey-Track Porphyry are present along a fault zone in the central portion of the map area. The porphyry is characterized macroscopically by white tabular phenocrysts of plagioclase. These euhedral phenocrysts range in size from 10 to 60 mm in length and occur randomly in a black aphanitic groundmass.

The rock has been and is commonly called an andesite or basalt, but based on its petrography, Cooper (1961) feels that the name Turkey-Track Porphyry is preferable. Near Mineta Ridge, three miles to the southeast, Cooper assigned a Miocene age to the Turkey-Track Porphyry based on its stratigraphic position. Damon (1970) dated the same porphyry at Mineta Ridge and derived a 26 m.y. age.

Silicified Zones

Several places have been mapped as silicified zones. They are characterized by the presence of abundant quartz veins and stringers, and complete replacement by silica (Figure 6). The areas of silicification are generally located in the middle of the southern half of the map area. The silica appears to be restricted to the more clastic sandy units and in this way the silicification is stratigraphically controlled. In places where large amounts of silica have been introduced the sandy units take on the appearance of quartzites.

The silicified zones appear to be restricted to the sandy units of the Pennsylvanian Horquilla Limestone. Near the center of the map area these zones are found capping the Mississippian Escabrosa Limestone suggesting that the silica may have been introduced along the contact between the Escabrosa and Horquilla Limestone. However, the units which exhibit this silicification have been altered to such a degree as to make their identification impossible and for this reason they have been mapped separately as silicified zones.

Figure 6. Photograph of quartz veins and stringers within the Silicified Zones of the Horquilla Limestone.

STRUCTURE

General Statement

The general structural configuration of the rocks within the study area can be characterized as eastward dipping sedimentary and metasedimentary rocks cut by high angle faults (Figure 7, in pocket). Mesoscopic folds are present in many of these sedimentary and metasedimentary rocks and a prominant lineation has been developed along their bedding planes. The faulting increases in frequency of occurrence towards the south and is restricted to a mile-wide north-south trending strip which cuts across the middle of the map area. The lineation is very abundant throughout the east-northeast quarter and southern half of the map area and the mesoscopic folds are found throughout most of the area except in the northwest quarter.

Faulting

The principal faults in the area trend north-northeast and east-west (Figure 2). The north-northeast trending faults are generally greater in length than the east-west faults but are not as numerous. The positions of the faults are marked by linear drainages, limestone brecciation, and aerial-photo linears. Outcrops of diabase and Turkey-Track Porphyry are also useful in locating faults in that they commonly occur along fault zones. Many of the faults are difficult to trace for any distance due to lack of good exposure and recognizable stratigraphic offset. The straightness of the faults indicates a predominance of essentially vertical attitudes. Where fault planes can be measured the dips are greater than 65°.

The north-south trending Buehman Canyon fault is the most prominent one in the area and the only one of the north-northeast trending faults that can be traced for more than a quarter of a mile. It extends for approximately two miles within the western half of the study area and appears to have exerted some control on the position of Buehman Canyon. The fault plane dips approximately 65°-70° to the west and its position is marked by limestone brecciation. The hanging wall block is downthrown to the west as is indicated along the northern half of the fault by the presence of Precambrian Apache Group east of the fault and Pennsylvanian Horquilla Limestone to the west. Along the southern half of the fault Pennsylvanian Horquilla Limestone is present on both sides indicating a decrease in stratigraphic offset towards the south.

The east-west-trending faults are found in the southern half of the study area east of the Buehman Canyon fault and are marked by east-west-trending drainages. The most prominant east-west trending fault is located approximately in the center of the map area and extends half a mile eastward from the Buehman Canyon fault. The fault plane dips approximately 70° to the south and the presence of Mississippian Escabrosa Limestone on the southern side of the fault with Cambrian Bolsa Quartzite on the northern side indicates that the southern block was downdropped. Slickensides on this fault display a prominance of dip-slip movement with little or no strike-slip component. Stratigraphic offset along the fault trace decreases to the east and in general traces of east-west faulting are not found in the eastern quarter of the area.

The absence of strike-slip movement in the area is suggested by slickenside orientations and the lack of lateral separations. Rotation of the fault blocks seems unlikely because of the consistency in orientations of bedding and a pre-faulting lineation (to be described) from one fault block to another. Displacement of Paleozoic rocks indicates that the faulting is post-Paleozoic.

Lineation

A prominent lineation is present in most of the limestone units throughout the area; it is particularly abundant in the Horquilla Limestone (Figure 8). The lineation is made up of grooves and ridges, or striations along bedding planes. The grooves and ridges are spaced one-half to three inches apart and have amplitudes ranging from one-eighth to one-half inch. Tension fractures are often associated with this lineation and are oriented normal to the striations. These fractures have produced a chipping effect on the bedding surfaces which is similar in appearance to chattermarks. Chlorite and sericite are present on many of the bedding planes and elongation of minerals parallel to the striations has resulted in a streaked appearance. Cloos (1946) has described and illustrated a similar-looking lineation which he has called a slickensiding lineation. He attributes this type of lineation to slippage between bedding planes.

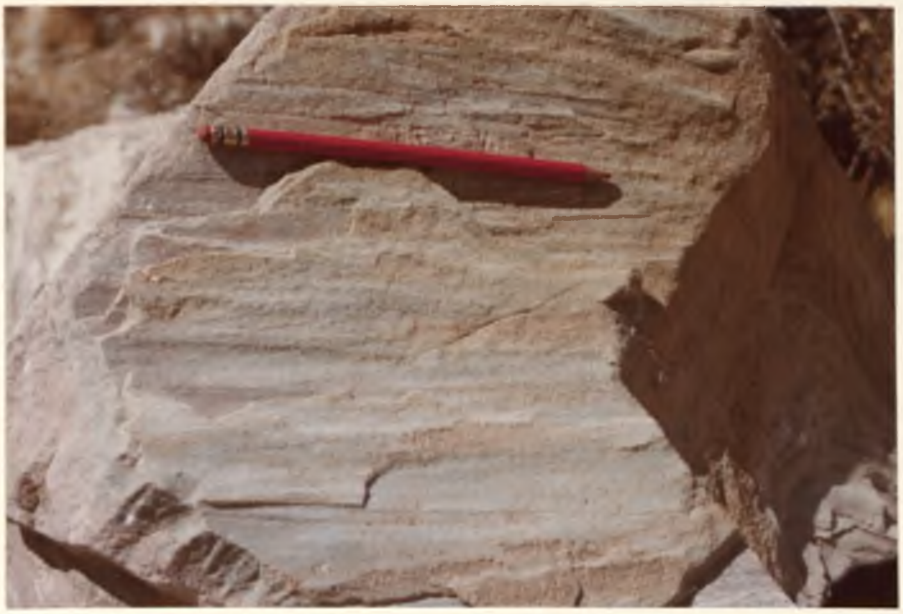

Figure 8. Photograph of the east-west trending slickenside lineation in the Horquilla Limestone.

Folds

Method of Study

Folds in metasedimentary rocks within a six-square-mile area on the southeastern flank of the Santa Catalina Mountains were analyzed as to style, orientation, and symmetry. Sander (1970) wrote extensively on the concepts of symmetry and believed that the symmetry of the physical factors involved in deformation is reflected in the geometry of the deformed rock. If this concept is applied to folding, then the fold symmetry should reflect the symmetry of the movement which produced the folding. Therefore it was assumed that fold orientations and asymmetry could be used to define the movement of the layers within which the folds are contained.

Approximately 210 folds were measured in the area. Two distinct fold styles were found, each with its own preferred orientation. The two styles will be referred to as upright and overturned and treated separately in this study. The small size and good exposure of the folds permitted direct measurement of axes and axial surfaces in the field. These orientation measurements were then converted by computer to lower-hemisphere equal-area net projections using programs devised by Davis (1971, 1972).

The slip-line direction for the inclined folds was determined using the methods of Hansen (1971). The axial surfaces of these folds show a preferred orientation parallel to the planar distribution of the fold axes. They can therefore be treated geometrically as slip folds and their separation angle confines the slip-line orientation. Hansen

(1971, p. 51) defines the separation angle as "the planar angle that separates fold axes by orientation into groups of opposite asymmetry." The slip-line directions referred to herein are for the folded beds relative to the adjacent beds that did not fold.

The fold morphology was described in detail. The folds were classified according to their shape, tightness, and form of individually folded surfaces. Fold shape was determined by comparing folds in the thesis area to 30 idealized fold forms constructed by Hudleston (1973) in his "visual" Fourier profile analysis. According to this method each fold is given a shape/amplitude alphanumeric index which corresponds to a specific shape and amplitude of one of the idealized fold forms (Figure 9).

Tightness of the folds was determined by measuring the interlimb angle and then classified according to Fleuty (1964) (see Figure 10). The forms of the folded layers were then assigned to a "Ramsay" class and/or subclass by comparison with his fundamental types of fold classes which are based on geometric considerations (Ramsay 1967) (see Figure 11). These methods were employed by Davis (1973, 1974) in the Rincon Mountains and this work begins the extension of these methods to other blocks in the Santa Catalina Mountains.

Fold Analysis

The limestone, shales, and siltstones of the upper Paleozoic units are well exposed east of the Santa Catalina Mountains. In the study area numerous mesoscopic folds can be seen within the easterly dipping units of the Horquilla Limestone. The folds are best seen in

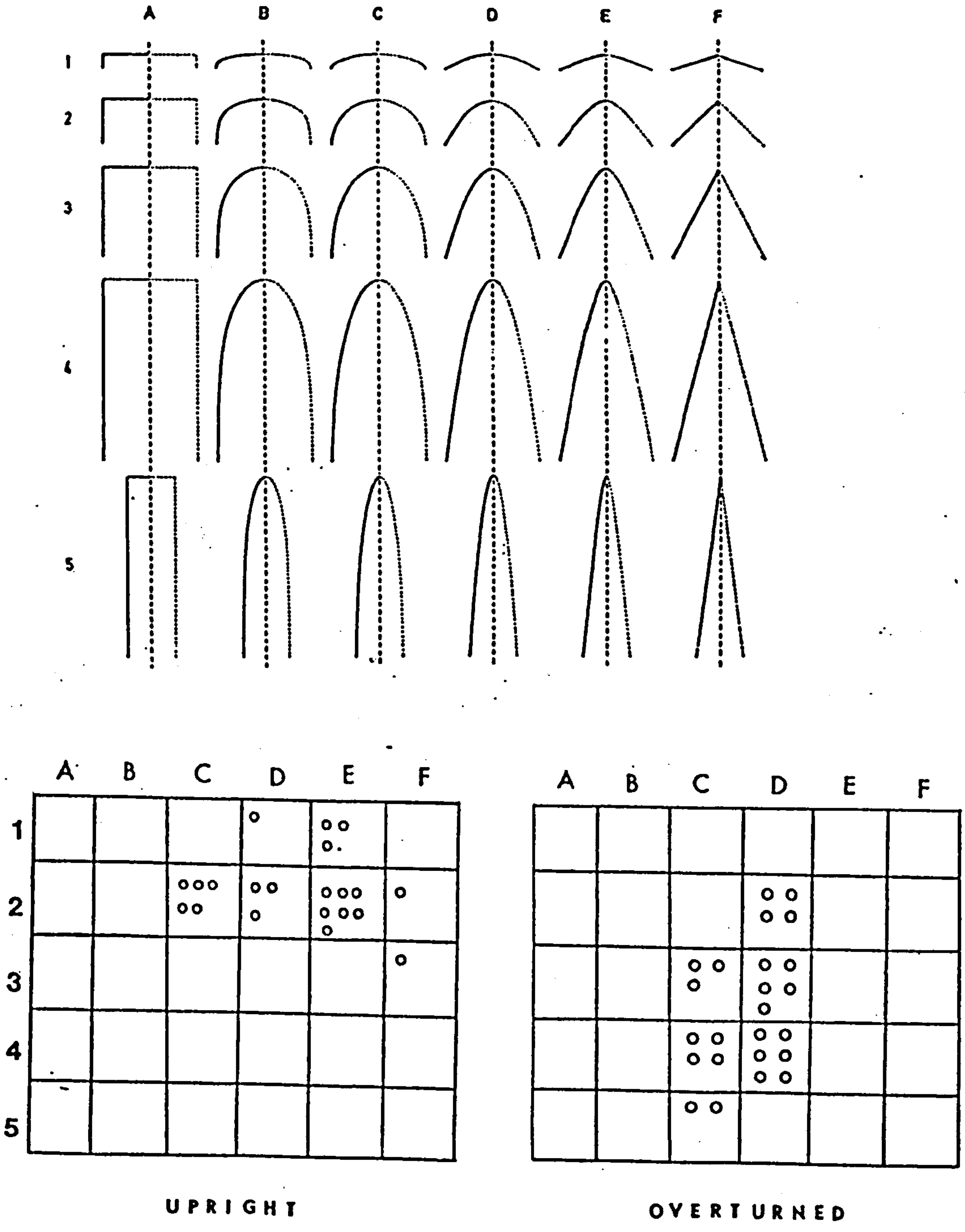

Figure 9. Diagram showing Hudleston's 30 idealized fold forms (6 categories of "shape" A-F; 5 categories of "amplitude" 1-5) and the shape/amplitude distribution of the upright and overturned folds.

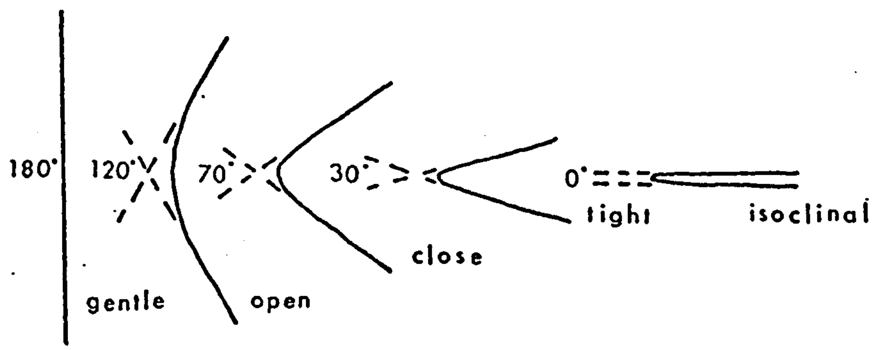

Figure 10. Diagram showing Fleuty's classification of fold tightness.

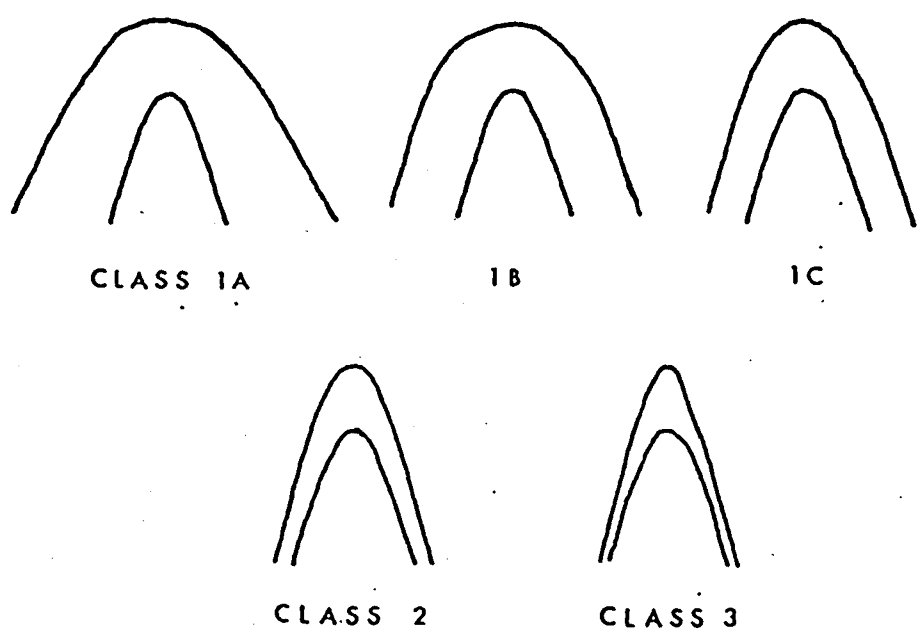

Figure 11. Fundamental fold types. -- Class 1. Curvature of the inner fold arc always exceeds that of the outer arc. Class 2. Curvatures of the inner and outer arcs are equal. Class 3. Curvature of the inner fold arc is always less than that of the outer arc. Taken from Ramsay (1967).

the shales and sandy units and are of two distinct types: (1) overturned folds which occur mainly in locations I and II of Figure 2 and (2) upright folds which are best exposed at locations II, III, IV, and V of Figure 2.

Overturned Folds. The overturned folds are much more widespread than the upright folds and can be found at many locations within the Horquilla Limestone, particularly in the southeast and southwest sections of the area. They are generally found in the sandier units within the limestones where the siliceous interbeds weather out and display folding which might otherwise go undetected. Amplitudes and wavelengths range from several inches to two or three feet, and at any one location the folds are contained within 30 feet of stratigraphic thickness.

The folds are characterized by subhorizontal to gently plunging axes and gently inclined axial surfaces. Lower-hemisphere equal-area net projections based on 106 folds (Figures 12 and 13) reflect an average axial plane orientation of N 20°-40° W, 20°-40° NE. Axis orientations are widely scattered from north-northeast to south-southeast, with maxima at approximately N 60° E and S 25° E. The axes of 87 distinctly asymmetric folds were plotted stereographically and although the orientations are widely scattered, a systematic distribution is apparent. The Z-shaped folds range in trend from north-northeast to east whereas the S-shaped folds range in trend from south to southeast. In addition the axes orientations for the asymmetric folds can be approximated by a great circle which defines the slip-surface (Figure 14).

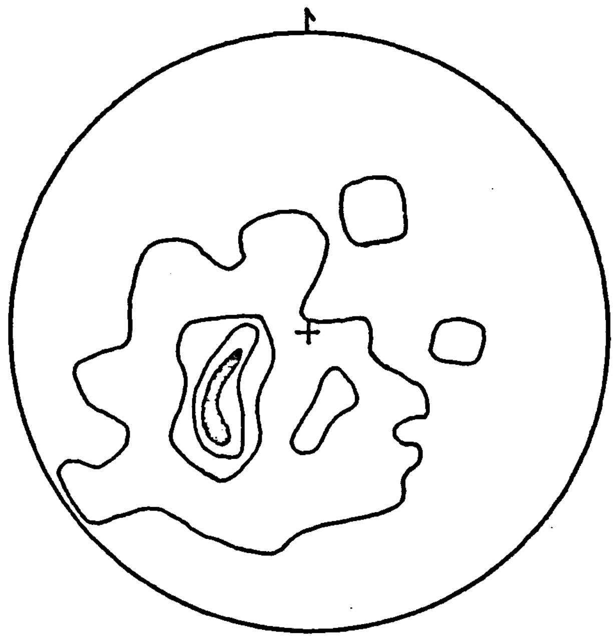

Figure 12. Lower-hemisphere equal-area net projection of poles to axial surfaces of overturned folds.

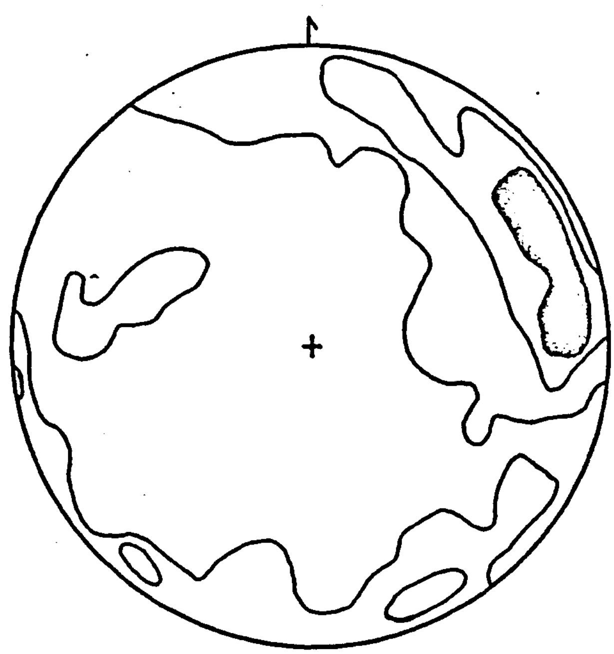

Figure 13. Lower-hemisphere equal-area net projection of axis orientations of the overturned folds.

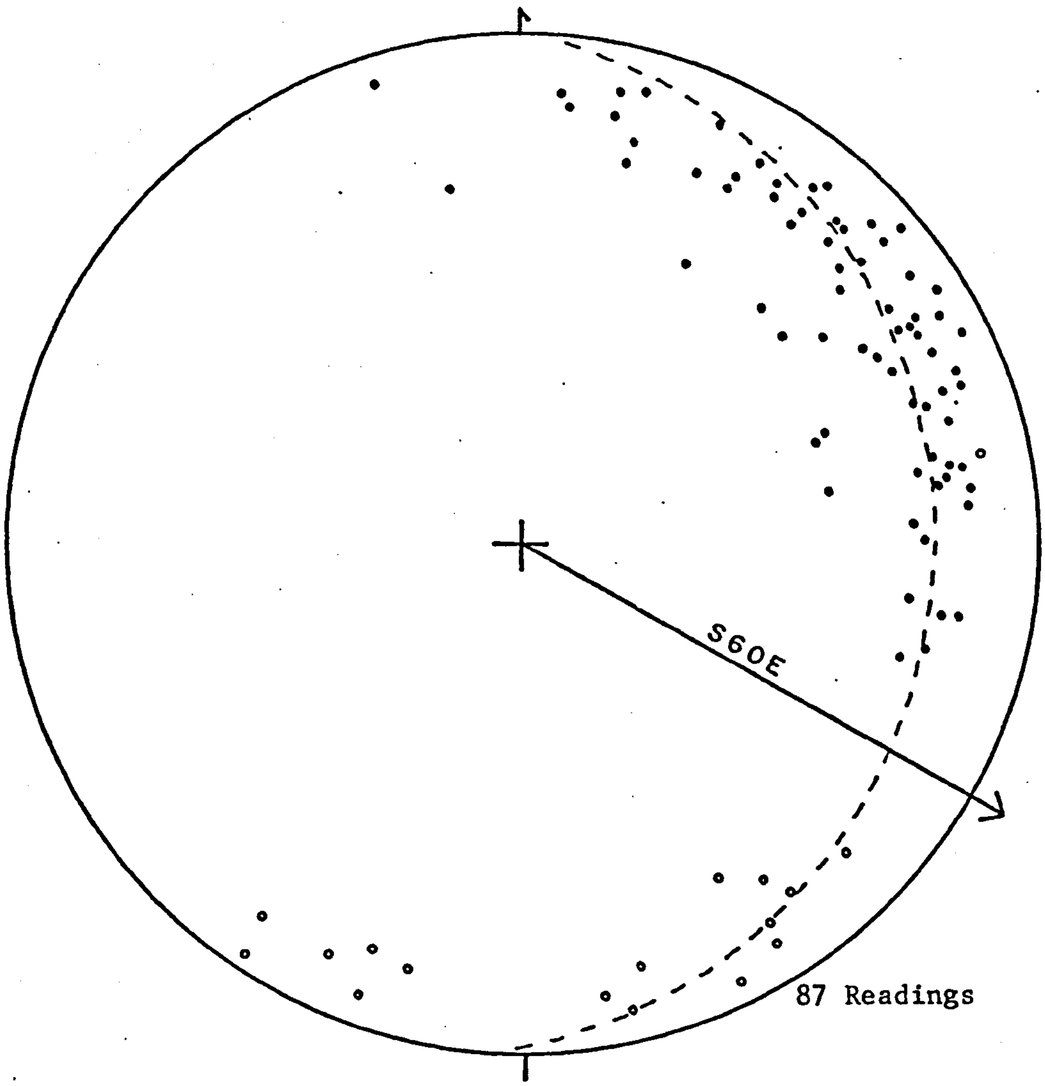

Figure 14. Lower-hemisphere equal-area net projection showing axes orientations of Z shaped (●) and S shaped (○) folds and the inferred slip-line direction of the sheet containing these folds.

The profiles of 24 folds were examined using Hudleston's (1973) visual methods and were found to reveal the shape/amplitude distribution shown in Figure 9. Most of the folds have interlimb angles ranging from 15^{o} to 70^{o} and thus range from "tight" to "close." The hinge zones are rounded to subrounded and the shapes of the folded surfaces are transitional between Class 1C and Class 2 (ideal similar) (Figure 11).

Upright Folds. The upright folds are limited to a few outcrops generally found in the north-northeast portion of the study area and are approximately 30 feet lower in the Horquilla section than the overturned folds. They are found within a ten-foot-thick shale and siltstone unit and, unlike the overturned folds, are not found in the limestones. Amplitudes and wavelengths vary from a fraction of an inch to about six feet and have a greater range in size than the overturned folds (Figures 15 and 16).

These folds are referred to as upright by the author but many have axial plane dips of less than 80^{o} and would be termed inclined according to Fleuty (1964; Figure 10). However, because few of the folds have axial plane dips less than 60^{o}, upright serves as a useful general term.

Stereographic projections of the fold elements show that the folds are characterized by gently plunging axes and steeply inclined axial surfaces (Figures 17 and 18). Specifically the axial surfaces strike on the average N 30^{o}-50^{o} W and dip 65^{o}-75^{o} NE, with an axis maximum at 10^{o} S 50^{o} E. Visual harmonic analysis of 21 folds gave the distribution shown in Figure 9. The interlimb angles range from about

Figure 15. Photograph of flexural-slip folds within the Horquilla Limestone, looking southeast.

Figure 16. Photograph of folds within the Horquilla Limestone.

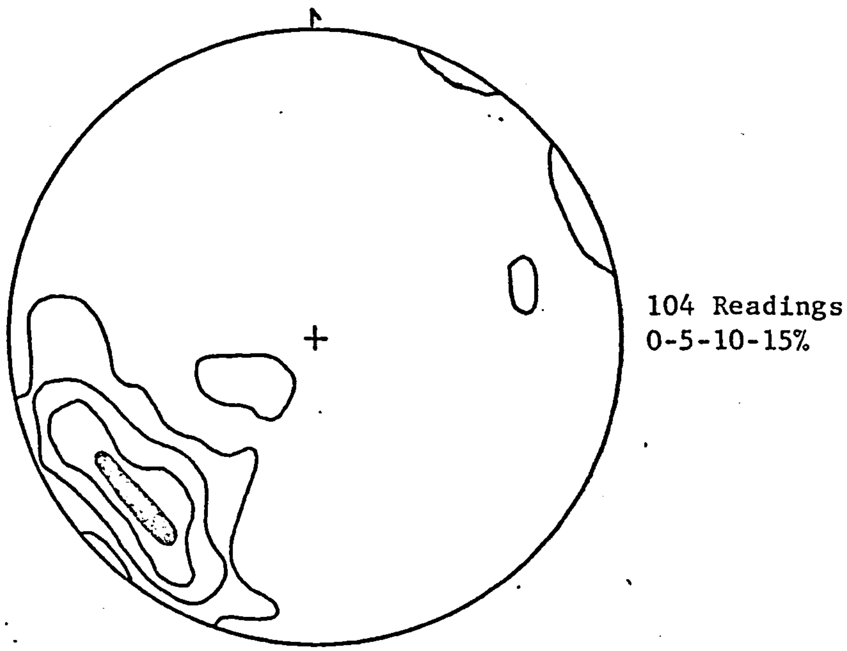

Figure 17. Lower-hemisphere equal-area net projection of poles to axial surfaces of the upright folds.

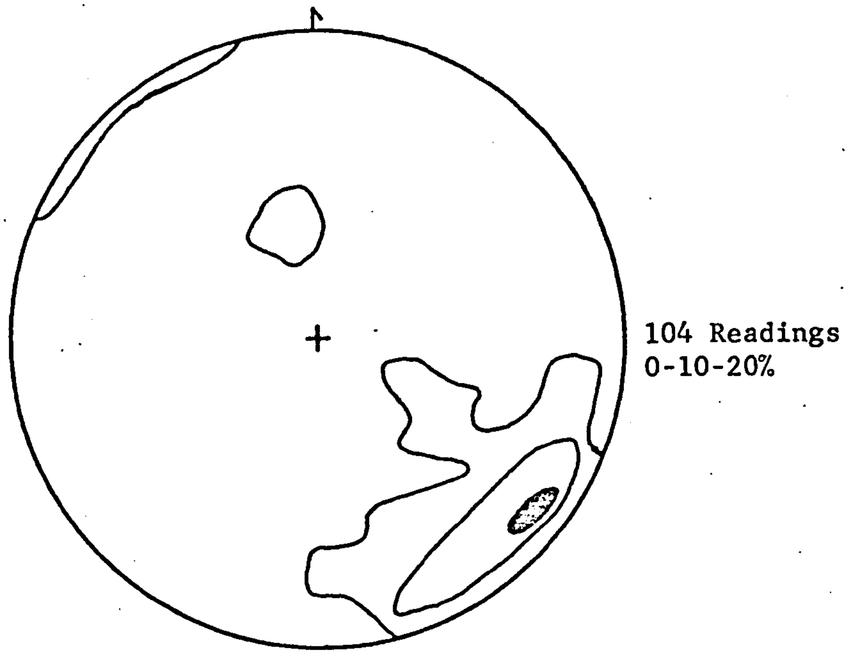

Figure 18. Lower-hemisphere equal-area net projection of axes orientations of the upright folds.

50° to 130° and are therefore classified as "open" to "gentle." The hinge zone would best be termed subangular and the shapes of the folded surfaces conform best to Ramsay's (1967) 1B (ideal parallel) and 1C Classes (Figure 11).

CONCLUSIONS

Origin of the Folds

The overturned folds are more widely distributed throughout the area than the upright folds. They are similar in style with thickened hinge zones produced by flow from the limbs (Figure 19). They display a consistent eastward asymmetry throughout the area suggesting movement in that direction towards the San Pedro Valley basin (Figure 20). This is supported by a S 60° E slip-line direction (Figure 14) derived from 87 distinctly asymmetric folds according to the methods of Hansen (1971). This slip-line direction displays a geometric relationship to the general bedding attitudes in the area in that the slip sense is generally normal to the strike. This S 60° E movement direction corresponds closely to the extremely consistent S 82° E lineation previously described. Ninety-two lineations were measured with range in attitude from about S 65° E to N 80° E (Figure 21). On the basis of similarity between this lineation and a slickenside lineation described by Cloos (1946) together with the stretched and striated appearance of the bedding surfaces, the lineation is interpreted as a product of slip between bedding planes. The lineation can therefore be used to support an east-southeast transport direction.

The forms of the folds analyzed conform to the characteristics of gravity folds described by de Sitter (1954). Features such as "cascade piles" of overturned folds and a characteristic asymmetry in

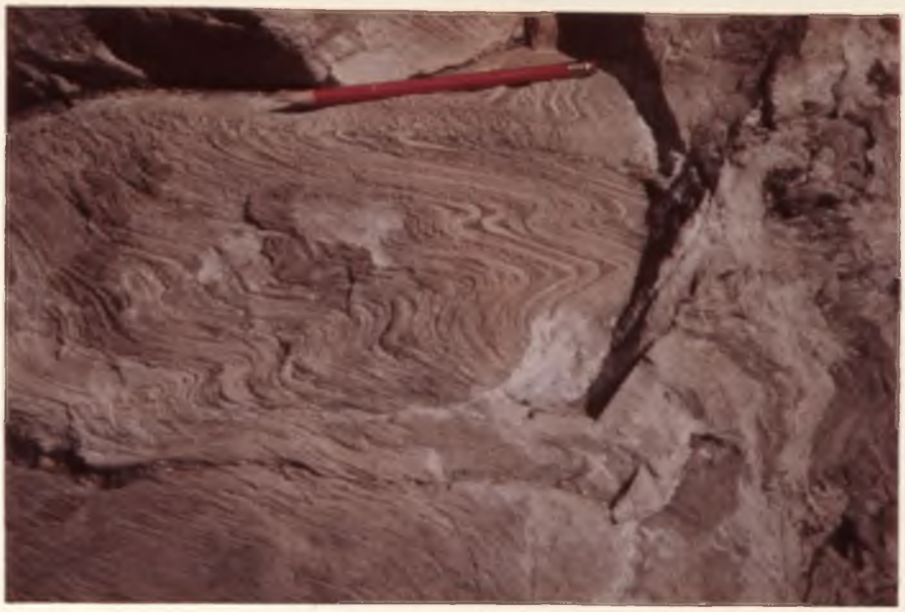

Figure 19. Photograph of similar folds within the Horquilla Limestone, looking north.

Figure 20. Photograph of S shaped folds and cascade folds within the Horquilla Limestone, looking south.

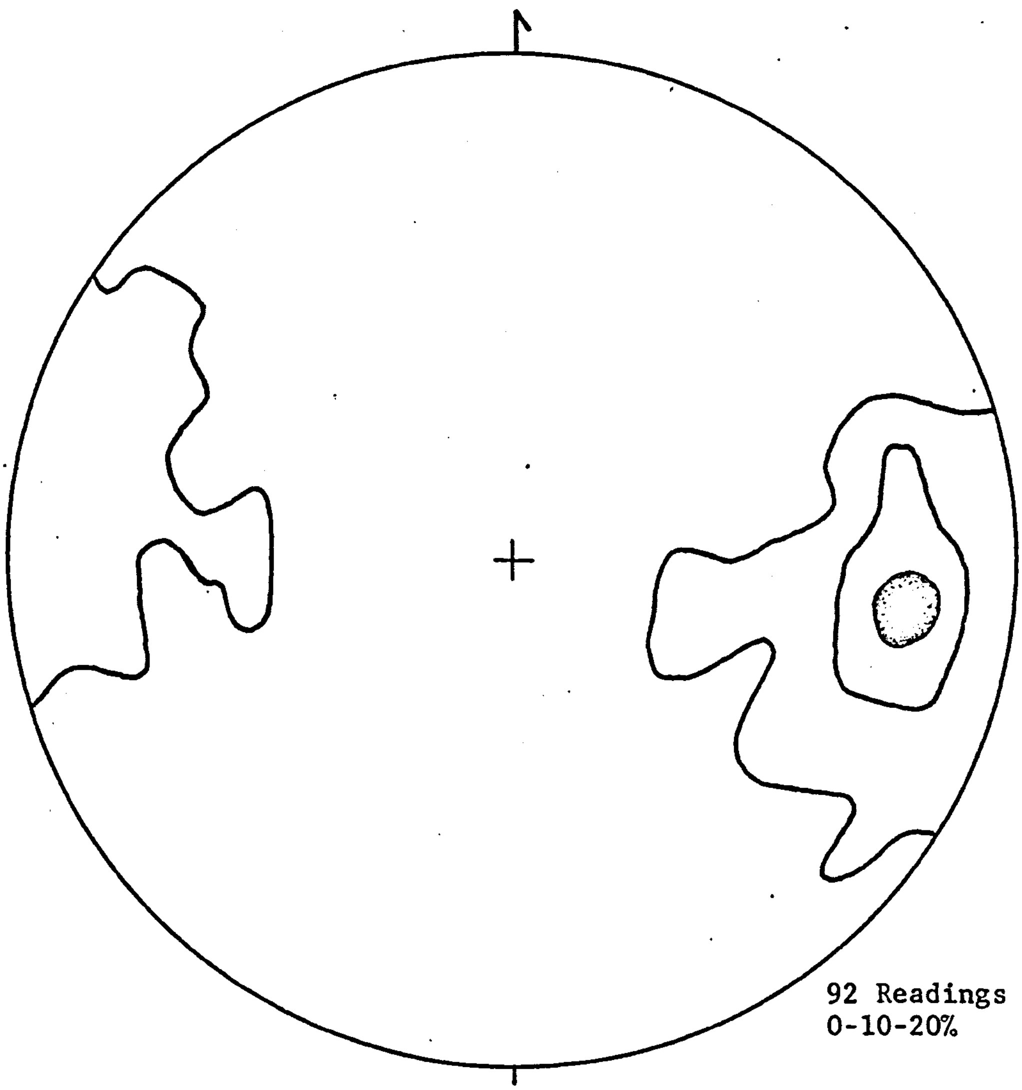

Figure 21. Lower-hemisphere equal-area net projection of orientations of slickenside lineations.

the direction of gliding are illustrated in cross-sections of gravity structures pictured in de Sitter's essay. Cascade piles of folds are present in the study area (Figure 22) and the inferred eastward movement direction satisfies the condition of asymmetry (Figures 23 and 24).

The slip-line direction, the trend of the lineation, and the fold forms previously described all suggest that the overturned folds within the sedimentary rocks on the southeastern flank of the Santa Catalina Mountains were a response to gravity gliding along bedding planes. The overturned folds are therefore considered gravity folds with an east-southeast slip-line direction.

The upright folds are restricted to a few outcrops and are in sharp contrast to the overturned folds. They show little hinge zone thickening, are concentric in geometry, and appear to have formed by flexural-slip. The upright folds are commonly found in the shaly units and are characteristically associated with abundant quartz veins and stringers. The consistent axis and axial plane orientations of the upright folds suggest a common origin and they appear to post-date at least some of the gravity gliding. Evidence for this is found where the prominent east-west lineation has been folded about the S 50° E trending axes of the upright folds (Figures 25 and 26). Any explanation for the upright folds would therefore have to account for (1) the upright nature and consistent orientation of the folds, (2) the restriction of the folds to the shaly units, and (3) the folding of the east-west-trending lineation.

Figure 22. Photograph of cascade fold within the Horquilla Limestone, looking east.

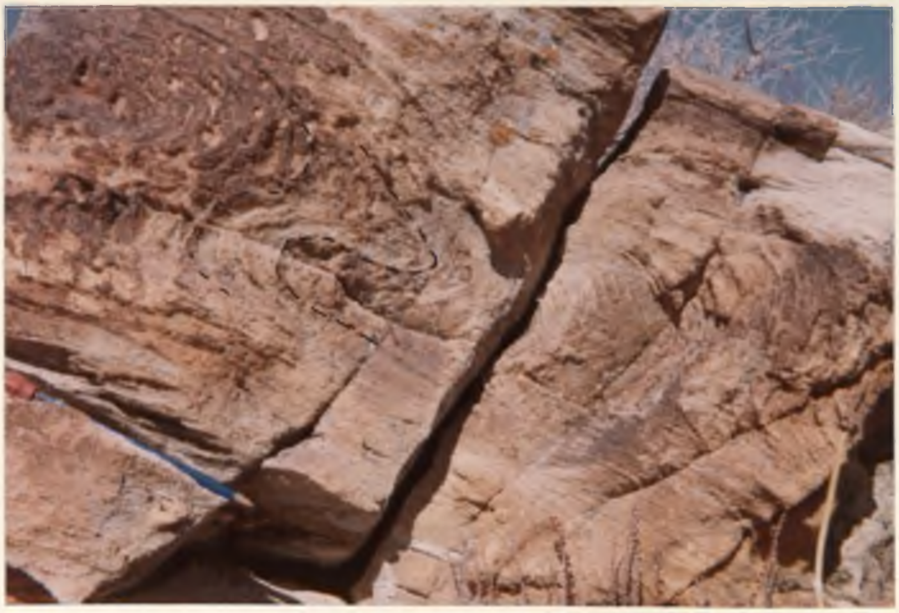

Figure 23. Photograph of Z shaped fold within the Horquilla Limestone, looking northeast.

Figure 24. Photograph of asymmetrical fold within the Horquilla Limestone, looking north; inferred movement to the east.

Figure 25. Photograph of east-west trending lineation (parallel to white pencil) on the bedding plane of folded shales (fold axes parallel to red pencil) within the Horquilla Limestone.

Figure 26. Photograph of lineation (parallel to pencil) trending east-west and folded about a northwest-southeast trending axis of an upright fold.

The northeast dip of the axial planes and the S 50° E trending axes of the upright folds would support the possibility of thrusting from the northeast. If this was the case, thrusting would have had to take place during Tertiary time in order to fold the gravity related lineation. However, thrusting from the northeast has not been previously described east of the Santa Catalina Mountains and southeast directed movement from the San Pedro Valley basin towards the Santa Catalina Mountains in Tertiary time seems unlikely. In addition there is no compelling stratigraphic evidence for thrusting and all the units dip eastwardly in their normal stratigraphic position (Figure 7).

A large gneissic-granite intrusive has been mapped a quarter of a mile to the west-southwest of the study area by Raabe (1959). The trend of the gneissic-granite contact parallels the orientation of the upright fold axes. The intrusive could have produced an underthrusting from the southwest resulting in the formation of upright folds with northeast dipping axial surfaces. However, this does not explain why the upright folds are restricted to the shaly units. It would also require the intrusive to post-date the gravity movement since the upright folds have folded the slickenside lineation. The gravity movement is proposed to be associated with Tertiary uplift of the Santa Catalina Mountains (Davis 1974). If this is true, the gneissic-granite would have to be late-Tertiary in age and no granites of this age have been previously mapped in the Santa Catalinas.

Another hypothesis is that the upright folds were produced by buttressing of the sedimentary sheets to the northeast during the later stages of gravity gliding. Buttressing is a common end effect in gravity gliding (Kehle 1970) and buttressing effects have been mapped bordering the Rincon Mountains to the south (Davis, Frost and Schloderer 1974). As the glide sheets moved down slope the presence of a buttress to the northeast of the study area would cause the plates to crumple against the buttress forming northwest-southeast trending folds. Continued eastward movement of the sheets against the stationary buttress to the northeast would produce a southwest directed force. This southwest directed push produced by buttressing to the northeast could account for the northeast dip of the axial surfaces. Buttressing would develop during the later stages of sliding and could explain the folding of the earlier formed lineation. The restriction of the upright folds to the shaly units could be a function of bedding thickness. It has been shown through field observation and laboratory study (Currie, Patnode and Trump 1962) that stratification of sedimentary rocks is significant in determining how a sequence of rocks will respond to deformation. Specifically, Currie et al. (1962) demonstrated that the wavelength of folds increases with an increase in bedding thickness. Therefore, deformation would produce mesoscopic folds within the thinly bedded shale units and broad undulations with extremely small amplitudes within the thicker bedded limestone units.

If buttressing is accepted as an explanation for the upright folds, both the overturned and the upright folds can be attributed to a common origin, namely, gravity gliding to the east. The Horquilla Limestone may represent a décollement zone as described by Kehle (1970).

According to his model, orogenic translation is accomplished by the deformation of the least competent strata within a rock sequence. The mode of deformation is simple shear. The Horquilla Limestone may represent the incompetent unit within the rock sequence of the study area and thus explain why penetrative deformation seems to be restricted to the Horquilla Limestone.

Geologic History

The sedimentary and meta-sedimentary rocks on the southeastern flank of the Santa Catalina Mountains range in age from Precambrian to Recent. The older rocks are made up of the Younger Precambrian Apache Group and are composed of quartzites, shales and conglomerates. Ordovician and Silurian rocks are not present in the study area indicating a long period of non-deposition or erosion. It was during this period of time that the Apache Group was intruded by diabase sills, uplifted, and eroded.

By Middle Cambrian time the seas of the Sonoran geosyncline (McKee 1951) invaded southeastern Arizona from Mexico, reworking the Precambrian surfacial debris and depositing the Cambrian Bolsa Quartzite. Sedimentation continued throughout the Cambrian depositing the Abrigo Formation upon the Bolsa Quartzite. The variable lithologies of the Abrigo Formation might represent transgression and regression of the seas.

As the seas regressed at the close of the Cambrian, a period of non-deposition marked early Devonian time until the seas again encroached from the south and deposited the clastics and carbonates of the Devonian Martin Formation (McKee 1951).

The Devonian sequence is conformably overlain by the Lower Mississippian Escabrosa Limestone with no evidence of a disconformity. The Escabrosa Limestone is composed primarily of limestones with a small amount of clastics representing deposition in a shallow sea of the Sonoran geosyncline. The seas retreated in Late Mississippian time and re-entered in Pennsylvanian time deposition the Horquilla Limestone. The thick sequence of Pennsylvanian limestones suggests a deeping of the basins at this time.

Post-Horquilla Limestone sediments may have been deposited in the area but if so have subsequently been removed by erosion between the end of Permian time and the beginning of the Cretaceous. By the end of Paleozoic time the area was apparently near or above sea level because Jurassic and Triassic sedimentary rocks are absent in most of southern Arizona. To the north Early Cretaceous (?) rocks (McKenna 1966) rest in angular discordance upon Pennsylvanian sedimentary rocks, but none have been found in the study area.

In post-Cretaceous time, deformation began which strongly affected the Santa Catalina Mountains and the rocks of the study area. It has been suggested by Damon et al. (1963) that the Santa Catalina complex has been subjected to a Cretaceous-Tertiary metamorphic event ending in Upper-Oligocene/Lower-Miocene time. Uplift and doming of the Santa Catalina Mountains in Tertiary time has also been suggested by

Mayo (1964), Waag (1968), and Peterson (1968) in their studies of the Catalina Mountain complex.

Initiation of gravity folding in the study area is attributed to doming of the Santa Catalina Mountains. As doming began the sediments were tilted to the east resulting in gravity-induced folds as the sedimentary rocks moved down-slope along bedding planes. Formation of the prominent east-west lineation accompanied bedding plane slip as slickensiding was produced along the bedding surfaces. The gravity folds and the associated lineation are therefore considered Tertiary in age, formed during doming of the Santa Catalina Mountain complex. Deformation within the Apache Group as exhibited by the stretched-pebbles may have also occurred at this time.

As rocks in the Santa Catalina complex began to cool during the later stages of doming, brittle fracture as displayed by the faulting replaced gravity gliding as the dominant mode of deformation. Support for this idea can be found by consideration of the prominent north-south-trending Buehman Canyon fault. This fault displays several hundred feet of stratigraphic offset. Had it existed prior to gravity sliding it would have presented a formidable obstacle to eastward-directed bedding plane movement. In addition, gravity folds are present on both sides of the fault in the southern half of the map area indicating that sliding was continuous over the area marked by the present fault trace.

The Buehman Canyon fault is a normal fault indicating tension in the east-west direction. In the northwest corner of the map area the Buehman Canyon fault forms the eastern boundary of a thick alluvial cover, which may represent an old graben structure that has been filled in with detritus. This graben structure bordered by normal faulting on the east also suggests tension in the east-west direction. The tension may have been caused by continued uplift and cooling of the Santa Catalina Mountains and as suggested by Peterson (1968) could have been relieved by normal faulting.

The east-west trending faults appear to be a result of differential displacement along the Buehman Canyon fault. Displacement along this fault decreases towards the south. The decrease in downward movement on the east side of the Buehman Canyon fault is made good by dropping the southern hanging wall sides of adjacent east-west faults.

Metamorphism within the study area represents several different time periods. Some metamorphism of the Apache Group may have taken place during Precambrian time or it may have all taken place during a much later event which resulted in recrystallization of the Paleozoic limestones. Metamorphism of the Paleozoic section is attributed to Tertiary doming and heating of the Catalina Gneiss to temperatures of 400° C to 600° C (Pilkington 1962). Evidence for this is the increase in metamorphic grade within the map area to the southwest towards a gneissic-granite complex which has been mapped by Raabe (1959) and related to the main Santa Catalina Mountain complex. Contact metamorphism accompanied intrusion of the Precambrian diabase sills within the Apache Group and intrusion of diabase dikes and plugs within the Paleozoic units. The dikes and plugs are often associated with fault zones suggesting that they have been emplaced along faults and therefore post-date the faulting.

Summary

Mapping on the southeastern flank of the Santa Catalina Mountains has shown the rocks to consist of folded and faulted sedimentary and metasedimentary rocks ranging in age from Precambrian to Pennsylvanian. Bedding throughout the area is fairly uniform in attitude, striking generally north-south and dipping 20° to 60° eastward off the Santa Catalina Mountains towards the San Pedro Valley. The major structural features in the study area are inclined to overturned folds and normal faults.

The chief conclusion of this study is that the folds on the southeastern flank of the Santa Catalina Mountains are a result of eastward directed gravity gliding along bedding planes in response to uplift of the Santa Catalina Mountains in mid-Tertiary time. The 20° to 60° eastward dip of bedding off the Santa Catalina Mountains provides sufficient slope for gravity gliding to take place. The overturned and cascade nature of the folds together with their consistent eastward asymmetry also lend credence to this idea. Further support is given by a S 60° E slip-line direction and a prominent east-west slickenside lineation produced by movement along bedding planes. This interpretation is also consistent with the findings of Davis (1973, 1974) in his study of folds within the sedimentary and metasedimentary rocks marginal to the Rincon Mountains directly to the south.

Except for movement between bedding planes the faults in the area are exclusively high angle as indicated by their very linear trends. Where offset can be determined, the faults are seen to be normal. The north-south-trending Buehman Canyon fault displays several hundred feet of displacement and is by far the major fault in the area with the east-west faulting a result of differential movement along the Buehman Canyon fault. The faulting appears to post-date the gravity movement and to have been produced by brittle failure in response to east-west directed tensional stresses. These stresses could have developed during the later stages of doming and cooling of the Catalina Gneiss.

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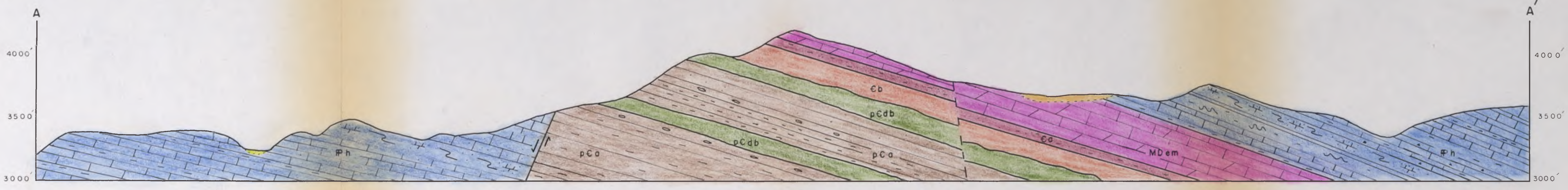
2 maps

FIGURE 7. GEOLOGIC CROSS-SECTION OF THE REDINGTON PASS AREA, NORTH OF PIETY HILL, PIMA COUNTY ARIZONA



SCALE 1 : 6000

0 500 1000 1500
feet

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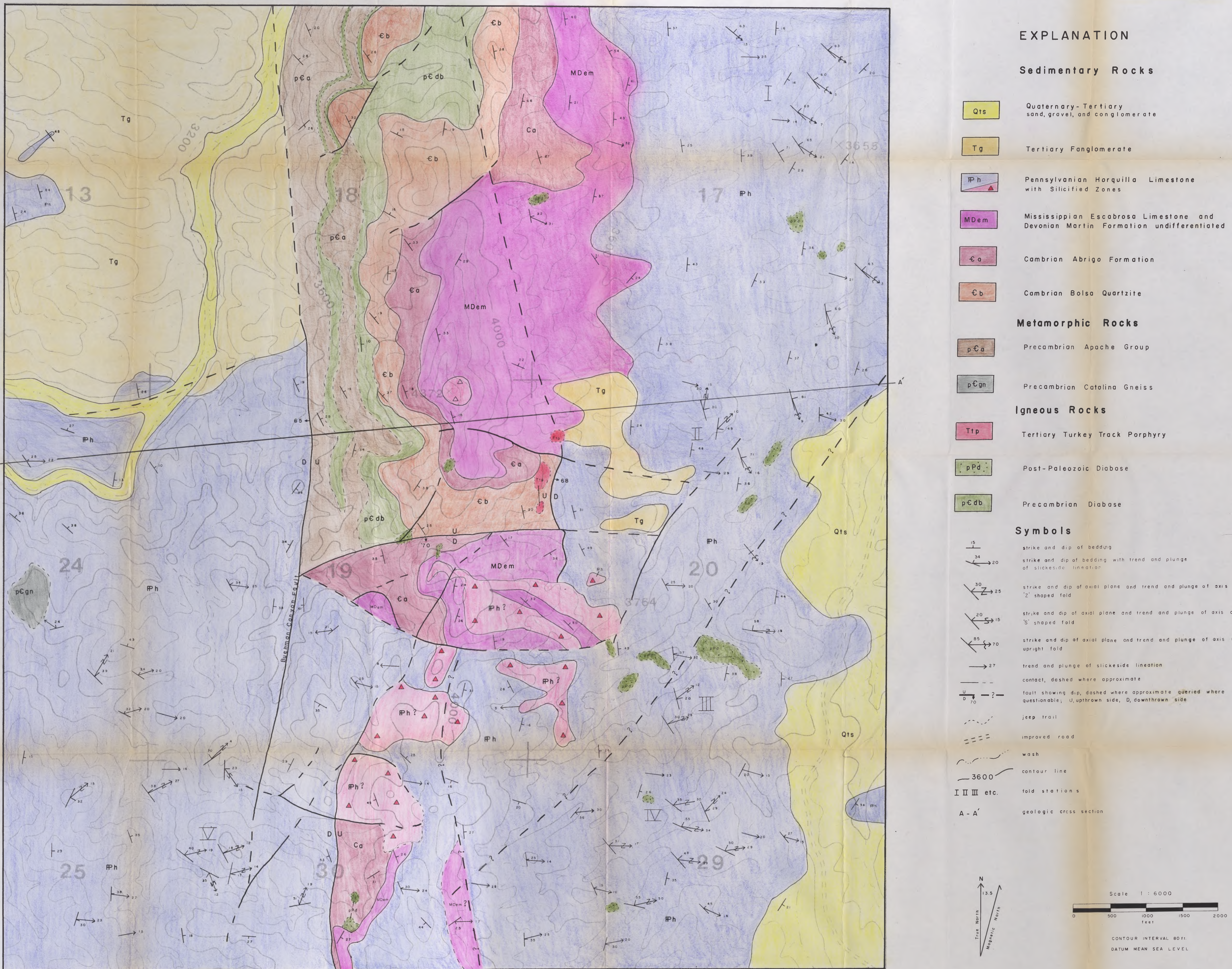
FIGURE 2. GEOLOGIC MAP OF THE REDINGTON PASS AREA, NORTH OF PIETY HILL, PIMA COUNTY, ARIZONA



Base from U.S. Geological Survey,
Bellota Ranch 15' quadrangle

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