EARLY CRETACEOUS TECTONICS AND DEPOSITION OF THE
GLANCE CONGLOMERATE, SOUTHEASTERN ARIZONA

A DISSERTATION
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DOCTOR OF PHILOSOPHY

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July 1979
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ABSTRACT

The middle Mesozoic tectonic environment of southeastern Arizona is poorly understood. Previous work suggests that during this time the area experienced pronounced local and regional uplift, local volcanic activity, extensive erosion, and subaerial sedimentation. Unfortunately, many of the details of the structural deformation that occurred during this time of major crustal instability have been obscured or destroyed by complex igneous and tectonic overprinting during the Late Cretaceous-Early Tertiary (Laramide) and mid-Tertiary (Basin and Range) orogenies.

In southeastern Arizona, a sedimentary record of the erosion and clastic deposition that accompanied the mid-Mesozoic tectonism is contained in the Glance Conglomerate, the basal formation of the Lower Cretaceous Bisbee Group. Detailed stratigraphic, sedimentological and structural analysis of the Glance Conglomerate in six key areas was made to clarify some aspects of the middle Mesozoic tectonic environment, particularly the critical relation between sedimentation and tectonics.

Regionally, the Glance Conglomerate was deposited on an extensive, though irregular, erosion surface and has a discontinuous distribution. The Glance Conglomerate is composed of poorly sorted cobble to boulder conglomerate and breccia containing clasts of Paleozoic limestone and quartzite, Mesozoic volcanics, Jurassic granite, and Precambrian schist and granite. It ranges in thickness from less than a meter to over 2000 meters, with large variations over short distances. Typically, the clasts are angular to subangular where the unit is relatively thick and subrounded to rounded where thin. Vertical variations in clast composition within the Glance often define a locally consistent internal stratigraphy that reflects exposure and erosion of progressively older pre-Cretaceous rocks within its source areas. The coarse clastic character of the unit requires that the distribution of the Glance be proximal to whatever structural deformation generated its formation and that the provenance of the clasts be relatively nearby.
Within the Glance, matrix-supported debris-flow deposits are commonly interbedded with clast-supported fluvial or braided stream deposits. Sheetflood sands and finer grained mudflow deposits are also present. The presence of these types of deposits, mapped thickness variations, lithofacies changes, and paleocurrent flow directions all suggest that the Glance Conglomerate is a proximal alluvial fan deposit shed from a rising mountain block into a local subsiding basin bounded on at least one side by normal faults. These normal faults typically trend east-west or northwest-southeast and were active during the deposition of the Glance Conglomerate.

This structural setting is strikingly different from that found farther to the north. During the Early Cretaceous, a continental margin magmatic arc existed along the entire west coast of North America. In Utah, Nevada, and California, Early Cretaceous back-arc compression and crustal shortening were generating the low-angle thrust fault structures characteristic of the Sevier Orogeny, while southeast of the Colorado Plateau, the back-arc area was a zone of continental rifting or extensional tectonics, parallel to the arc. Three tectonic models have been developed to explain this striking difference in back-arc tectonic style: A) propagation of a continental rift (aulacogen), related to the Jurassic separation of North America from South America, from the Gulf of Mexico area northwestward across Chihuahua, Mexico to reach southeast Arizona by Early Cretaceous time; B) a steeply dipping subducting slab under southeastern Arizona and a more shallowly dipping slab under Nevada, with either a bend or tear in the downgoing plate at the latitude of the Colorado Plateau; or C) an apparent anticlockwise rotation of the interior of the North American plate with respect to the continental margin arc, hinged at a pivot point centered in the Colorado Plateau area. These three models are not mutually exclusive and can be combined to form a logical tectonic history of the region.
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CHAPTER I

1. Introduction

During middle Mesozoic time, southeastern Arizona was the location of pronounced local and regional uplift, local volcanic activity, extensive erosion, and subaerial sedimentation. The details of the structural deformation that occurred during this time of major crustal instability are not well known due to complex igneous and tectonic overprinting by Late Cretaceous–Early Tertiary (Laramide) and mid-Tertiary (Basin and Range) orogenies.

In principle, much can be learned about the sequence and geometry of specific tectonic events by studying the sedimentary rocks that are deposited coincident with or in response to structural deformation. In southeastern Arizona, a sedimentary record of the erosion and clastic sedimentation that accompanied the mid-Mesozoic tectonism is contained in the Glance Conglomerate, the basal formation of the Lower Cretaceous Bisbee Group. Regionally, the Glance Conglomerate was deposited on an extensive, though irregular, erosion surface and has a discontinuous distribution. The Glance Conglomerate is composed of poorly sorted, cobble to boulder conglomerate and breccia of highly variable thickness and composition. The coarse clastic character of the unit requires that the distribution of the Glance be proximal to whatever structural deformation generated its formation and that the provenance of the clasts be relatively nearby.

Detailed stratigraphic, sedimentological and structural analysis of the Glance Conglomerate in a few selected localities greatly clarifies some aspects of the middle Mesozoic tectonic environment, particularly the critical relation between sedimentation and tectonics. The purpose of this study is to document both the depositional environment of the Glance Conglomerate and the interrelationship of this unit to major middle Mesozoic faults and related structures. The syntectonic nature of the Glance makes it an important key to understanding the regional Late Jurassic–Early Cretaceous tectonic events in southeastern Arizona and their role in the plate tectonic evolution of the southern Cordillera.
Figure 1. Southeast Arizona location map; Glance Conglomerate in yellow; areas of some smaller exposures exaggerated.
The known exposures of Glance Conglomerate and its possible equivalents are found in the region between Tucson and the southeastern corner of Arizona (Fig. 1). This region lies within the Basin and Range physiographic province and displays the characteristic linear mountain ranges interspaced with wide alluvial valleys and basins. The mountain ranges generally trend north-northwest but vary in structural complexity and style.

2. Previous Work

The Glance Conglomerate was first described by Dumble (1902) in the Mule Mountains near the town of Bisbee. The first detailed mapping of the unit was done by Ransome (1904), also in the Mule Mountains. The formation was named for a station on a now-abandoned railroad near the Glance Mine, though no type section was designated. Since Ransome's work, the Glance Conglomerate has been mapped and described in most of the mountain ranges or mining districts of the region.

Hayes and Drewes (1968) and Hayes (1970a) provide extensive compilations of the locations and distribution of presently mapped Lower Cretaceous rocks, including the Glance, in southeastern Arizona. Local studies where the Glance or its equivalents were mapped or described include those by: Hayes and Landis (1964) and Hayes (1970b) in the Mule Mountains; Drewes (1971a, 1971b, 1971c, 1972) in the Santa Rita Mountains; Hayes and Raup (1968) and Hayes (1970b) in the Huachuca Mountains and Canelo Hills; Finnell (1970, 1971) in the Empire Mountains; Gilluly (1956) and Keith and Barrett (1976) in the Dragoon Mountains; Creasey (1967) in the Whetstone Mountains; Cooper (1959, 1960) and Sabins (1957a, 1957b) in the Dos Cabezas and northern Chirichahua Mountains; Cooper and Silver (1964) in the Little Dragoon Mountains and Gunni-son Hills; and Simons (1972, 1974) in the Patagonia Mountains. No detailed work has previously been done on the Glance, though workers have compared the Glance, in a general way, to present-day fanglomerates and noted its syn-tectonic character. In an early paper, McKee (1951, p. 496) clearly construed the tectonic significance of the Glance Conglomerate and stated:

"This apparent wide distribution of similar types of conglomerate, of
local derivation and at the base of a sequence of Cretaceous strata, strongly suggests uplift of regional extent. ...there is a strong suggestion that the uplift responsible for the conglomerates was largely achieved in the form of warping and/or block faulting.... the conglomerates are all accountable to one period of uplift, and the most probable date was early in the Cretaceous or approximately at the time of the Nevadan Revolution."

The earliest recognition of middle Mesozoic faulting or tectonic activity was by Ransome (1904) in the Mule Mountains. There Ransome described major WNW-trending normal faults that cut late Paleozoic limestones but were covered by unfaulted Lower Cretaceous Bisbee Group rocks. Gilluly (1956) recognized various pre-Cretaceous faults in the Dragoon Mountains and the northwest continuation of those mapped by Ransome in the Mule Mountains. At the north end of the Dragoon Mountains, in and around the Gunnison Hills, Cooper and Silver (1964) reported pre-Glance normal faults with northwest, northeast, and east-west trends. In the Dos Cabezas-northern Chiricahua Mountains, Sabins (1957b) reported pre-Cretaceous regional upwarping and deep erosion, though no recognizable mid-Mesozoic faulting. Drewes (1972) recognized and carefully documented a complex history of early to middle Mesozoic block faulting and syntectonic deposition in the Santa Rita Mountains.

Most recently, Titley (1976) has recognized the presence of a pronounced tectonic grain of middle Mesozoic age trending N55°W in southeastern Arizona. This grain is composed of northwest-trending "discontinuities" or highly discontinuous fault traces that border and delineate major structural blocks 30-40 km wide and hundreds of kilometers long. These discontinuities are characterized by substantial vertical tectonic displacements, though transcurrent movements may also have occurred along them. Titley also makes the observation that the Glance Conglomerate occurs along or near the traces of some of the discontinuities and is absent in the centers of some of the structural blocks. This suggests to him that the Glance is a fanglomerate related to movements on the discontinuities.
3. Regional Setting

Pre-Cretaceous Rocks

The oldest rocks in southeastern Arizona are the metasedimentary and metavolcanic rocks of the Early Precambrian Pinal Schist. The Pinal Schist has a wide temporal as well as spatial distribution and is locally intruded by plutonic rocks also of Precambrian age (Wilson, 1962). Silver (1978) places the metamorphism and major orogenic deformation of the Pinal Schist at 1625-1680 m.y. b.p. Depositionally overlying this crystalline basement are the Late Precambrian clastic sedimentary and volcanic rocks of the Apache Group. In the study area, the Apache Group rocks are restricted to the Little Dragoon Mountains, though they occur more widely to the north (Cooper and Silver, 1964). Silver (1978) dates the Apache Group strata as 1100-1400 m.y. old.

The Paleozoic section is composed of 1500-2100 m (5000-7000 feet) of sedimentary rock deposited primarily in a late Paleozoic structural basin variously called the Sonoran Geosyncline (Wilson, 1962), the Sonoran Embayment (Titley, 1976), or the Pedregosa Basin (Peirce, 1976; Greenwood and others, 1977). Epeirogenic fluctuations caused repeated transgressions and withdrawals of marine waters with widespread deposition of Cambrian, Devonian, Mississippian, Pennsylvanian, and Permian strata throughout the region. These rocks are primarily shallow marine-shelf carbonates with some shale and sandstone. Silurian strata are not exposed anywhere in southeastern Arizona, whereas Ordovician rocks are rare and restricted to the mountain ranges along the eastern edge of the region (Pye, 1959; Wilson, 1962; Hayes and Landis, 1965; Peirce, 1976). Several disconformities caused by the epeirogenic movements are known throughout the stratigraphic section (see Figure 2).

The Mesozoic stratigraphy of southeastern Arizona can be divided into three major groups separated from each other by major unconformities: 1) Triassic and Jurassic rocks, 2) Lower Cretaceous rocks, and 3) Upper Cretaceous rocks. The Upper Triassic(?) and lower Jurassic strata are largely volcanic tuffs, flows, and breccias with subordinate amounts of sedimentary redbeds, are generally restricted to the western portion of the region, and rest unconformably on Paleozoic marine rocks. These strata have a combined
<table>
<thead>
<tr>
<th>SERIES</th>
<th>FORMATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td>Alluvium</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Gravels and Basin Fill</td>
</tr>
<tr>
<td></td>
<td>Pantano Formation Faraway Ranch Formation</td>
</tr>
<tr>
<td>Late Cretaceous</td>
<td>Salero Formation Bronco Volcs. Nipper Fm.</td>
</tr>
<tr>
<td></td>
<td>Fort Crittenden Formation</td>
</tr>
<tr>
<td>Early Cretaceous</td>
<td>Turney Ranch Formation</td>
</tr>
<tr>
<td></td>
<td>Cintura Formation Shellenberger Canyon Fm.</td>
</tr>
<tr>
<td></td>
<td>Mural Limestone Apache Canyon Formation</td>
</tr>
<tr>
<td></td>
<td>Morita Formation Willow Canyon Formation</td>
</tr>
<tr>
<td></td>
<td>Glance Conglomerate Bathtub Formation</td>
</tr>
<tr>
<td></td>
<td>Temporal Formation</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Canelo Hills Volcanics</td>
</tr>
<tr>
<td></td>
<td>Gardner Canyon Formation</td>
</tr>
<tr>
<td>Triassic(?)</td>
<td>Mount Wrightson Formation</td>
</tr>
<tr>
<td>Permian</td>
<td>Erp Formation</td>
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<tr>
<td></td>
<td>Horquilla Limestone</td>
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<tr>
<td></td>
<td>Black Prince Limestone</td>
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<td>Pennsylvanian</td>
<td>Paradise Formation</td>
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<tr>
<td>Devonian</td>
<td></td>
</tr>
<tr>
<td>Ordovician</td>
<td></td>
</tr>
<tr>
<td>Cambrian</td>
<td>Pinal Schist</td>
</tr>
<tr>
<td>Older Precambrian</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Regional stratigraphic column for southeastern Arizona.
thickness of over 3000 m with a distribution that suggests deposition in linear fault-controlled basins (Hayes, Simons, and Raup, 1965; Hayes and Drewes, 1968; Drewes, 1971c). The most extensive outcrops are found in the Canelo Hills, the Santa Rita Mountains, the Huachuca Mountains, and the Mustang Mountains. Granitic plutonic rocks of Jurassic age are also known in the western and central parts of the region. The volcanic and plutonic rocks are part of the continental-margin magmatic arc that trended west-northwest across southern Arizona in Late Triassic through Early Jurassic time (Coney, 1978).

Lower Cretaceous Rocks

Separating Lower Cretaceous strata from all older rocks is a widespread unconformity that locally shows strong relief. Lower Cretaceous strata, excluding the basal Glance Conglomerate, comprise over 350 m of sandstone, siltstone, shale, and limestone. The type section is located in the Mule Mountains, and was divided by Ransome (1904) into three conformable formations, the Morita Formation, the Mural Limestone, and the Cintura Formation. The dominantly nonmarine Morita Formation is composed of fluvial and deltaic sandstone, siltstone, and shale with some minor limestone near its upper contact. The Mural Limestone is a relatively thick-bedded, fossiliferous, shallow marine-shelf limestone unit which weathers to distinct topographic ridges where it is particularly thick and massive. Conformably above the Mural, the marine siltstone and shale of the Cintura Formation grades abruptly upward into nonmarine deltaic and fluvial sandstone nearly impossible to distinguish from those in the Morita Formation. This total sequence of strata represents the transgression and regression of a shallow marine sea during Aptian-Albian time. This sea entered Arizona from the southeast where it had existed in Mexico as a northwest-trending linear trough since the Late Jurassic (Cordoba and others, 1971; Hayes, 1970a; Rangin, 1978).

The Bisbee Group rocks change in character as the shoreline of the Aptian-Albian sea, or the maximum transgressive limit of the marine facies, is reached. To the north and west, the proportion of limestone decreases to small amounts of thin-bedded, silty, brackish water limestones, and as a result, the Cintura and Morita Formations can no longer be differentiated as
mappable units. In the Santa Rita, Empire, and Whetstone Mountains, the Bis-
bee Group has been divided into a different set of mappable formations. Here
the Willow Canyon Formation, Apache Canyon Formation, Shellenberger Canyon
Formation, and Turney Ranch Formation conformably overlie the Glance Con-
glomerate (Tyrrell, 1957; Finnell, 1970; Drews, 1971c). These formations are
composed predominantly of nonmarine conglomerate, sandstone, siltstone, and
shale, though the Apache Canyon Formation contains a few thin beds of silty
limestone (Drews, 1971c; Finnell, 1970).

Post-Lower Cretaceous Rocks

Rocks of Late Cretaceous age include thick, though spatially restricted,
sequences of dominantly fluvial sedimentary rocks, conformably overlain by
much more widely distributed latest Cretaceous andesitic to rhyolitic volcanics.
These rocks rest with major unconformity on deformed earlier Mesozoic strata
and overlie rocks as old as Precambrian in some areas (Hayes and Drewes,
1968).

Plutonic rocks of Late Cretaceous and early Tertiary age are widespread
in southeastern Arizona. Intruded during the Laramide Orogeny, they often
have the form of shallow stocks and are closely associated with the many por-
phyry copper deposits known in the region. These intrusives have destroyed,
deformed, or metamorphosed much of the older Mesozoic record. Also during
the Laramide, the region was subjected to northeast-southwest directed com-
pressive stresses which produced northwest-trending folds and various types
of faults (Drews, 1978).

The Tertiary sedimentary rocks are all continental deposits and include
coarse clastic basin fills as well as fine-grained lacustrine sediments. Vol-
canic units are also known in some areas. The paucity of fossils in these non-
marine strata has hindered the formulation of regional time-stratigraphic cor-
relations. Middle Tertiary deformation and tectonic denudation related to the
evolution of metamorphic core complexes resulted in thermal uplift and devel-
opment of local large-scale gravity slide blocks (Davis, 1975; Davis and Coney,
1979). Late Tertiary and Quaternary volcanism along with Basin and Range
tectonism (mostly normal faulting) have covered, or caused to be covered,
much of the older stratigraphic record in southeastern Arizona.

4. General Stratigraphy of the Glance Conglomerate

Throughout southeastern Arizona the Glance Conglomerate varies greatly in thickness, clast composition, texture, subjacent contact relationships and even in age. This characteristic variability, coupled with the absence of fossils, marker beds, and lack of continuous exposure or the exposure of strata in more than two dimensions, has severely hindered past stratigraphic correlation and interpretation of this unit. Regional recognition of the Glance has been based solely on its coarse nature, its stratigraphic position conformably below dated Lower Cretaceous strata, and its unconformable relations with underlying pre-Cretaceous rocks. The Glance rests with angular unconformity on rocks of Jurassic to Precambrian age and interfingers both laterally and vertically with the sandstone and mudstone of the Lower Cretaceous Morita Formation or its stratigraphic equivalents. When analyzed in detail, the high variability of certain characteristics in the Glance make it an exceedingly useful tool for reconstructing local as well as regional tectonic patterns.

Regionally, the Glance Conglomerate was deposited on an extensive, though irregular, erosion surface and has a discontinuous distribution. In thickness, the Glance ranges from zero (locally absent) to over 2000 m, with large variations over short distances. Lithologically, it contains mostly poorly sorted, irregularly bedded cobble to boulder conglomerate and breccia which lack distinguishable internal, as well as bedding plane sedimentary structures. Stratification is not clearly discernible, though bedding attitudes can usually be approximated from small interbedded sandstone and siltstone lenses or from vertical changes in grain size, sorting, or framework packing. The thin intra-conglomerate sandstone lenses are flat-bedded or cross-stratified with very low dip angles.

Texturally, the Glance ranges from a very poorly sorted, matrix-supported, disorganized conglomerate to relatively well sorted, clast-supported, well bedded conglomerate. The matrix-supported conglomerate is locally abundant where the Glance is relatively thick. Regionally, however, the Glance is
predominantly a clast-supported conglomerate with a sandy matrix. Cut-and-fill channel structures are locally present.

Compositionally, the Glance consists of clasts derived from a wide variety of rock types with diverse ages. Late Paleozoic limestone and dolomite, Cambrian quartzite, Precambrian schist and granitic rocks, Triassic(?) and Jurassic (or possibly even Lower Cretaceous) volcanic rocks, and Jurassic granitic rocks are the most abundant clast types. Usually, at any given locality, one of these clast types predominates, but given the great diversity of rock types in the source areas, many combinations of clast types can be found. In the western part of the region, which includes the Huachuca and Santa Rita Mountains areas, the Glance Conglomerate is locally interbedded with significant thicknesses (hundreds of meters) of andesitic to rhyodacitic volcanic flows, breccias, and pyroclastics (Hayes, 1970b; Drews, 1971c).

Where the Glance is thin (1-10 m), the clasts are subrounded to rounded cobbles and pebbles, have a sandy matrix, and usually contain one dominant clast type. Where relatively thick (100-2000 m), the Glance is coarser with boulders commonly reaching 2 m in maximum diameter. Typically, it contains large amounts of silt- and clay-sized matrix and has subrounded to subangular clasts of many different rock types. In areas, these different clast types show a systematic vertical variation that defines specific clast assemblages producing a locally consistent internal stratigraphy. The various clast assemblages delineate conglomerate-clast lithofacies units named for the most abundant clast type or types present. As a result, the Glance Conglomerate can be divided into limestone-, quartzite-, schist-, granitic-, and volcanic-clast lithofacies, though no more than three such units are usually present in any one area.

Consistent vertical stacking of clast lithofacies is well developed in only two of the major outcrop localities, the Mule Mountains and the Empire Mountains. In these two areas, the Glance contains an inverted stratigraphy of the various pre-Cretaceous formations found within the respective source terranes, and thus reflects the sequential uplift, exposure, and erosion of successively older rock units. In the other areas of major expanses of Glance outcrop,
internal stratigraphy is less well developed or even absent. These exposures display only a single lithofacies or a clast composition so mixed that lithofacies boundaries cannot be resolved.

5. Areas of Study

Field work was concentrated in six major outcrop localities in southeastern Arizona. These six areas are the: 1) Mule Mountains, 2) Empire Mountains, 3) Huachuca Mountains, 4) Santa Rita Mountains, 5) Dragoon Mountains-Gunnison-Red Bird Hills area, and 6) Dos Cabezas-Chiricahua Mountains area (Fig. 1). The primary evidence for post-Paleozoic, pre-Cretaceous tectonic activity in these areas comes from three interrelated indicators: 1) syntectonic sedimentary rocks (the Glance Conglomerate), 2) syntectonic volcanic and plutonic igneous rocks, and 3) mappable structural features, principally faults. This study is mainly concerned with the first source of information, but where applicable, data from the other two sources are discussed and integrated into the regional synthesis.
CHAPTER II

MULE MOUNTAINS

1. Introduction

The best known and most extensive exposures of Glance Conglomerate are in the southern Mule Mountains near Bisbee. Here the Glance is exposed in three principal outcrop areas, one long, narrow, ridge-capping band north of Bisbee, and two broad tracts of reasonably good exposure to the southeast of town. These three outcrop areas are separated from each other by two west-northwest trending fault zones, the Dividend-Lavender Pit fault zone and the Abrigo-Bisbee West-Gold Hill fault zone (Fig. 3). The faults delineate three individual structural blocks, each of which contains Glance Conglomerate with a unique set of physical characteristics and stratigraphic relationships. Distinct differences in the thickness of the Glance, its overall clast composition, subjacent rock types, and average paleocurrent flow directions are notable between the three blocks. Though some of these physical parameters show abrupt changes across the faults, the variations are systematic and can be related to syndepositional vertical displacements along the two fault zones.

2. Stratigraphy of the Glance Conglomerate

Northern Block

North of the Dividend fault, the Lower Cretaceous Glance Conglomerate unconformably overlies either Precambrian Pinal Schist or Jurassic Juniper Flat Granite. Conformably above the Glance are up to 1600 m of Lower Cretaceous sedimentary rocks which include the Morita, Mural, and Cintura Formations of the Bisbee Group (Fig. 4). The entire section dips homoclinal to the northeast and covers the northeastern half of the mountain range (Hayes, 1970b). The low relief nonconformity at the base of the Glance represents a period of uplift and erosion that stripped the entire Paleozoic section, at least 1500 m of strata, from the northern structural block and exposed the Precambrian
Figure 3. Generalized geologic map of the Mule Mountains. (Modified from Hayes and Landis, 1964)
Figure 4. View northward from Gold Gulch. Ivanhoe Mine in foreground. Upper (massive) member of the Mural Limestone caps ridge in background with lower member Mural Limestone (grayish) and Morita Formation (reddish beds) cropping out below. In the distant foreground, schist-clast member Glance Conglomerate (on the right) unconformably laps up onto more steeply dipping Horquilla Limestone. Mule Mountains.
metamorphic basement and a Jurassic granitic pluton.

The Glance Conglomerate is nowhere more than 30 m thick in the northern structural block, and due to minor local relief on the basal unconformity, is occasionally absent. In most places, the thickness of the Glance ranges from 5 to 15 m. In three widely spaced holes, drilled through the overlying Bisbee Group rocks farther to the east, 15-16 m of conglomerate was encountered overlying Pinal Schist (Table 1). These drill hole data confirm that the entire Paleozoic section was eroded from the northern structural block prior to Glance deposition for at least as far as 4 km east-northeast of the nearest Glance outcrops.

For the most part, the Glance Conglomerate of the northern block is a poorly sorted, fairly well bedded, clast-supported conglomerate with a matrix of reddish brown to purplish red silt, sand, and grit. Its clasts are typically rounded to subangular cobbles and pebbles, the largest of which measured 50 cm in diameter, though the average size range is from 5-10 cm. Coarse, pebbly sandstone beds interfinger with the conglomerate as the gradational upper contact with the Morita Formation is reached. Thus the Glance grades upward into progressively finer grained, better sorted, and better bedded rocks. Local relief of the unconformity, usually most pronounced over the heavily weathered surface of the Juniper Flat Granite, occasionally causes the Glance to pinch out and places the sandstones and siltstones of the Morita Formation directly on granitic basement.

Compositionally, the clasts of the Glance Conglomerate reflect the immediately underlying rock type. Where it overlies Pinal Schist, it usually contains over 80% gray aphanitic quartz-mica-schist clasts with less than 20% white quartz, brown to gray quartzite, and pink granitic clasts. Conglomerate with this high percentage of schist clasts will be referred to as schist-clast conglomerate. Locally, the Pinal Schist contains a massive body of gray quartzite, and the Glance reflects this change in subjacent rock type with higher quartzite clast percentages. The percentage of granitic clasts in the conglomerate increases northwestward along the outcrop belt until a predominantly granitic-clast conglomerate is found overlying the Juniper Flat Granite. Lenses
Table 1. Table of drill hole information concerning the thickness of Glance Conglomerate encountered in the hole and the rock type beneath the Glance. Data courtesy of Phelps Dodge Corporation.

<table>
<thead>
<tr>
<th>Location</th>
<th>Collar Elevation (Feet)</th>
<th>Thickness Glance (Feet)</th>
<th>Rock Underlying Glance</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. 22S., R. 24E., E/2 Sec. 27</td>
<td>5,000</td>
<td>50</td>
<td>Schist</td>
</tr>
<tr>
<td>T. 23S., R. 24E., S/2 Sec. 10</td>
<td>5,400</td>
<td>54</td>
<td>Schist</td>
</tr>
<tr>
<td>T. 23S., R. 25E., SW/4 Sec. 7</td>
<td>5,200</td>
<td>50</td>
<td>Schist</td>
</tr>
<tr>
<td>T. 23S., R. 25E., N/2 Sec. 19</td>
<td>5,000</td>
<td>353</td>
<td>Limestone</td>
</tr>
<tr>
<td>T. 23S., R. 25E., Center Sec. 29</td>
<td>5,100</td>
<td>606</td>
<td>Limestone</td>
</tr>
<tr>
<td>T. 24S., R. 25E., E/2 Sec. 5</td>
<td>4,700</td>
<td>2,110</td>
<td>Limestone</td>
</tr>
<tr>
<td>T. 24S., R. 25E., SE/4 Sec. 6</td>
<td>4,800</td>
<td>2,363</td>
<td>Limestone</td>
</tr>
</tbody>
</table>
of schist-clast conglomerate are also found throughout the dominantly granitic-clast section as would be expected if, as the drilling shows, Pinal Schist underlies the Lower Cretaceous Bisbee Group strata northeast of the Juniper Flat pluton. About 700 m due north of the "State Radio Tower" above Mule Pass, well rounded limestone clasts, as large as 20-25 cm across, were found in a few restricted cobble lenses. This suggests that some Paleozoic rocks may still be preserved under the Bisbee Group cover far to the northeast.

Central Block

South of the Dividend fault, but north of the Abrigo-Bisbee West-Gold Hill fault zone, the Glance Conglomerate dips 10°-20° northeast and rests with angular unconformity on late Paleozoic rocks ranging in age from the Mississippian Escabrosa Limestone to the Permian Colina Limestone (Fig. 3 and Plate 1). Major relief on the unconformity is demonstrated by the fact that the Glance is only 25-50 m thick where it rests on Colina Limestone, but increases to 100-200 m in thickness where it overlies Escabrosa and Horquilla Limestone basement. Data from two drill holes in the central block document these thickness trends farther to the east under the Bisbee Group cover. This thickness variation and the outcrop pattern of the unconformity suggest that major canyons cut into Paleozoic basement were subsequently filled by Glance Conglomerate. The Paleozoic strata beneath the unconformity were tilted 20°-30° northeastward prior to deposition of the Glance Conglomerate, suggesting rotation of this fault block around a northwest-trending, horizontal axis parallel to the bounding faults, in pre-Glance time. No Glance Conglomerate or Bisbee Group rocks are preserved on the central block west of the Lavender Pit.

The central block is split by the northeast-trending Quarry fault into two separate blocks, referred to by Ransome (1904), as the Copper Queen block on the east, and the Bisbee block on the west, though Ransone's Bisbee block also included the Juniper Flat Granite and the Lower Cretaceous strata on the northern structural block. The Quarry fault displays 150 m down-to-the-northwest normal displacement (Hogue and Wilson, 1950), and does not offset the Dividend or the Bisbee West faults. The central block has thus not acted as one single mass but has experienced different tectonic movements during post-Paleozoic,
pre-Cretaceous time.

The Glance Conglomerate exposed in the central block is very similar, in most respects, to that found in the northern structural block. Here, it is a very poorly sorted, poorly bedded, cobble-to-boulder conglomerate with a reddish, silty to sandy matrix. Typically, the conglomerate has a clast-supported framework, though zones of matrix-supported conglomerate occur locally. Most of the clasts are subrounded to subangular and are 10-15 cm across, but some are angular, and occasional boulders measure as much as 1.5 m in diameter.

Cobbles of gray Pinal Schist are the dominant clast type in the Glance Conglomerate of the central structural block. Typically it makes up 80% of the clasts, with bulb quartz, chert, and brown quartzite comprising 15%, and sandstone, limestone, and volcanic clasts the remaining 5%. Thus, this conglomerate belongs to the schist-clast conglomerate lithofacies. The only granitic clasts found are a few random cobbles in the westernmost outcrops scattered around the town of Warren, due south of Bisbee. If any granitic-clast conglomerate had existed farther to the west, it has been subsequently eroded. Local concentrations of quartzite, limestone, and volcanic clasts significantly alter the clast proportions and the general aspect of the conglomerate in some areas. The amount of quartzite increases downward in the conglomerate, as does the number of limestone clasts and overall proportion of volcanic clasts. Limestone clasts actually make up an angular limestone breccia along the basal contact where the Glance unconformably overlies Paleozoic limestone. This breccia is 15-50 cm thick and is restricted to this zone with only an occasional rounded limestone cobble or layer with scattered limestone clasts found higher in the section.

In the lower half of the thicker parts of the section, concentrations of light pink rhyolitic volcanic clasts are found. These rhyolitic clasts are up to 1.5 m in diameter and may constitute 25-35% of some zones, giving the Glance a much lighter appearance in outcrop. The matrix also becomes finer grained throughout these areas. The rhyolitic clasts are particularly abundant in the drainage basin near the Ivanhoe Mine, northwest of Gold Hill (Plate 1). Other
volcanic clasts are found in the Glance including a dark red porphyry, with one excellent roadcut containing a couple of different varieties located along the northeast side of the main road that runs through Warren. Here, a 30 cm volcanic clast of dark red, amygdaloidal lava and a 25 cm long clast of pink to off-white tuff or rhyolite with quartz and feldspar phenocrysts are found. The dominant clast type in this roadcut is still Pinal Schist. No previous recognition of volcanic clasts in the Glance Conglomerate of the Mule Mountains, except for porphyry, has been reported in the literature, and no local exposures of pre-Cretaceous volcanic rocks are known in the area to act as source rocks. Thus, the origin of these volcanics is unknown, but must be local, as their large size argues against long sedimentary transport.

Southern Block

South of the Abrigo-Bisbee West-Gold Hill fault system, the Glance Conglomerate rests unconformably on late Paleozoic strata, primarily the Pennsylvanian Hornquilla Limestone. Actual exposure of the unconformity, unlike the widespread exposure in the two blocks to the north, is limited to a few local outcrops along the eastern, upthrown side of the Glance fault (Plate 1). This structure is a previously unmapped, north-northwest trending, high angle, reverse fault that splays off the Gold Hill fault zone and divides the southern block into two separate tracts of Glance Conglomerate (see Appendix 1 for discussion of the origin of the Glance fault). West of the Glance fault, the conglomerate dips gently southwestward and is conformably overlain by the maroon colored sandstones and siltstones of the Morita Formation. East of the fault, the Glance dips gently northeast and is faulted against Paleozoic limestone and Morita Formation along the Gold Hill fault zone. Due to uplift and erosion of this fault block, the upper contact with the Morita is missing along with a major portion of the Glance itself. The Glance fault thus occupies the position of the axis of a northwest-trending anticlinal fold structure. The presence or absence of an actual flexural fold in this location has been the basis for many of the previous structural interpretations of the southern Mule Mountains.

The thickness of the Glance Conglomerate in the southern block is up to ten times greater than the thickness of Glance of the central block. Using drill
hole information and structural field data, a thickness of 1800-2300 m of conglomerate is estimated to overlie Horquilla Limestone basement. Exact measurement of the thickness is not possible, since the bottom of the formation is not exposed on the downfaulted side of the Glance fault, and the top is missing on the eastern, upthrown side. Relief on the sub-Glance unconformity, as demonstrated in the central block, also introduces a great deal of uncertainty to any thickness estimates.

Compositionaly, only the upper 400-600 m of conglomerate in this block are similar to the schist-quartzite conglomerate located in the central and northern structural blocks. The underlying 1200-1700 m of section gets increasingly richer in limestone and dolomite clasts downward until a limestone-clast conglomerate is found in the lower part of the formation. This vertical variation in clast composition defines specific clast assemblages or lithofacies that give the Glance a locally consistent internal stratigraphy of mappable members. Three lithofacies units or members can be delineated in the southern structural block: a limestone-clast conglomerate member, a mixed-clast conglomerate member, and schist-clast conglomerate member.

**Limestone-clast Conglomerate**

The limestone-clast conglomerate member is found at the base of the formation, where the unit unconformably overlies late Paleozoic limestone. The limestone-clast conglomerate member varies from 600 to 900 m in thickness, increasing northward toward the Gold Hill fault zone. The limestone clasts are subangular to subrounded, light gray, dark gray, and pink in color, vary from 1 cm to 2 m in diameter, and usually make up 70-90% of the framework clasts in this facies. Frequently, 15-20% of the clasts are light brown to pink sandstone cobbles and in localities not far south of the Gold Hill fault zone, dark purplish red volcanics, some up to 50-80 cm size, comprise up to 30% of the clasts. Minor amounts of dark chert and pale quartz are always present. The matrix is typically calcareous, pink in color, and of silt to sand size. Interbedding of matrix-supported and clast-supported conglomerate layers 1-2 m thick is evident throughout this facies. Contacts between the matrix and clast-supported layers are typically sharp and distinctive in the field, as shown
in Figures 5a and 5b, though at some locales, the massive nature of the outcrops argue for amalgamation of multiple matrix-supported or clast-supported layers in beds 10-20 m thick. Lateral tracing of specific beds is not possible due to the limited and discontinuous nature of the exposures. Small sandstone lenses, 2-10 cm in thickness, are frequently found, and channels of well bedded, better sorted, clast-supported conglomerate cut into matrix-supported zones can occasionally be delineated (Fig. 6), though once again, the small outcrop size does not usually permit lateral mapping of these features. Inverse grading in both clast-supported and matrix-supported conglomerate layers can also be occasionally recognized in this and the two overlying facies.

**Mixed-clast Conglomerate**

Gradationally above the limestone-clast conglomerate member is the mixed-clast or limestone-quartzite-schist conglomerate member. This unit is actually a thick transition zone, estimated to be 800 m in thickness, between two, more distinct conglomerate types, the limestone-clast conglomerate and the schist-clast conglomerate. This member is recognized by two principal characteristics: 1) the presence of an appreciable amount of quartzite clasts in the conglomerate, and 2) the dark reddish brown color of the matrix. The amount of quartzite clasts in this member is rarely as high as 50% of the total and is usually, though not always, equal to or less than the quantity of limestone or schist clasts. The quartzite clasts are derived from the Cambrian Bolsa Quartzite Formation, though some may come from a quartzite facies within the Pinal Schist that crops out above Mule Pass on the northern structural block. Typically, limestone clasts are present throughout the member with percentages as high as 40-50% near the lower member boundary and as low as 5-10% near the upper boundary. These clasts come from a wide variety of Paleozoic formations, with cobbles from the Horquilla, Escabrosa, and Martin Formations especially recognizable. Schist-clast percentages show an opposite trend, making up 40-50% of the clasts at the upper member boundary and are nonexistent at the bottom. Cobbles and pebbles of chert and quartz are as ubiquitous as usual, and dark purplish red porphyritic volcanic clasts can usually be recognized at most outcrops. Clasts of Juniper Flat Granite are
Figure 5a. Contact between clast-supported and matrix-supported conglomerate in the limestone-clast member, Glance Conglomerate. Southern block, Mule Mountains.

Figure 5b. Close-up of clast-supported/matrix-supported conglomerate contact.
found only west of the Glance fault and are rare in the mixed clast conglomerate member.

The dark reddish brown color of the matrix provides a quick and easy method of differentiating this conglomerate member from the underlying limestone-clast conglomerate with its light pink to gray colored matrix. This color change in the conglomerate matrix is relatively distinct between the two members, as shown in Figure 7. When trying to delineate the contact by changes in clast composition, the interbedding of layers with strikingly different clast composition percentages makes the actual delineation of the member contact very difficult and results in defining an exceedingly thick (100 m) transition boundary. The change in color of the matrix, however, fortunately confines this zone to just a few tens of meters or less. There are a few places where the contact is sharp and dramatic, for example, at the base of the west-facing cliff on the ridge to the west and south of the Glance Mine. Here the contact is silicified in part, shows evidence of shearing along limited lengths of the boundary, and may represent a diastem within the Glance.

Texturally, the mixed-clast conglomerate member is similar to the underlying limestone-clast conglomerate member with the exception that the average grain size of the matrix is greater, with more sand and granule sizes, and the clasts are better rounded. It is generally poorly sorted and poorly bedded, though some fairly well bedded zones of conglomerate exist. And although most of the conglomerate is clast-supported, matrix-supported layers are common and occasionally thick (2-4 m). The clasts are subangular to rounded with the roundness increasing upsection.

Schist-clast Conglomerate

The mixed-clast conglomerate member grades vertically into the overlying schist-clast conglomerate through a very thick transition zone. The member boundary is difficult to locate precisely in the field, since the matrix in the two members is similar in both color and composition and the gradation in clast composition is definitely not sharp, with quartzite comprising a small but notable percentage at most localities in the schist-clast conglomerate member. The schist-clast conglomerate of the southern block is identical to the conglomerate.
Figure 6. Clast-supported conglomerate filling an erosional channel cut into matrix-supported conglomerate. Note clast size-layering in channel fill. Limestone-clast member Glance Conglomerate, southern block, Mule Mountains. Channel axis oriented nearly normal to photo.

Figure 7. Boulder of mixed-clast conglomerate with dark reddish-brown matrix resting on limestone-clast conglomerate with light pink matrix. Southern block Glance Conglomerate, Mule Mountains.
erate in the northern block and the upper half of the Glance in the central block (Fig. 8). The lower half of the Glance section in the central block is part of the mixed-clast to schist-clast conglomerate transition zone and possibly should be considered mixed-clast conglomerate, though no contact was mapped in the field.

The schist-clast conglomerate is poorly sorted, poorly to fairly well bedded, mostly clast-supported with a matrix of dark brownish red to maroon silt and sand and frequent small lenses of maroon siltstone and sandstone. Occasional matrix-supported zones help delineate bedding attitudes (Fig. 8). The clasts are subrounded to rounded pebbles, cobbles, and occasional boulders, with few clasts over 25 cm in diameter. The clast size decreases upward until the average size is in the range of 3-5 cm near the upper contact with the Morita Formation. Dark maroon sandstones, siltstones, and shales are interbedded with pebble beds as this gradational contact is reached.

Compositionally, the schist-clast conglomerate member contains 80-90% schist clasts, with 5-10% quartzite, and the rest being granite, limestone, chert, and vein quartz. Granitic clasts are mostly found in the highest level and thus westernmost outcrops of the schist-clast conglomerate in the western half of the southern structural block. The eastern block, between the Glance fault and the Gold Hill fault, contains only a limited capping of transition zone mixed-clast to schist-clast conglomerate. The schist-clast conglomerate member of the Glance has been removed from this block by uplift and erosion.

3. Paleocurrent Determinations

In the southern Mule Mountains, the direction of sediment transport in the Glance Conglomerate can be resolved using clast imbrications, channel orientations, and oriented clast fabrics. A total of 139 directional current structures were measured, their azimuths recorded (see Table 2), and their interval percentages plotted on rose diagrams for easy comparison (Fig. 9). All of the data points have been corrected for tectonic tilt. In the Mule Mountains, the Lower Cretaceous rocks generally dip homoclinally to the northeast or southwest, except near fault zones, thus requiring only a single rotation
Figure 8. Contact between clast-supported and matrix-supported conglomerate in the schist-clast conglomerate member, Glance Conglomerate. Southern block, Mule Mountains.
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<th>Southern Block</th>
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</table>

Table 2. Distribution of bedding-structure orientation resultants by azimuth classes (in degrees from north) for the Glance Conglomerate in the various structural blocks of the Mule Mountains, Arizona.
Figure 9. Paleocurrent direction roses for the Glance Conglomerate in the Mule Mountains. The 3 roses represent: Northern structural block (63), Central structural block (16) and Southern structural block (60).
about a horizontal axis to correct for the post-depositional tilt of the strata. A stereonet was used to rotate the data and subtract out the bedding plane dip ("two-tilt problem"). The paleocurrent data recorded in subsequent chapters were accorded similar treatment.

As a whole, the orientation of current structures indicate a dominant southward direction of sediment transport in the Glance Conglomerate. By plotting the specific observations particular to each of the three structural blocks on separate rose diagrams, certain correlations become apparent (Fig. 9). The dominant paleocurrent flow direction in the Glance, north of the Dividend fault, is to the southwest. Here the Glance is relatively thin (1-30 m) or locally absent, has rounded cobble and pebble sized clasts overlying a low relief bedrock surface. The paleocurrent directions in the central block are mainly to the south. Here the Glance is much thicker (50-200 m) and much coarser. South of the Abrigo-Bisbee West-Gold Hill fault complex, the direction of sediment transport is to the south-southeast. The Glance of the southern block is very thick (2000+ m), very coarse, and was deposited over a much longer time span than the Glance of the central and northern blocks. The paleocurrent measurements were taken at various outcrop levels scattered throughout the total thickness of the unit, from top to bottom. No systematic vertical variations in paleocurrent flow directions were noted in any of the blocks.

The data indicate a change in trend of the paleoflow directions from southeast to southwest. This change may reflect a shift of the local drainage system through time toward the southwest as the basin of deposition filled and a pediment developed across the northern eroded fault block. Another possibility is that the change in trend is due only to areal location, with the drainage system curving from southwest to southeast as one moves down drainage, from the northern to the southern blocks, or from the pediment out to the basinal area.

4. Environment and Mechanism of Deposition

The poorly sorted, rather disorganized matrix-supported conglomerates, which contain large boulders and a high percentage of fine grained matrix and angular clasts, are interpreted as subaerial debris-flow deposits. Debris-flow
deposits are classically poorly sorted sediments with cobbles and boulders embedded in a finer grained, muddy matrix. The sediment is transported by high density mass or viscous flow, with the boulders being supported in part by high buoyancy forces due to the high density of the muddy matrix. According to Hooke (1967), deposition of the entire flow takes place when actual flow is no longer possible because the maximum shear stress in the flow falls below the yield stress of the mud matrix. Debris-flow deposits are usually deposited as sheets that have a length/width ratio of roughly 5 to 20. Some factors that enhance the formation of debris-flows are large amounts of water (intense rainfall or runoff) over short periods of time, steep topography with insufficient vegetative cover to prevent rapid erosion, and a source terrane containing rock types that will supply sufficient silt and clay-sized detritus for matrix material (Bull, 1972; Walker, 1975). Shale beds in the Paleozoic section, mica schists in the Precambrian section and possibly early Mesozoic volcanics are likely sources in the Mule Mountains for fine grained material.

The better sorted, better rounded, clast-supported conglomerates with frequently well oriented fabrics are examples of fluvial traction-flow, possibly braided stream and stream channel deposits. These sediments, transported by direct interaction with running water, commonly contain lenses of sand and silt, remnants of low bars and islands in a network of braided distributary channels. Some of the more laterally continuous sand lenses may be the result of sheet-floods or surges of sediment-laden water that spreads out from the end of a channel during times of intense, infrequent rainfall or runoff (Bull, 1972). Occasionally, fluvial conglomerates are found filling stream channels that were temporarily entrenched into previously deposited matrix-supported conglomerate. The ratio of clast-supported/matrix-supported conglomerate generally increases to the south (in the southern block).

The ubiquitous interbedded relationship of matrix-supported debris-flow deposits and clast-supported fluvial deposits in the Glance of the Mule Mountains (Figs. 5 and 8), plus the dramatic local changes in thickness and lithofacies, the great thickness of conglomerate in the southern block, and the lateral and vertical interfingering of Glance with the sandstones and siltstones of the Morita
Formation suggest that the Glance Conglomerate is a proximal alluvial fan deposit shed south-southwestward into a subsiding basin from an actively rising mountain front. The paleocurrent directions recorded from clast imbrications, channel orientations, and oriented clast fabrics are supportive of this interpretation. North-northeastward erosional retreat of the mountain front, coupled with continued subsidence in the basin, created the low relief, sub-Glance pediment surface developed across the Pinal Schist and Juniper Flat Granite on the northern structural block.

The middle and distal parts of the alluvial fan complex, of which the Glance is a part, lie farther to the south in Mexico. Due south, in the Cabullona Basin area, the Morita Formation is composed of 1500 m of sandstones and siltstones overlying 270-750 m of Glance Conglomerate (Taliaferro, 1933). The Morita in the Mule Mountains is only 800 m thick, suggesting that the Cabullona section may comprise the distal fan and basinal fine grained sediments deposited coeval with the upper proximal conglomerates of the Glance alluvial fan complex of the southern Mule Mountains.

5. Igneous Rocks

The most extensive intrusive igneous body in the Mule Mountains is the Juniper Flat Granite. This intrusive forms a northwest-trending elongated pluton completely surrounded by Precambrian Pinal Schist and unconformably overlain by the Lower Cretaceous Glance Conglomerate (Fig. 3 or Plate 1). Associated with this pluton are a series of dikes, sills, and irregular intrusive bodies that intrude Paleozoic rocks and are considered to be comagmatic with the Juniper Flat Granite on the basis of composition and relative age (Ransome, 1904; Bryant and Metz, 1966). One K-Ar, biotite age of 163 ±7 m.y. and two Rb-Sr, biotite ages of 186 ±7 m.y. and 188 ±8 m.y. (Lower to Middle Jurassic), were calculated on a granite sample located at the northwest end of the Juniper Flat Granite (Marvin and others, 1973).

The dikes and intrusive bodies are especially concentrated in a belt about 1-1.5 km wide and 13 km long that lies 2 km southwest of, and trends parallel to, the long axis of the Juniper Flat Granite. This belt of interconnecting
intrusives is very complex with a great many of the dikes having intruded along pre-existing faults (Ransome, 1904, p. 80). The elongation of the Juniper Flat pluton and the linear nature of its southwest contact suggests that its intrusion may also have been structurally controlled by a pre-existing fault (Ransome, 1904).

Located about 3 km southeast of the Juniper Flat Granite is the Sacramento stock, a copper mineralized quartz porphyry considered to be of similar age, Jurassic, to the Juniper Flat Granite. There are no published age dates for the Sacramento stock. Early underground development, reported by Bonillas, Tenney, and Feuchere (1916, p. 1428), show that the stock intruded up the Dividend fault, that the porphyry is "plug-like", and that little of the later movement on the Dividend fault took place along the original line through the intrusive mass. Open-pit mining of the stock has revealed that Glance Conglomerate unconformably overlies the intrusive and that the stock itself is an intrusive complex rather than a single intrusion (Bryant and Metz, 1966). Various types of porphyry and intrusive breccias were found with the primary mineralization being associated with all of the units except for the "older porphyry". The older porphyry is primarily found on the north side of the stock, separated from the copper-rich porphyry by a system of east-west trending faults that cut the stock. These faults merge eastward into the Dividend fault, which also appears to cut the stock (Fig. 10).

6. Structural Features

The structure of the southern Mule Mountains is predominantly characterized by a system of high angle faults that can be divided into two main categories based on strike. The faults in the first category have trends ranging from northwest to west-northwest and comprise most of the major pre-Cretaceous fault structures in the area. These include the Dividend, Bisbee West, Abrigo, and Gold Hill faults, as well as most of the granitic dike-filled faults found 2 km southwest of, and running parallel to, the Juniper Flat Granite (Ransome, 1904; Hayes and Landis, 1964).

The second category of faults involves those of northeast trend.
Figure 10. Map of Lavender Pit, Dividend fault and Lavender Pit splay faults.
(After Bryant and Metz, 1966)
faults are clearly subordinate to the northwest-trending fractures, frequently terminating against them. Though many of these are undoubtedly of pre-Cretaceous origin, those that cut and offset the northwest-trending faults also typically displace Bisbee Group rocks and thus are post-Lower Cretaceous in age.

Dividend Fault

For the purposes of this study, the most important structure in the Mule Mountains is the west-northwest trending Dividend fault. This major fault passes under the town of Bisbee and juxtaposes Paleozoic sedimentary rocks on the south against Precambrian schist on the north. The Dividend fault dips $65^\circ$-$75^\circ$ to the south-southwest and thus has a normal displacement (south side down). Rotation of the northeast-dipping Cretaceous section to original horizontality results in steepening the dip on the Dividend to $75^\circ$-$80^\circ$ to the south-southwest during Early Cretaceous time.

As previously noted, the Dividend fault bisects the Sacramento stock quartz porphyry, and exhibits little horizontal (strike-slip) separation. The stock apparently occupies an important structural locus because the Dividend shows an abrupt change in strike and amount of vertical offset as it crosses the stock. Westward from the stock, the strike of the fault is approximately $N70^\circ W$, has a dip-slip displacement of about 610 m, and is lost northwestward as it passes into the steeply foliated Pinal Schist. Eastward from the stock, the Dividend has a roughly east-west strike, a 1525 m dip-slip displacement, and disappears about 2.5 km to the east under warped but mostly unfaulted Bisbee Group rocks (Hayes and Landis, 1964; Bryant and Metz, 1966).

Deformation of the Bisbee Group rocks eastward along strike with the projection of the Dividend fault resulted in a single large west-northwest trending overturned fold verging to the northeast, suggesting reactivation of the fault structure in post-Cretaceous time and that the fault does indeed continue eastward beneath the cover of Lower Cretaceous sediments (Plate 1). The 915 m difference in displacement along the two sections of the Dividend fault may be accounted for by dip-slip movement along the complex set of east-west trending faults that splay from the Dividend where it changes strike within the Sacramento
stock (Fig. 10). The most prominent of these fault splays, the Lavender Pit fault, dips southward about $70^\circ$ and has a normal displacement of about 152 m (Bryant and Metz, 1966). These data suggest that the eastern segment of the Dividend fault and the Lavender Pit fault splays form an east-west fault zone that has an additional 915 m of dip-slip displacement that post-dates the original 610 m of vertical offset that occurred along the entire length of the Dividend fault. This later displacement thus post-dates emplacement of the Sacramento stock and possibly the Juniper Flat Granite as well. The fairly linear and regular southwestern contact of the Juniper Flat pluton aligns quite well with the projected northwestward extension of the Dividend fault, suggesting a causal relationship. The southwestern contact curves gently northward until it trends N45$^\circ$-50$^\circ$W at the northern end of the mountain range. The suggestion that the intrusion of the Juniper Flat Granite was structurally controlled fits well with this interpretation.

This evidence thus implies that the earlier episode of faulting on the predominantly northwest-trending Dividend fault, accounting for 610 m of displacement and controlling magmatic intrusion, is Jurassic in age and the later, post-intrusive, 915 m of displacement along the east-west section of the Dividend and Lavender Pit faults occurred during deposition of the Glance Conglomerate. The dramatic change in thickness of the Glance Conglomerate across the Dividend fault, from 30 m maximum thickness on the northern block to upwards of 200 m on the central block, and the deep erosion and removal of the entire Paleozoic section off the northern block supports the existence of major syndepositional normal fault movement on the Dividend fault.

Bisbee West and Abrigo Faults

South and southwest of the Juniper Flat pluton and the Dividend fault are two groups of faults that are northwest-trending, dip steeply to the southwest, and have normal displacements (Fig. 3 or Plate 1). In this part of the Mule Mountains, all post-Jurassic rocks have unfortunately been removed by erosion. The first of these two groups is designated the Bisbee West fault zone and coincides with the mapped Bisbee West fault and the dike-filled faults that run parallel to, but 2-3 km southwest of, the southwestern edge of the Juniper
Flat Granite. The second zone of faulting is composed of one simple fault, the Abrigo fault (Ransome, 1904; Hayes and Landis, 1964).

The Bisbee West zone of faults and intrusives (called the Escabrosa zone by Ransome) is a complex network of interconnecting faults and dikes. The Bisbee West fault itself is a high angle fault that dips steeply to the southwest. Along strike to the northwest, the fault trace expands into a wide zone of fractures which become increasingly intruded by granite and rhyolite porphyry believed to be comagmatic with the Juniper Flat Granite. Stratigraphic displacement across this zone is normal, with the southwest side down about 600-760 m (Ransome, 1904, p. 96). The Bisbee West fault strikes about N55°W, and the fault-and-dike system strikes about N45°W.

The Abrigo fault, located in the northern Naco Hills about 2-3 km southwest of the Bisbee West fault, places late Paleozoic rocks on the south side against early Paleozoic strata on the north. The Abrigo fault has a simple, linear trace, with a strike of N75°W and a 75° southerly dip. The displacement is normal, south-side-down, with a throw of 760-915 m (Trischka, 1938). No Jurassic intrusives are known south of this fault in the Mule Mountains area.

Gold Hill Fault

If the Abrigo and Bisbee West faults are projected eastward along strike, they intersect under the alluvium in the vicinity of Don Luis. The convergence of these two faults display the same geometry as the intersection of the Dividend and the Lavender Pit faults a few kilometers to the north. This similarity is probably not coincidental. Continuing this projection eastward as one fault zone past the point of intersection and along the strike of the Abrigo fault, the zone ties directly into the western end of the Gold Hill fault zone (Fig. 3 and Plate 1). Unfortunately, the Gold Hill fault zone has experienced significant post-Cretaceous movement. Originally a zone of down-to-the-south normal faulting during deposition of the Glance Conglomerate, the Gold Hill fault was reactivated in post-Lower Cretaceous time as a moderate to high angle reverse fault. Paleozoic limestone is presently upfaulted over Lower Cretaceous Bisbee Group strata on the northern side of Gold Hill. Ransome (1904) included a detailed description of this fault and the highly deformed and fractured rocks that are exposed
along and within the zone of the fault. An analysis and reinterpretation of this fault zone is presented in Appendix 1.

7. Tectonic Implications

The striking contrast of thickness and lithology of the Glance Conglomerate across the Dividend-Lavender Pit fault zone and the Abrigo-Bisbee West-Gold Hill fault complex indicates that these two fault zones were active during the deposition of the Glance. Local geologic relationships, previously detailed, suggest that the syndepositional movement was primarily south-side-down normal displacement. The total structural relief across the two essentially east-west trending fault systems is at least 3350 m, including 1525 m of south-side-down normal displacement on the Dividend fault and 1830+ m of south-side-down normal displacement on the Abrigo-Bisbee West-Gold Hill faults. These two normal fault zones were thus part of an east-west range-front system of faults that separated a large subsiding basin to the south from a rising mountain block to the north (Fig. 11).

The presence of large volcanic cobbles and boulders in the lower parts of the Glance and the absence of any volcanic flows or tuffs either beneath or intercalated in it, suggests that the related volcanic activity occurred before major normal displacements on the two faults elevated the terrain and formed the Glance Conglomerate. The volcanic clasts may be derived from a completely eroded volcanic pile that was produced by surface venting of the intrusive Sacramento stock or possibly even by the Juniper Flat Granite. Since the Glance rests unconformably upon both of these intrusive bodies, uplift and deep erosion must have occurred between the time of intrusion and possible volcanism, and the deposition of the conglomerate.

The Juniper Flat Granite and its associated dikes and veins intrude a large number of northwest-trending faults, including the Dividend fault, also suggesting that the deposition of the Glance is totally related to post-intrusive movement on the more westerly trending faults. The east-west trending Lavender Pit normal fault cuts and vertically offsets the Sacramento stock (Fig. 10 and merges eastward with the east-west segment of the Dividend fault,
Figure II. Schematic cross section across the Dividend and Abrigo-Bisbee West-Gold Hill faults, southern Mule Mountains, during Early Cretaceous time. (Kgs) Glance schist-clast conglomerate member, (Kgm) mixed-clast congl. member, (Kgl) limestone-clast congl. member, (Pz) Paleozoic undifferentiated, (Jg) Jurassic Juniper Flat Granite, (pCp) Precambrian Pinal Schist.
adding support to the interpretation of two distinct ages of pre-Late Cretaceous faulting in the Mule Mountains area. The first faulting episode includes normal faults that strike N45°-70°W, and are Early Jurassic or pre-intrusive in age. The second episode is post-intrusive or Early Cretaceous in age and involves normal faults with predominantly east-west strikes. Thus, two separate episodes of normal faulting, one Early Jurassic, the other Early Cretaceous, along distinctly different trends, is evident in this region. Post-Early Cretaceous reactivation of these structures complicates the present structural relations of the area and is discussed in detail in Appendix 1.
CHAPTER III

EMPIRE MOUNTAINS

1. Introduction

In the Empire Mountains, the Glance Conglomerate is most extensively exposed along the northern and eastern flanks of the range. Isolated exposures of Glance are also located farther to the north, west, and south (Fig. 12 and Plate 2). Like the Glance Conglomerate in the Mule Mountains, the unit varies greatly but systematically in thickness, clast composition, and subjacent rock type. The contact of the Glance with the overlying Willow Canyon Formation (Morita equivalent) is well exposed for many kilometers along strike. The sub-Glance unconformity and the Glance-Willow Canyon contact are both exposed within a relatively uninterrupted sequence of southeasterly dipping strata that form the northwestern limb of a large, open, southwesterly plunging syncline along the southeast flank of the range (Plate 2). This simple synclinal structure is locally disrupted by complex sets of faults that are related to the intrusion of a quartz monzonite stock (Laramide granite in Fig. 12) dated at 70.3 ±2.5 m.y., K-Ar, biotite (Marvin and others, 1973), and to younger post-intrusive deformation. The syncline is truncated on the north by a major east-west trending fault system, here called the Murphy Ranch fault zone, that effectively separates two stratigraphically similar but structurally different terranes. This fault zone is made up of a series of north-dipping reverse-slip faults that place Precambrian basement rocks on the north over Lower Cretaceous and Paleozoic strata to the south.

2. Stratigraphy

The Glance Conglomerate rests with angular unconformity upon either Precambrian granitic rocks, Upper Permian Rainvalley Formation or local canyon-fill remnants of Triassic(?)-Jurassic redbeds and volcanics of the Gardner Canyon Formation, or possibly the Canelo Hills Volcanics (Finnell,
Figure 12. Generalized geologic map of the Empire Mountains, Arizona. (Modified from Finnell, 1971)
It is only in the northern outcrops, mostly north of the Murphy Ranch fault zone, that the Glance directly overlies Precambrian granitic and metamorphic rocks. Immediately south of this structure, the Glance unconformably overlies Rainvalley Formation and Gardner Canyon Formation (Fig. 13), is 1000 m thick, and gradually thins to less than 1 m, or locally absent, farther to the south. This gradual southward thinning is accompanied by lateral intertonguing of the Glance Conglomerate with the overlying Willow Canyon Formation.

As in the Mule Mountains, the Glance Conglomerate in the Empire Mountains can be vertically divided into three lithofacies units based on the dominant clast type present. These are: 1) a lower limestone-clast conglomerate member, 2) a middle, transitional mixed-clast or quartzite-limestone-granitic-clast conglomerate member, and 3) an upper granitic-clast conglomerate member. This vertical variation in clast composition gives the formation an internal stratigraphy that can be mapped and correlated throughout the area. The vertical change in clast types is also an inverted stratigraphy of the Paleozoic and Precambrian formations once exposed in the source terrane. The three lithofacies are best exposed in the southwest-trending outcrop belt along the northeast side of the range. The total composite thickness of all three lithofacies is on the order of 1500 to 1600 m. It must be remembered that this is a composite thickness and that the Glance does not exceed 1000 m in thickness, and is generally thinner, in any single vertical section.

Main Outcrop Area

Limestone-clast Conglomerate

The lower limestone-clast conglomerate member consists of poorly sorted, poorly bedded, clast-supported, angular to subrounded pebbles, cobbles, and boulders of pink and gray limestone, dolomite, some pink sandstone, and minor chert bound in a sparse, pink to gray matrix of calcareous siltstone and sandstone (Fig. 14). Clasts derived from various lower and upper Paleozoic formations are identifiable. The thickness of this member ranges from 120 m at the north end of the outcrop belt near Murphy Ranch, to less than a meter far to the south. This member rests exclusively on limestones of the
Figure 13. Small remnant of Triassic(?)-Jurassic Gardner Canyon Formation redbeds resting unconformably above Permian Rainvalley Formation and below limestone-clast conglomerate member, Glance Conglomerate. View is to the south-southwest, along the east flank of the Empire Mtns. Beds dip moderately to the east. (Px) Paleozoic undivided, (JT g) Gardner Canyon Formation, (Kgl) limestone-clast member, Glance Conglomerate.
Rainvalley Formation or erosional remnants of Triassic(?)-Jurassic redbeds and volcanics. Boulders up to 3 m in diameter are frequent in the northern half of the member, and large exotic blocks, as much as 300 m long and 60 m wide, of late Paleozoic limestone are found near the base of the unit. These large exotic limestone blocks are restricted to the more northerly exposures of this lithofacies (see Plate 2). A few of the exotic blocks are situated within Glance strata, directly over locally thick Triassic(?)-Jurassic redbed units, indicating that they are definitely not basement outcrops.

**Mixed-clast Conglomerate**

The contact between the limestone-clast conglomerate member and the overlying mixed-clast conglomerate member is relatively sharp and occasionally sheared in some places but gradational in others, though the contact can generally be located within a few meters. Where the contact is abrupt, it appears to be a diastem, as the clast composition and nature of the matrix changes dramatically from one conglomerate bed to the next. This diastem is marked by the sudden appearance of appreciable amounts of pink to light reddish brown, angular to subrounded quartzite fragments set in a matrix of dark reddish brown or maroon sandstone and sandy siltstone. These quartzite clasts are predominantly derived from the Cambrian Bolsa Quartzite.

The mixed-clast conglomerate member is, in general, a poorly sorted, poorly bedded quartzite-limestone-granitic-clast conglomerate with the amount of limestone clasts decreasing and the amount of granitic clasts increasing up-section (Fig. 15). This lithofacies unit is basically a transition zone between two more distinct monomictic conglomerate types, the limestone-clast conglomerate below, and the granitic-clast conglomerate above. The mixed-clast conglomerate member is distinguished from the other two members by the same two diagnostic characteristics distinctive to the mixed-clast lithofacies in the Mule Mountains, namely: 1) the presence of an appreciable amount of quartzite clasts in the conglomerate (30% or more) and 2) the dark reddish brown color of the matrix. The quantity of quartzite clasts may reach 70% of the total in some beds near the middle of the unit, though an average of 40-60% quartzite clasts in the mixed-clast conglomerate member is more common.
Figure 14. Typical poorly sorted limestone-clast conglomerate, Glance Conglomerate. Main outcrop belt, east flank of the Empire Mountains.

Figure 15. Mixed-(quartzite-granitic)-clast conglomerate member, Glance Conglomerate, main outcrop belt, northeastern flank Empire Mountains. Dark reddish-brown clasts are Bolsa Quartzite; light, speckled clasts are Precambrian granitics.
Boulders of quartzite up to 2 m in diameter are occasionally found with blocks 0.5 to 1 m across more widespread. Matrix-supported conglomerate with a silty red matrix is common in the upper half of this lithofacies, especially in the more northerly exposures. Sand lenses, 3-10 cm thick and 1-2 m long, are also frequently found throughout the unit.

The thickness of the mixed-clast conglomerate member ranges from 1 to 600 m, thinning southward as it intertongues laterally with the sandstones and siltstones of the Willow Canyon Formation. Many of the tongues of conglomerate can be traced 100 m or more into the finer grained strata.

**Granitic-clast Conglomerate**

The granitic-clast conglomerate member is restricted to the northeasternmost section of the main outcrop area, the expanse of Glance just west-southwest of the Murphy Ranch fault zone, and the scattered exposures of basal Cretaceous conglomerate farther north. This lithofacies rests either on the mixed-clast conglomerate member or, with major unconformity, upon Precambrian granitic and metamorphic rocks. Where it overlies mixed-clast conglomerate, the contact may occasionally be sharp but usually is gradational from a quartzite-granitic-clast conglomerate to a pure granitic-clast conglomerate composed primarily of subangular to subrounded Precambrian gneissic quartz diorite and porphyritic quartz monzonite pebbles, cobbles, and boulders set in a reddish brown arkosic matrix (Fig. 16). Where the granitic-clast conglomerate rests on the Precambrian basement, the clast composition is about 98% Precambrian granitic fragments with a few Precambrian Pinal Schist clasts also present. The thickness of the unit ranges from 1 m to 800 m, and thins southward, while laterally interfingering with the upper Willow Canyon Formation and possibly with some of the Apache Canyon Formation, as suggested by Finnell (1970).

Both clast-supported and matrix-supported conglomerate are common in the poorly to fairly well bedded granitic-clast conglomerate member. Large granitic boulders 1-2 m in diameter are frequently concentrated in distinct boulder beds or boulder trains. Typically, these are located at the top of matrix-supported zones. The granitic-clast conglomerate weathers to a
Figure 16. Typical granitic-clast conglomerate member, Glance Conglomerate, with maroon, arkosic matrix. North end of main outcrop belt, Empire Mountains.
distinctive orange to yellowish brown arkosic colluvium which aids in mapping its lower contact with the reddish brown or maroon colored mixed-clast conglomerate lithofacies.

Northern Area

North of the Murphy Ranch fault zone, but south of Interstate 10, the Glance Conglomerate is a relatively thin (1-15 m) arkosic pebble conglomerate derived directly from the underlying Precambrian granitic rocks. Compositionally, it consists of the weathering products of decomposed granitic basement, mainly weathered k-feldspar, quartz, mica, and lithic fragments of various sizes. Pebbles and cobbles up to 12 cm in diameter occur sporadically through the unit. Typically, the outcrops are so highly weathered and altered that distinguishing between the granitic basement and the arkosic conglomerate is extremely difficult. The arkosic conglomerate grades upward into alternating sandstones and shales of arkosic composition, mapped as Shellenberger Canyon Formation (Cintura Formation equivalent) by Finnell (1971).

Central Area

Just southwest of Murphy Ranch, over the hill and due west of the main outcrop belt, is a poorly exposed expanse of Glance Conglomerate. The Glance in this area is predominantly mixed-clast conglomerate, with some limestone-clast conglomerate exposed below and a small amount of granitic-clast conglomerate exposed at the highest levels. The upper contact of the Glance is a fault, placing granitic-clast conglomerate against Paleozoic strata on the east side of the outcrop area. To the west, the Glance rests unconformably on a block of late Paleozoic limestone, which in turn overlies Triassic (?)–Jurassic Gardner Canyon Formation redbeds and local lenses of limestone-clast conglomerate. The Paleozoic limestone, immediately underlying the Glance, is thus a large exotic block, possibly 800 m long, embedded in the lower limestone-clast conglomerate member of the Glance Conglomerate. Other, smaller exotic blocks are present near the base of this member within many nearby outcrops. This section of Glance Conglomerate makes up part of the trough and western limb of a faulted syncline that plunges gently to the north, with the strata in the limb dipping about 30°–35°ENE. To the north, the strata are structurally truncated
by the Murphy Ranch fault zone and are locally cut by many faults and shear planes that complicate the outcrop patterns.

The lower limestone-clast conglomerate is identical to that found 1 km to the east in the main southwest-trending outcrop belt. The conglomerate is poorly sorted, clast-supported, has 95% gray and pink limestone, 5% sandstone and chert clasts, and a pink, calcareous silty/sandy matrix. The limestone-clast conglomerate here is 60-80 m thick, not counting the underlying exotic blocks.

The contact with the overlying mixed-clast conglomerate member is similar to that in the main outcrop area, being very sharp and appearing to be sheared in places, with extensive flattening and stretching of limestone cobbles in the lower member near the contact. The mixed-clast conglomerate member is a quartzite-granitic-limestone-clast conglomerate, with the amount of limestone quickly decreasing up-section. The quartzite clasts get more rounded and less abundant as the upper contact is approached, while the percentage of granitic clasts as well as the number of boulders in the 1-2 m size range, increase. The matrix is a poorly sorted, dark reddish brown or maroon silty/sandy arkose with coarse granules and pebbles of granitic lithics. Most exposures are clast-supported conglomerate, but a few matrix-supported beds are present locally.

**West-Central Area**

Three kilometers farther to the southwest, in the western foothills of the mountain range, 1.5 km south of the Andrade Ranch and just northeast of the intersection of the "old" and "new" Sonora Highway, State Route 83, is another area of Glance Conglomerate outcrop. Here the Glance dips 5°-35°NE and rests unconformably on either Permian Rainvalley Formation limestone or redbeds of the Triassic(?)-Jurassic Gardner Canyon Formation. The Glance has been moderately deformed by local faulting, folding, and intrusion of a quartz latite porphyry dike. The intrusion has locally altered the gray limestone clasts within the conglomerate to clasts of white marble.

Lower limestone-clast conglomerate and some hill-capping mixed-clast conglomerate are well exposed at this locale. The limestone-clast
member is 10-20 m thick with about 5-10 m of mixed-clast conglomerate preserved on top. The limestone-clast conglomerate is a pebble to boulder conglomerate with 90% limestone and 10% sandstone and chert clasts near the basal contact. Boulders of Devonian Martin Limestone have been reported within the Glance by Sopp (1940). The clasts in some zones are flattened and sheared parallel to the lower bedding contact, which also shows some evidence of shearing along it in places. Large boulders or small 4-8 m exotic blocks of limestone are present at two localities within the limestone-clast member. One rests directly on Triassic(?)--Jurassic redbeds.

Quartzite clasts first show up about 5-10 m above the basal unconformity and increase gradually upward until they are the predominant clast type. Thus the contact between the limestone-clast member and the mixed-clast member is gradational. Within the stratigraphically highest mixed-clast conglomerate preserved, cobbles of gneissic quartz diorite are present and locally make up 30-40% of the clasts in some beds.

All of the Glance Conglomerate at this locality is poorly sorted, and clast-supported. The conglomerate looks identical to that located 3 km due east in the main outcrop belt, where the Glance is fairly thin (50-150 m).

Western Area

Six kilometers farther to the west-northwest, but still within the Empire Mountain 15' quadrangle, at the northeasternmost end of the Santa Rita Mountains, Glance Conglomerate a few hundred meters thick rests unconformably on Gardner Canyon Formation redbeds, late Paleozoic limestone, and Precambrian Pinal Schist (see Plate 2). Two intrusive bodies, one small quartz diorite stock dated at 73.6 ±2.8 m.y., K-Ar, biotite and a large quartz monzonite stock dated at 73.8 ±2.6 m.y., K-Ar, biotite (Marvin and others, 1973), have thoroughly metamorphosed the entire section, altering the limestone clasts to marble and the sandstone clasts to quartzite. This particular locality of Glance Conglomerate is included in this section because it has a more direct relationship to the Glance in the Empire Mountains than to that found farther to the south in the central Santa Rita Mountains.

At the north end of this outcrop band, the Glance Conglomerate rests
directly on Pinal Schist and is predominantly a granitic-quartzite- or mixed-clast conglomerate. Where the Glance directly overlies Paleozoic limestone and Gardner Canyon Formation redbeds, it contains 95% limestone cobbles and boulders. The percentage of quartzite clasts is thus low near the base but quickly increases away from the contact. Though metamorphosed, the conglomerate contains fairly angular clasts and still displays the poor sorting and poor bedding of the protolith. The southernmost outcrops contains limestone-clast conglomerate with 10-20% quartzite clasts near the upper contact with the overlying Willow Canyon Formation.

This section of Glance may be as thick as 400 m and does not correlate exactly with the Glance of similar thickness farther to the east in the Empire Mountains, though the overall clast lithofacies types and subjacent rock relationships are similar. At the north end of this outcrop area, a west-northwest trending structure, possibly a fault, juxtaposes Precambrian Pinal Schist and Precambrian granitic rocks against Paleozoic limestone beneath continuous Glance Conglomerate. About 1.5 km to the northeast, arkosic sandstones of the Willow Canyon Formation rest directly on Precambrian granitic rocks with no intervening Glance Conglomerate. Thus the Glance thins dramatically across a sub-Glance structure in a manner similar to the Glance farther east in the main Empire Mountain exposures.

3. Paleocurrent Determinations

In the Empire Mountains, sedimentary structures that indicate the direction of transport of Glance Conglomerate include clast imbrications, channel orientations, and oriented clast fabrics. The poor exposure, coupled with the degree of metamorphism and shear deformation in much of the Glance, made collection of these data difficult. A total of thirty-three paleocurrent determinations were recorded (see Table 3) and are plotted on the rose diagram in Figure 17. All of the paleocurrents were recorded from outcrops south of the Murphy Ranch fault zone because the arkosic conglomerate to the north is very poorly exposed and did not yield any definitive sedimentary structures. No paleocurrent determinations could be made in the westernmost
Table 3. Distribution of bedding-structure orientation resultants by azimuth classes (in degrees from north) for the Glance Conglomerate in the Empire Mountains, Arizona.

<table>
<thead>
<tr>
<th>Azimuth Classes (degrees)</th>
<th>Empire Mountains Area</th>
<th>Azimuth Classes (con't)</th>
<th>Empire Mountains Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-30..............</td>
<td></td>
<td>181-210..............</td>
<td>11</td>
</tr>
<tr>
<td>31-60..............</td>
<td></td>
<td>211-240..............</td>
<td>13</td>
</tr>
<tr>
<td>61-90..............</td>
<td></td>
<td>241-270..............</td>
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</tr>
<tr>
<td>91-120..............</td>
<td></td>
<td>271-300................</td>
<td></td>
</tr>
<tr>
<td>121-150..............</td>
<td>1</td>
<td>301-330................</td>
<td></td>
</tr>
<tr>
<td>151-180..............</td>
<td>6</td>
<td>331-360................</td>
<td></td>
</tr>
</tbody>
</table>

Total number of localities...... 33
Figure 17. Paleocurrent direction rose for the Glance Conglomerate in the Empire Mountains. Note dominant SSW-trend.
outcrop locality at the northeastern end of the Santa Rita Mountains due to the high degree of metamorphism and local deformation.

The rose diagram indicates that the direction of sediment transport within the Glance Conglomerate was toward the south-southwest. No systematic change in paleocurrent direction is apparent either vertically or laterally within the total Glance section. The data show a consistent southerly paleoslope for all of Glance time.

4. Environment and Mechanism of Deposition

The Glance Conglomerate in the Empire Mountains is very similar, in most respects, to that found to the southeast in the Mule Mountains. Poorly sorted, diaorganized matrix-supported conglomerate and better sorted, clast-supported conglomerate with a highly oxidized reddish brown matrix are both present in each area. The mechanisms of transport and deposition of these two types of deposits were previously and thoroughly discussed in section 4 Chapter II on the Mule Mountains. The processes that resulted in the deposition of the Glance in the Empire Mountains are the same as those that operated in the Mule Mountains during the Early Cretaceous. Thus both subaerial debris-flow and fluvial deposits make up the major portion of the Glance Conglomerate in the Empire Mountains.

The Glance Conglomerate also extensively intertongues laterally with the sandstones and siltstones of the Willow Canyon and possibly higher formations, suggesting that these formations are lateral facies equivalents of the Glance. This relationship plus additional evidence, including the interbedding of debris-flow and fluvial deposits, the systematic vertical variation of clast lithofacies from Paleozoic limestone at the base through Cambrian quartzite and up into Precambrian granitic-clast conglomerate, suggests that the Glance Conglomerate in the Empire Mountains is a proximal alluvial fan deposits. The thin arkosic conglomerate overlying Precambrian granitic basement north of the Murphy Ranch fault zone are coarse colluvial gravels covering an Early Cretaceous pediment. The finer grained, laterally equivalent, Willow Canyon Formation is the middle and distal fan facies of the alluvial fan system that
was fed sediment from the northern source terrane. Early Cretaceous erosion stripped the entire Paleozoic section (2000 m) and an undetermined thickness of Triassic(?)-Jurassic redbeds and Precambrian granitic and metamorphic rocks from the area north of the east-west structural discontinuity presently marked by the Murphy Ranch fault zone. This eroded material was washed down a south-southwest facing alluvial fan system and into a subsiding structural basin.

The large size and number of exotic limestone blocks just south of the discontinuity marked by the Murphy Ranch fault zone, indicate the presence of high relief across this zone in Early Cretaceous time. These large blocks of Limestone were broken from high scarps or cliffs of Paleozoic limestone and moved southward down a paleoslope by gravity sliding. The mechanism of emplacement of large limestone glide-blocks of this type is discussed in a recent paper on similar occurrences of exotic blocks in the Canelo Hills by Davis and others (1979).

5. Structural Features and Tectonic Implications

The salient structural features of the Empire Mountains have already been introduced. These are the large, faulted, southwest-plunging syncline on the eastern flank of the mountain range, the faulted syncline that plunges gently northward in the north-central part of the range, and the east-west trending Murphy Ranch fault zone that truncates both of the folds. All of these structures are of Laramide age (Late Cretaceous-Early Tertiary) or younger. The folds have a different trend, southwest-northeast, than most Laramide features in southeast Arizona, which have northwest-southeast trends. Many crosscutting northwest-southeast faults and folds are known in the area and suggest that the two synclines and their associated, though subsequently faulted out, anticlines are related to the intrusion of the quartz monzonite stock in the core of the mountain range and not to regional Laramide southwest-northeast compression.

The Murphy Ranch fault zone is a curious structure that may be related to mid-Tertiary development of a metamorphic core complex located due north of the area, the Catalina-Rincon complex. Only about 10 km to the north, major plates of deformed but essentially unmetamorphosed strata, tectonically
overlie metamorphosed (gneissic) igneous rocks along what are called décollement zones marked by thermal and strain gradients (Davis, 1975; Drews, 1977; Davis and Coney, 1979). The Murphy Ranch fault zone is one of the youngest structural features exposed in the area and is a logical choice, due to its trend and style of deformation, to be correlated with the structural activity of similar age to the north. The reverse faults of the Murphy Ranch zone are either part of the décollement zone where it resurfaces to the south or a zone of deformation within the cover rocks or upper plate assuming that the décollement does not return to the surface.

The Murphy Ranch fault zone is located near the hypothesized trace of an early Mesozoic structure that produced high relief, which in turn generated the exotic glide-blocks and the deposition of the Glance Conglomerate. Paleo-current direction studies suggest that the source of the limestone, quartzite, and granitic clasts lay to the north-northeast across the Murphy Ranch fault zone. There is over 1500 m of Glance Conglomerate on the south side of the structure and only 0-15 m on the north side. During the Early Cretaceous, this zone most likely was the location of a system of high angle, range-front normal faults which separated an upthrown northern block from a subsiding sedimentary basin to the south (see Fig. 18). The Glance Conglomerate is the coarse proximal facies of the alluvial fan complex that formed at the southern foot of the rising northern block mountain range. The Willow Canyon Formation comprises the mid-fan, distal fan, and basinal facies of the alluvial fan system and basin proper.

Interpretation of the Early Cretaceous structure as a syndepositional, south-dipping normal fault is based on analogy with the Dividend-Lavender Pit and Abrigo-Bisbee West-Gold Hill fault zones in the southern Mule Mountains (see Fig. 11). It is purely coincidental that the present trace of the north-dipping Murphy Ranch fault zone coincides with and obscures the south-dipping Early Cretaceous normal fault.

In the westernmost outcrop area, the fault structure that separates two different Glance Conglomerate terranes, with Glance resting on Pinal Schist to north and Glance on Paleozoic limestone to the south (see Plate 2), may either
Figure 18. Schematic cross section of the Empire Mountains in Early Cretaceous time showing similar Glance stratigraphy and syntectonic relationships to the Mule Mountains (fig. 14). (Kw) Willow Canyon Formation, (Kgg) Glance granitic-clast conglomerate member, (Kgm) mixed-clast congl. member, (Kgl) limestone-clast congl. member, (JT) Triassic(?)-Jurassic redbeds, (Pz) Paleozoic undifferentiated, (pCg) Precambrian granite and schist, (e) exotic slide-blocks of Late Paleozoic limestone.
belong to the same system of normal faults that generated the Glance in the northern Empire Mountains area or it may be an unrelated local feature. If the structure is correlated with the hypothesized normal faults to the east, a slightly west-northwest trend is suggested for the overall structure. If the feature is unrelated to the Early Cretaceous faulting in the Empire Mountains area, a more northwesterly trend can be suggested for the western extension of the Early Cretaceous normal faults. The Glance exposed in the west-central area is identical to the conglomerate located 3 km due east and suggests that the syndepositional normal faults were located a similar distance to the north and trended roughly east-west or slightly west-northwest (see Fig. 36).

At the extreme northeastern limit of the main outcrop belt, but to the south of the Murphy Ranch fault zone, granitic-clast conglomerate up to 400 m thick rests unconformably on Precambrian granitic basement. Just northward across the Murphy Ranch fault zone, arkosic sandstones of the Shellenberger Canyon Formation rest directly on Precambrian rocks with only occasional intervening lenses of Glance Conglomerate. This relationship suggests that either the northern structural block is tilted to the south or a relatively narrow fault block, with a capping of up to 400 m of granitic-clast conglomerate, is sandwiched between the northern block, with its thin coating of arkosic conglomerate and the southern block, with its full Paleozoic section and thick Glance/Willow Canyon sequence. The structural complexity and sense of displacement of the Murphy Ranch fault zone effectively obscures the actual Early Cretaceous structures, thus making absolute resolution impossible.

The amount of syntectonic erosion, the variation in thickness, and the distribution of lithofacies suggests that at least two normal faults, and thus three structural blocks, are involved in the Early Cretaceous tectonic framework of this area (Fig. 18). The Glance Conglomerate unconformably overlies Precambrian rocks in the northern and central blocks but overlies a complete Paleozoic section in the southern block. In contrast with the situation in the Mule Mountains, the central block has had the entire section of Paleozoic strata removed by erosion. Also, the attitude of the Paleozoic and Lower Cretaceous beds are subparallel rather than separated by an angular unconformity
displaying a pre-Glance tilt of $20^\circ - 30^\circ$. Thus the fault-block rotation noted in the Mule Mountains is not evident in the Early Cretaceous structural development of the Empire Mountains area, even though the trend and style of faulting and the mode of deposition appear to be nearly identical.
1. Introduction

The Glance Conglomerate in the Huachuca Mountains is principally exposed in an irregular and much faulted outcrop belt that runs down the southwestern flank of the mountain range. This band of outcrops stretches from the Mexican Border northwestward for 23 km to a point about 3 km northwest of Peterson Peak (see Fig. 19 and Plate 3). Local exposures of the Glance are also present as fault slices and limited outcrops at the northern end of the range, within many of the major faults along the axis of the range, and in the eroded core of a faulted anticline to the southwest, near the junction of Cave and Bear Creeks.

Structurally, the principal Glance exposure belt forms the southwestern limb of a northwest-trending anticline that has been extensively faulted, especially along its southeastern half. The structural complexity of the Huachuca Mountains, a result of intense post-Early Cretaceous tectonism, coupled with the wide variety of facies types in the Glance Conglomerate, make stratigraphic correlations difficult.

In general, the Glance Conglomerate in the Huachuca Mountains is similar to that found in the Mule and Empire Mountains, except that it is more difficult to subdivide into mappable lithofacies and contains a thick interbedded volcanic member composed primarily of rhyodacitic to andesitic lavas. These volcanic rocks are not very resistant to erosion and thus are poorly exposed. The thickness of the volcanic unit ranges from just a few meters, where present at all, to nearly 460 m (Hayes, 1970b). Conglomerate lenses are frequently found intercalated in the volcanic unit and thin lava flows are occasionally found in the conglomerate.
Figure 19. Generalized geologic map of the Huachuca Mountains.
(Modified from Hayes and Raup, 1968)
2. Stratigraphy

In the Huachuca Mountains, the Glance Conglomerate unconformably overlies either late Paleozoic sedimentary rocks, Jurassic quartz monzonite, or Triassic(?)-Jurassic volcanics and redbeds. Unlike in the Mule and Empire Mountains, the Glance rests on no rocks older than the Pennsylvanian-Permian Earp Formation. Conformably above the Glance are 1500-1800 m of Bisbee Group strata divided into the same map units, the Morita, Mural, and Cintura Formations, as in the Mule Mountains.

North-Central Area

The principal outcrop belt of Glance Conglomerate is located along the southwest flank and crest of the northern and central parts of the mountain range. It is composed of upper and lower conglomerate members, with a thick middle member of intermediate volcanic flows. The lower conglomerate member has a clast composition that strongly reflects the underlying rock type. To the north, at the head of Sawmill Canyon, where the Glance primarily overlies previously deformed Permian strata, the formation is entirely composed of limestone-clast conglomerate. At two restricted localities, one at the head of Garden Canyon, the other on Lyle Peak, some Triassic(?)-Jurassic volcanics and redbeds are preserved beneath the pre-Cretaceous unconformity and are overlain by limestone-clast Glance Conglomerate. Typically, the Glance near its basal contact is a poorly sorted, poorly bedded, clast-supported conglomerate or breccia containing 90% subangular light and dark gray limestone clasts, about 7% pink to reddish sandstone, and 3% dark chert. The conglomerate has a gray to pink, silty to sandy, calcareous matrix with rare, flat-laminated sandstone lenses, mostly about 30 cm wide and 10 cm thick. Limestone boulders, in the 1-2 m size range, are common. Fifteen to thirty meters above the basal contact of the Glance, the amount of pink sandstone becomes significant and reaches 50% of the total clast population in restricted layers within the central and upper parts of the lower conglomerate horizon. These sandstone clasts are probably derived from the Permian Scherrer Formation, a thick section of sandstone exposed and unconformably overlain by Glance near Pyeatt Ranch, at the north end of the Huachuca Mountains. Red
rhyodacitic volcanic clasts begin to show up in the upper third of the lower conglomerate horizon, becoming increasingly abundant upwards as the contact with the intercalated volcanic unit is approached. The matrix also becomes progressively darker red in color (Fig. 20). Locally, in Sawmill Canyon, cobbles and occasional boulders of quartz monzonite are found, probably derived from a local outcrop of the Jurassic Huachuca Quartz Monzonite. The proportion of granitic clasts increases towards the south.

Southward from the head of Sawmill Canyon, the lower conglomerate member rests unconformably on a thick section of Triassic(?)-Jurassic "siliceous volcanics of the Huachuca Mountains" (Hayes, 1970b) and is predominantly a volcanic-clast conglomerate, though a small number of limestone clasts are commonly present. The volcanic clasts are both dark purplish red felsite and lighter reddish maroon rhyodacitic tuff. Granitic and limestone cobbles are present but rarely exceed 20% of the clast population at any one outcrop. The exposures of this conglomerate lithofacies are poor, and the terrain is steep and forested, limiting the present study to a few scattered localities.

The upper Glance Conglomerate horizon, above the intercalated intermediate volcanic flows, is a mixed-clast conglomerate with significant numbers of volcanic, limestone, and sandstone clasts. Northward from the vicinity of Peterson Ranch, the upper horizon is predominantly a limestone-volcanic-sandstone-clast cobble conglomerate with frequent limestone clast percentages as high as 50%. From Peterson Ranch to the south, the upper horizon is principally a volcanic-limestone-sandstone-clast conglomerate with a distinct reddish brown matrix. The quantity of volcanic clasts in the upper conglomerate horizon thus increases to the south, along with a matching decrease in the amount of limestone clasts. The percentage of volcanic clasts reaches 100% within a few meters of the contact with the intercalated volcanic flows, and may be as high as 80% in restricted layers within the main body of the conglomerate. Occasional lava flows are also interbedded well up into the upper conglomerate horizon.

The upper conglomerate is mainly clast-supported, with scattered matrix-supported zones. The dominant clast sizes range from 5-30 cm, with
Figure 20. Limestone-volcanic-clast conglomerate with dark reddish-brown matrix, Sawmill Canyon, north-central area, Huachuca Mtns.
only an occasional rounded boulder in the 40-60 cm size range. The clasts are subrounded to subangular, with the limestone and sandstone clasts being better rounded than the volcanic clasts. No quartz monzonite clasts were identified in this conglomerate facies in this area, though some porphyritic dioritic cobbles were found.

No detailed analysis of the intercalated volcanic unit was attempted except to locate and collect samples for dating purposes. Unfortunately, no unaltered outcrops suitable for dating were located. Tertiary granodioritic porphyry and microgranodioritic dikes and irregular intrusive bodies, as well as Late Cretaceous and Tertiary tectonism, have destroyed most hopes of dating these rocks, except, perhaps, by Pb-U methods. Hayes (1970b, p. A13) reported a rapid rock chemical analysis of one, less altered, sample of volcanic rock. From this analysis, the rock would be classified a rhyodacite. At one locality in Copper Glance Canyon, a large lens of mixed-clast conglomerate, about 1 km long and 50-60 m thick, has a clast composition of 60% volcanics, 30-40% limestone, and small amounts of sandstone and chert. Other, smaller lenses are also common in the Copper Glance Canyon area. One lens even contains a stacked sequence of mudcracked and raindrop spattered, thin mudflow deposits. These deposits are 10-15 cm thick, with each layer graded from sand upwards to silt or mud.

The thickness of the Glance ranges from about 90 m less than 2 km north of Peterson Peak, where the intercalated volcanic unit is missing, to a total of more than 1400 m at a section measured from where Sawmill Canyon meets Garden Canyon southwestward into Sunnyside Canyon. This is a composite thickness of the lower conglomerate member (500 m), the volcanic member (600 m), and the upper conglomerate member (300 m). From this area toward the southeast, the upper conglomerate member gradually thins to zero, whereas the lower conglomerate thins to 200-300 m before north-northeast trending cross faults complicate the stratigraphy.

South-Central Area

The Glance Conglomerate that crops out to the south and southeast of Wakefield Camp, in the Bear Creek drainage, is somewhat similar to that
found farther to the north. Here the Glance is composed of an upper and lower conglomerate horizon separated by an intermediate volcanic flow member identical to that to the north. One major difference is that the lower conglomerate contains a large amount of subangular to angular cobbles and boulders derived from the Huachuca Quartz Monzonite. The lower conglomerate horizon is exposed in the eroded core of a northwest-trending anticline and as a northwest-trending band of outcrop that crosses the ridge projecting to the northeast of Sutherland Peak. Typically, the conglomerate has 50-60% granitic clasts, 25% red volcanics, and 15-25% clasts of limestone. The fabric is clast-supported with a maroon-colored, sandy matrix, and the largest clast is about 50 cm in diameter. The lower conglomerate unit is here about 200 m thick and rests unconformably either on Triassic(?)-Jurassic siliceous volcanics of the Huachuca Mountains or the Jurassic Huachuca Quartz Monzonite, dated at 164 ±6 m.y., K-Ar biotite (Marvin and others, 1973). The granitic clasts in this member are definitely derived from the Huachuca Quartz Monzonite which is exposed to the east at a lower stratigraphic and structural level.

The upper conglomerate horizon contains only rare, isolated granitic clasts and is predominantly a mixed-clast or volcanic-limestone-clast conglomerate. The conglomerate is mostly clast-supported, with a few local matrix-supported zones in the upper parts of the member. Locally, the conglomerate contains layers with large numbers of limestone clasts, up to 50%, but, as a rule, the percentages average 20-30%, with various reddish porphyritic and flow-banded volcanics making up the remaining 70-80%. Some horizons are 95-100% volcanic-clast conglomerates (Fig. 21). The volcanic clasts are subrounded to rounded, and the limestone clasts are subangular to subrounded. Boulders of red volcanic lava, 1-2 m across, are frequently found. Sandstone lenses up to 30 cm thick and 5-10 m long are common and increase in size and frequency as the contact with the overlying Morita Formation is reached. The thickness of the upper conglomerate member on the southwest limb of the small anticline is around 100 m, but this thickness thins to zero to the northeast and increases to the southwest with the disappearance of the underlying volcanic flows.
Near Lone Mountain Ranch, at the junction of Cave and Bear Creeks, about 5 km southwest of Wakefield Camp, the Glance Conglomerate is exposed along the southwest side of a fault that parallels the axes of some N65°W-trending folds (Fig. 52). Here the Glance is a mixed-clast conglomerate, though the volcanic clasts usually comprise the highest proportion of the clast assemblage. No intercalated volcanic flows are present, and the formation rests unconformably on Canelo Hills Volcanics and large limestone exotic blocks embedded in the pre-Cretaceous volcanics.

The Glance contains 80-90% granitic clasts at its basal contact, with the remaining 10-20% being clasts of volcanic origin. Ten meters above the base, the conglomerate quickly grades into a volcanic-limestone-granitic-clast conglomerate. This mixed-clast conglomerate is the dominant conglomerate type, with local deviations, up through the entire Glance Conglomerate section at this locality. Local departures from clast percentage norms involve restricted layers of up to 50% limestone, 80-90% granitic clasts, or 95-100% volcanic clasts. All clast types, in general, get better rounded upward through the section. The granitic clasts become smaller and increasingly weathered up-section as the amount of coarse, arkosic sand- and granule-sized material in the matrix becomes more abundant. The conglomerate is clast-supported and poorly sorted, though a rough type of sorting places most of the larger clasts in restricted boulder beds. Occasional, moderately sorted cobble, pebble, and sand lenses are present to supply bedding attitudes. As the upper contact with the Morita Formation is approached, the percentage of silt- and clay-sized material in the matrix, as well as the number of interbedded sandstone and siltstone beds, increases, and the amount of red and purple volcanic clasts also increases as the number of limestone and granitic clasts go to zero.

Southern Area

The Glance Conglomerate crops out over an area of almost 5 square kilometers within the Coronado National Monument, south of Montezuma Pass, at the extreme southern end of the mountain range. Here, the conglomerate rests unconformably on the upper rhyolite welded tuff member of the Canelo Hills Volcanics, as mapped by Hayes and Raup (1968), and is similar, in
Figure 21. Imbricated cobbles in volcanic-clast conglomerate, near Glance/Morita contact, south-central area, Huachuca Mountains.

Figure 22. Typical mixed (volcanic-limestone-granitic)-clast conglomerate near Lone Mountain Ranch, 4 km southwest of the Huachuca Mountains.
general, to the Glance farther north. Like the northern exposures, the Glance here has a lower and an upper conglomerate member and a middle volcanic member. One striking difference, though, is that the volcanic member is uniquely different from the intercalated flows farther north. Here it is composed of a string of very large exotic blocks of Permian Concha Limestone embedded in a single, 60 m thick, body of grayish red trachytic lava (Simons and others, 1966). The exotic blocks are as much as 450 m long, as thick as 60 m, and appear to have been carried or pushed by the trachyte flow as they are somewhat brecciated at their margins.

The lower conglomerate horizon is a poorly sorted, poorly bedded, and poorly exposed volcanic cobble to boulder conglomerate that is mostly clast-supported with usually less than 10% limestone clasts. At one roadcut on the Montezuma Pass road, just below the exotic block volcanic member, the limestone clast population is around 40% with 50% red, black, gray, and pink volcanic clasts and 10% chert, quartz, and sandstone clast types. This clast assemblage is unusual for the lower conglomerate member but is the norm for the upper conglomerate member above the volcanic-exotic block member.

The upper conglomerate member is a poorly sorted and poorly bedded volcanic-limestone conglomerate with a variety of subangular to subrounded volcanic tuff, lava, and porphyry cobbles making up the assemblage of volcanic clasts. Subangular limestone clasts are present in most exposures and frequently comprise 50% of the clast population. Clasts of orange-colored, coarse grained intrusive porphyry are common, and along with a few medium grained granitics, chert, and sandstone, may comprise another 30% of the clasts. That leaves 40% red, purple, and black volcanics, though they occasionally make up 60-70% of the total clasts present. Clast sizes rarely get larger than 20-30 cm in diameter.

Thick zones of very disorganized matrix-supported conglomerate, with maroon-colored silty matrix, are common throughout the upper member. It is only where the texture is clast-supported and the fabric becomes better sorted and organized, that stratification can be recognized. Occasional channels, cut into matrix-supported conglomerate and filled by clast-supported conglomerate,
are present. The thickness of the upper conglomerate member is at least 350 m, but may be more due to the fact that the upper contact with the Morita Formation is not exposed.

3. Paleocurrent Determinations

In the Huachuca Mountains, 125 paleocurrent measurements on such sedimentary structures as clast imbrications, channel orientations, oriented clast fabrics, crossbedding in sandstone lenses, and ripple marks on fine grained bedding surfaces were recorded (Table 4). When the individual data points were plotted on the area base map, certain groupings of specific trends became apparent in the data. Three paleocurrent trends are clearly distinguishable when the data are divided into four groups based on location and plotted on rose diagrams (Fig. 23).

The dominant paleocurrent direction within the Glance Conglomerate in the Huachuca Mountains is to the east-southeast. This direction is found in both the upper and lower conglomerate members from north of Peterson Peak southward to the vicinity of Wakefield Camp. This section of Glance contains abundant clasts of both limestone and various volcanic rocks. In the lower granitic-clast conglomerate at Wakefield Camp and at the junction of Bear and Cave Creeks, a notable west-southwest component of sediment transport is present in the data. This is significant because there is actually some Glance Conglomerate resting unconformably on the Huachuca Quartz Monzonite in Blind Canyon, located to the northeast. The third paleocurrent direction is found predominantly in the southernmost outcrop area, south of Montezuma Pass. This direction is to the north-northwest, nearly 180 degrees from the dominant paleocurrent directions found farther north.

The rose diagrams (Fig. 23) demonstrate that at Wakefield Camp, the lower granitic-clast conglomerate member, in which the southwest paleocurrent directions were recorded, has a different source direction than the upper mixed-clast conglomerate member, suggesting that the granitic highs that supplied the arkosic detritus were eroded down or buried by basin aggradation or volcanic activity prior to the arrival of the clastic debris of the upper
Table 4. Distribution of bedding-structure orientation resultants by azimuth classes (in degrees from north) for the Glance Conglomerate in the Huachuca Mountains, Arizona.

<table>
<thead>
<tr>
<th>Azimuth Classes (degrees)</th>
<th>Peterson Ranch Area</th>
<th>Wakefield Camp Area</th>
<th>Lone Mountain Ranch</th>
<th>Montezuma Pass Area</th>
<th>Total</th>
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<tbody>
<tr>
<td>1-30</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>31-60</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>9</td>
<td></td>
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</tr>
<tr>
<td>91-120</td>
<td>19</td>
<td>8</td>
<td>1</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>121-150</td>
<td>18</td>
<td>3</td>
<td>2</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>151-180</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>181-210</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>211-240</td>
<td>3</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>241-270</td>
<td>3</td>
<td>7</td>
<td></td>
<td>8</td>
<td></td>
</tr>
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<td></td>
</tr>
<tr>
<td><strong>Total number of localities</strong></td>
<td><strong>62</strong></td>
<td><strong>26</strong></td>
<td><strong>15</strong></td>
<td><strong>22</strong></td>
<td><strong>125</strong></td>
</tr>
</tbody>
</table>

Table 4. Distribution of bedding-structure orientation resultants by azimuth classes (in degrees from north) for the Glance Conglomerate in the Huachuca Mountains, Arizona.
Figure 23. Paleocurrent direction roses for the Glance Conglomerate in the Huachuca Mountains. The 4 areas are: Peterson Ranch (62), Wakefield Camp (26), Lone Mountain Ranch (15) and Montezuma Pass (22).
conglomerate member from the west-northwest.

In general, the paleocurrent data suggest that three different topographic high areas were shedding coarse clastics into the Huachuca Mountains area from three different directions during Early Cretaceous time. At least two of these overlapped somewhat in time and space because the east-southeast and the west-southwest paleocurrent directions are both present in the Wakefield Camp area. The conglomerate in the southern outcrop area, with the north-northwest paleocurrent directions, appears to merge into the conglomerate strata that strike southeastward from Wakefield Camp, but the complexity of the fault zone that runs just north of Montezuma Pass has been greatly simplified on the map and may actually separate the two terranes. No other systematic variations were identifiable in the data.

4. Environment and Mechanism of Deposition

The Glance Conglomerate in the Huachuca Mountains has the same broad textural characteristics and wide range of lithologic clast types as in the Mule and Empire Mountains. Poorly sorted, poorly bedded, disorganized matrix-supported conglomerate deposits are most common in the upper conglomerate member of the north-central or Peterson Peak area, in the lower conglomerate member in Garden Canyon, and in the upper member at the extreme southern locality, southern locality, south of Montezuma Pass. These localities are also the areas where the two members of the Glance are thickest and contain their most diverse assortment of clast types. As previously noted, these deposits are the products of subaerial debris-flows. The coarse, poorly sorted, clast-supported conglomerate that comprises the main body of the Glance Conglomerate is the result of deposition from fluvial processes, probably braided streams. The interbedding of these two types of deposits, suggests deposition on an alluvial fan, at least in the areas where the Glance is thickest.

The overlying Morita Formation, or at least its lower parts, is considered to be part of the subaerial alluvial fan system, mainly the finer grained mid-fan and distal-fan facies. Figure 24 shows a cross section along the axis of the outcrop belt and the relative thickening and thinning of the Glance and the
Figure 24. Diagrammatic cross section of the Glance Conglomerate in the Huachuca Mountains, showing relief on both pre- and post-Glance surfaces and variations in thickness of the Glance and its members. Approximate 5X vertical exaggeration. (Modified from Hayes, 1970b)
Morita Formations. The Morita thickens southeastward as the Glance thins, suggesting lateral facies development.

Though no direct evidence is present to identify its location, a local volcanic vent was present in the vicinity of the Huachuca Mountains during deposition of the Glance Conglomerate. The large limestone exotic blocks, encased in the volcanic flows within the Glance south of Montezuma Pass, indicate proximity to relatively high cliffs or scarps of Paleozoic strata or possibly some sort of caldera complex. The high numbers of large limestone exotic blocks in the Triassic(?)–Jurassic siliceous volcanics of the Huachuca Mountains concentrated at the southern end of the mountain range adds more support to the suggestion that the volcanic vent was proximal to the southern end of the range as opposed to being located farther north. The possible existence of more than one local volcanic vent cannot be ruled out, but no evidence is known to suggest its possible location.

5. Structural and Igneous Features

The two most significant structural features in the Huachuca Mountains are: 1) a major N40°W-trending, northeast-dipping, both high and low angle reverse-slip fault zone that runs the length of the mountain range and 2) a large, northwest-trending anticline on the west flank of the range. The major reverse-slip fault zone places Precambrian basement and early Paleozoic rocks structurally over Lower Cretaceous strata of the Bisbee Group. This southwest-directed compressional deformation probably caused, or at least was contemporaneous with, the major folding that occurred along the western flank of the mountain range and produced the major anticline there. This deformation is probably late Laramide (Early Tertiary) in age.

Major post-Cretaceous northwest-trending faults also cut through the south part of the Huachuca Mountains, just north of Montezuma Pass. Much Glance Conglomerate and older Triassic(?)–Jurassic siliceous volcanics of the Huachuca Mountains are involved in the faulting. The fault patterns, their relationship to the trends and axial traces of the major and minor folds of the area, and the correlation of Glance lithofacies across the faults, suggest
vertical displacements, rather than strike-slip, as the major mode of movement on the structures.

As for pre-Cretaceous structural features, three areas have striking structural or stratigraphic discontinuities that are suggestive of pre-Glance movements. The first area is northeast of Peterson Ranch, in the Paleozoic strata that underlie the Glance Conglomerate (Plate 3). Here the Paleozoic strata are cut by a series of faults that cut Permian sedimentary rocks but do not cut the Glance Conglomerate. This is also the area where the Glance thickens to its greatest extent. Gently dipping Permian limestone is faulted against a steeply dipping stack of lower Paleozoic strata and Precambrian granite. The dip of the overlying Glance is closer to the dip of the more steeply dipping Paleozoic rocks suggesting that the more shallowly dipping Permian strata may be a rotated fault block, downdropped along an Early Cretaceous normal fault. The particular fault in question trends east-northeast, just north of Garden Canyon, and is truncated by one of the major northwest-trending reverse-slip faults to the east.

The second area containing pre-Cretaceous structural features is just to the south, at the head of Sawmill Canyon (see Plate 3). Here Hayes and Raup (1968) mapped siliceous volcanics of the Huachuca Mountains striking into or "lapping onto" an "old hill" or scarp of Permian Colina Limestone. From that contact northward, the formation is missing, with its stratigraphic position marked by an unconformity between Paleozoic and Cretaceous strata. To the south, upward of 900-1200 m of these Triassic(?)-Jurassic siliceous volcanics and redbeds are present overlying Paleozoic strata and beneath Glance Conglomerate. The east-northeast trending contact is poorly exposed, though a limestone breccia-conglomerate is occasionally present along contact. Sawmill Spring, the only water source for kilometers, is also located very close to the contact. These relationships, plus the high angle between the strike of the contact and the strike of the Triassic(?)-Jurassic strata and the similarity of the strike of the contact to the strike of the pre-Cretaceous fault just to the north, suggests that this is a structural as well as depositional discontinuity, most probably a Jurassic or Early Cretaceous fault trace.
The third pre-Cretaceous structural feature is even less sharply defined. This structural feature runs parallel to the southwest edge of the mountain range, is a locus of post-Early Cretaceous fault deformation, and is, along its northern half, a pre-Glance stratigraphic disconformity. On the geologic map of the Huachuca Mountains by Hayes and Raup (1968), the Lone Mountain fault occupies the position of this feature. To the southwest of this structural zone, the thickness of the Jurassic Canelo Hills Volcanics varies from about 2800 m in the north near Canelo Pass, to 450-1050 m to the southeast. The Canelo Hills Volcanics have not been confidently identified on the northeast side of the zone but may be correlative with the somewhat metamorphosed siliceous volcanics of the Huachuca Mountains found in the southern half of the range. As evidenced by the quartz monzonite detritus and paleocurrents in the Glance Conglomerate exposed near the junction of Cave and Bear Creeks, this structural feature has no significant post-Early Cretaceous strike-slip movement on it and may be a reactivated dip-slip fault that was originally active along its northern section during the Jurassic or Early Cretaceous. The possibility of Early Cretaceous syndepositional movement on this structure cannot presently be proven as direct evidence to support this suggestion is lacking.

6. Tectonic Implications

Although the Glance Conglomerate has a similar depositional environment to the Glance in the Mule and Empire Mountains, no mappable faults can be directly indicated as the active structures that produced the local relief which, in turn, was eroded to supply the coarse detritus that makes up the Glance. The evidence needed to relate the identified pre-Glance structures to deposition of the Glance Conglomerate is lacking in the present data. The paleocurrents from the northern conglomerate outcrops indicate a west-to-northwest source but post-Early Cretaceous deformation and erosion have unfortunately obscured any positive identification of specific structures. The progressive southwestward overturning of folds, northward along the trend of the major reverse-slip fault zone, suggests that some rotation around a vertical axis may have affected the northern Glance strata, and because this is not an
easily quantifiable effect, it was not corrected for in the paleocurrent data. This may possibly swing some of the determinations to a more northerly source direction and possibly indicate a closer relationship to the two identified pre-Cretaceous fault structures in the Sawmill Canyon area.

The high percentages and wide variety of volcanic clasts in the northern exposures of Glance strongly suggests a western source terrane of exposed Canelo Hills Volcanics. The limestone clasts were probably derived from the high standing Paleozoic strata to the north and northwest which have a relatively thin cover of Glance Conglomerate. The east-west trending pre-Glance faults in the Sawmill Canyon area may be Early Cretaceous fault splays from the Jurassic age structure that is marked by the northern half of the Lone Mountain fault and the elongation of the Huachuca Quartz Monzonite (Plate 3). This structural geometry is somewhat similar to that of the pre-Cretaceous structures in the Mule Mountains.

At the south end of the Huachuca Mountains, the paleocurrents suggest a southern source, somewhere in Mexico, for the Glance Conglomerate. The alluvial fan depositional environment of the conglomerate strongly suggests that the uplift to the south was structurally controlled, and considering the general similarities here with the Glance in the Mule and Empire Mountains, an east-west or northwest-trending, down-to-the-north normal fault with Early Cretaceous dip-slip displacement, is interpreted to exist south of the Border. Thus a restricted basin or local graben existed in the Huachuca Mountains area during Early Cretaceous time.

The Glance Conglomerate in the Huachuca Mountains supports the regional interpretation of Early Cretaceous vertical tectonics producing high relief mountains and subsiding basins. Unfortunately, the actual location and trend of the high angle faults that are inferred to have bounded these mountain blocks and basins are covered by younger strata, obscured by later deformation or just happen to be located in Mexico. Only the two short, east-northeast trending faults at either end of Sawmill Canyon have some identifiable post-Paleozoic, pre-Cretaceous movement on them.
SANTA RITA MOUNTAINS

1. Introduction

In the Santa Rita Mountains, the Glance Conglomerate is principally exposed along the east flank of the mountain range. The Glance has been recognized in a few widely spaced exposures north of the northwest-trending Sawmill Canyon fault zone and is correlative with a large expanse of time-equivalent basal Cretaceous conglomerate and volcanic rocks south of the fault zone. The Lower Cretaceous section just south of the Sawmill Canyon fault zone (see Fig. 25) is composed of a lower conglomerate unit (upper member, Temporal Formation), a middle volcanic unit (upper member, Temporal Formation), an upper conglomerate unit (lower member, Bathtub Formation), and a capping volcanic sequence (middle and upper members, Bathtub Formation). Drewes (1971b, 1971c) mapped and named the Temporal and Bathtub Formations as distinct and separate from the Glance Conglomerate in the Santa Rita Mountains but suggested a possible correlation with the lower part of the Glance Conglomerate in the Huachuca Mountains. This present study considers the conglomerate members of the Temporal and Bathtub Formations stratigraphic equivalents of the mapped Glance Conglomerate farther north. Details of the volcanic members and the stratigraphic units as a whole are presented in a thorough study of the Mesozoic stratigraphy of the Santa Rita Mountains by Drewes (1971a).

The Glance Conglomerate and its equivalent strata unconformably overlie rocks ranging in age from Precambrian to Jurassic. North of the Sawmill Canyon fault zone, the Glance rests either on Permian sedimentary rocks, Cambrian strata or Precambrian granitic rocks. South of the fault zone, the Temporal and Bathtub Formations rest either on Triassic-Jurassic volcanic and sedimentary rocks or on Early and Middle Jurassic granitic rocks. Conformably above the Glance Conglomerate, north of the fault zone, is a thick section of Bisbee Group divided into the same map units as in the Empire
Figure 25. Generalized geologic map of the central Santa Rita Mountains. (Modified from Drewes, 1971b, c and Finnell, 1971)
Mountains (Willow Canyon Formation, Apache Canyon Formation, etc.). South of the fault zone, any Bisbee Group rocks that may once have existed have been faulted out or removed by erosion.

2. Stratigraphy

Northern Block

North of the Sawmill Canyon fault zone, the Glance Conglomerate is exposed in many restricted, typically fault-bounded, outcrops and varies widely in clast composition and subjacent rock type. Though much of the Glance is poorly exposed or highly deformed and therefore of only minor use in this study, there are two areas that provide a sufficient amount of information to make some reasonable correlations. These two areas are: 1) the Box Canyon area, where there is extensive Glance exposure and 2) the Rosemont mining district, where subsurface information was graciously supplied by the ANAMAX Mining Company.

Box Canyon Area

In the Box Canyon area (Fig. 25), the Glance can be divided into two separate outcrop terranes. The more westerly exposures, where the Glance rests unconformably on Precambrian and Cambrian rocks, are structurally separated from an eastern outcrop area, where the Glance unconformably overlies Permian rocks, by a major low angle fault. This fault places Pennsylvanian Horquilla Limestone over Lower Cretaceous Willow Canyon Formation. Local fault slices of Devonian Martin Formation and Cambrian Abrigo Formation are found along the trace of the fault. This fault is part of a north-south trending, east-dipping system of low angle faults that are subparallel to the bedding in the Paleozoic rocks.

(a) Western Outcrops

The Glance Conglomerate west of the north-south trending low angle faults is a poorly sorted, arkosic or granitic-clast conglomerate containing a minor amount of greenish gray, fine grained schist and brown quartzite clasts. Where the Glance overlies Precambrian Continental Granodiorite, the conglomerate contains 90-100% subrounded to subangular porphyritic granodiorite and
other coarser and finer grained granitics in an arkosic matrix of coarse sand and granules. Where the Glance overlaps Cambrian Bolsa Quartzite and Abrigo Formation with angular unconformity, the percentage of subangular quartzite clasts locally increases to 20-30% with the remainder made up of granitic clasts of various types and a few schist (Pinal) clasts. No limestone or volcanic clasts were found.

The thickness of the granitic-clast conglomerate is 100-120 m. The contact with the overlying Willow Canyon Formation is gradational, with sandy lenses and maroon mudstone stringers increasingly interbedded with the conglomerate until only minor pebble conglomerate lenses are found above the contact.

(b) Eastern Outcrops

Structurally above the granitic-clast conglomerate and some Willow Canyon Formation is a block of Glance Conglomerate with a different clast composition and basal contact relationships. Here the Glance overlies Pennsylvanian Horquilla Limestone, has an intercalated volcanic unit, and can be divided into three clast lithofacies. The lithofacies include a basal limestone-clast conglomerate, a middle mixed-clast or quartzite-limestone-granitic-clast conglomerate, and an upper granitic-clast or arkosic conglomerate. This sequence is strikingly similar to the Glance found in the Empire Mountains (see Chapter III).

Close to the major east-dipping low angle fault the Glance is highly sheared and foliated. This deformational fabric decreases in intensity away from the fault in a northeasterly direction. The basal Glance contact with the Horquilla Limestone is occasionally sheared, though in a few places the contact appears unconformable. Near the contact, the Glance is a 90-95% limestone-clast conglomerate with limestone boulders up to 2 m in diameter. Also included are chert and sandstone/quartzite clasts. The matrix is pink to light reddish brown fine sand and silt, and fills interstices within a clast-supported framework. The conglomerate beds dip westward into the unconformity where shear foliation has not obscured the bedding structures.

Along the western edge of the eastern outcrop area, the limestone-clast
conglomerate is thin (1-5 m) or nonexistent, and quickly grades upward and away from the contact into a mixed-clast or quartzite-granitic-limestone-clast conglomerate. The matrix gets coarser, more arkosic and darker in color upward. There is distinct lateral intertonguing of 90% quartzite-granitic-clast conglomerate with the more limestone-rich conglomerate beds.

In the northern part of the outcrop area, the Glance dips steeply (60°) to the west, with a thin zone of limestone-clast conglomerate commonly, but not always, present along the western contact and a thick section of stratigraphically lower limestone-clast conglomerate exposed on the eastern side of the area. The eastern boundary of the Glance is a Cenozoic high angle, east-dipping normal fault. A steeply dipping shear foliation is present in the Glance near this contact, but it decreases westward away from the fault. The thickness of the limestone-clast conglomerate member is about 20-30 m, with no basal contact exposed.

The limestone-clast cobble conglomerate grades vertically into mixed-clast or quartzite-limestone-granitic-clast conglomerate by a systematic increase in the amount of subangular quartzite clasts and eventually the addition of granitic clasts to the overall clast assemblage (Fig. 26). The matrix of the limestone-clast conglomerate is gray to pink calcareous cement and silt-sized material but becomes darker, redder, and coarser up-section within the mixed-clast conglomerate. The clasts are subangular to subrounded and range in size from 5-20 cm.

Amygdaloidal, aphanitic, light and dark gray andesitic volcanic rocks are interbedded in the upper part of the mixed-clast conglomerate unit. Some of the contacts appear conformable, while others are at steep angles to the layering in the conglomerate. Drews (1971b) interpreted these volcanic rocks as Tertiary intrusives, but the presence of angular cobbles of andesite in the overlying conglomerate suggests that they are mostly Lower Cretaceous lava flows that may have filled locally incised channels of stream canyons.

The southern third of the eastern outcrop area contains mixed-clast conglomerate with large amounts of porphyritic granodiorite clasts (20-50%), quartzite (35-60%), and lesser amounts of limestone (10-40%). The abundance
Figure 26. Quartzite-limestone-clast conglomerate, Glance Conglomerate, eastern outcrop area, Box Canyon, Santa Rita Mountains.
of quartzite and granodiorite cobbles and occasional boulders 30–40 cm in diameter, increases up-section. The upper Glance contact has been removed by erosion. The resulting total thickness of Glance Conglomerate, including volcanic units, is 300–400 m.

**Rosemont District**

About 3½ km farther north is the old Rosemont mining district, now owned by ANAMAX Mining Company. Only two small exposures of Glance Conglomerate have been mapped in the area, but almost every hole drilled searching for ore encountered Glance in the subsurface. Analysis of the drill core for composition of the conglomerate and the various thicknesses and contact relationships of pertinent units provided the following data.

The Glance Conglomerate can be subdivided into a lower limestone-clast conglomerate and an upper arkosic or quartzite-granitic-clast conglomerate. An andesitic volcanic flow unit is intercalated in the upper arkosic conglomerate member, and clasts derived from this volcanic unit are present in the conglomerate above it. The Glance rests unconformably on Permian Scherrer Formation limestone as identified by ANAMAX geologists, though the underlying limestone is lithologically similar to the Permian Rainvalley Formation that also crops out in the area, or is faulted against a variety of other Paleozoic formations. This faulted contact is an east-dipping, low angle fault that surfaces to the west and may be a northward continuation of the north-south trending, low angle fault zone in the Box Canyon area. The upper arkosic conglomerate grades vertically into the sandstones and siltstones of the overlying Willow Canyon Formation.

The thickness of the various members within the Glance Conglomerate is highly variable. Two diagrammatic cross sections, drawn west-to-east across the district, are shown in Figure 27. These cross sections were constructed using information from a series of drill holes spaced along the two sections. The southern cross section (B) shows a limestone-clast conglomerate-filled paleocanyon cut into Permian Scherrer or Rainvalley Formation. Overlying the limestone-clast conglomerate member is an arkosic conglomerate member with the intercalated andesitic volcanic unit. The arkosic
Figure 27. East-west cross sections through the Rosemont mining district, northern Santa Rita Mountains showing thickness variations and 2 lithofacies of Glance Conglomerate. (A) is the northern section, (B) the southern.
conglomerate contains a small amount of volcanic clasts that become increasingly abundant to the east. The arkosic conglomerate contains quartzite, granitic, and volcanic clasts set in a coarse arkosic matrix and is gradational up into the Willow Canyon Formation. The northern cross section (A) shows similar relationships except that the volcanic unit is thicker and the lower part of the limestone-clast conglomerate has been faulted out along the east-dipping low angle fault.

The two cross sections, plus information from intervening drill holes, suggest that the limestone-clast conglomerate filled a paleocanyon which trends north-south or north-northeast to south-southwest. In one drill hole in the extreme northeastern corner of the district, 140 m of limestone-clast conglomerate was encountered underlying 120 m of quartzite-granitic-volcanic-clast conglomerate that graded up into thick arkosic sandstones of the Willow Canyon Formation. The limestone-clast conglomerate bottomed at the low angle fault and thickened eastward and northward.

Southern Block

South of the Sawmill Canyon fault zone, Drews (1971b) recognized the Glance Conglomerate in only a single, restricted outcrop locality, though he mentioned the possibility that the Temporal and Bathtub Formations are correlative with the lower part of the Glance in the Huachuca Mountains (Drewes, 1971a, p. C-43). The single body of Glance rests with slight angular contact relationships against the middle volcanic member of the Bathtub Formation and occurs within a zone of deformation along a major north-northwest trending post-Cretaceous fault (see Fig. 25).

Temporal Formation

The basal Cretaceous unit in the southern half of the Santa Rita Mountains is the Temporal Formation. This unit contains rhyolitic to andesitic volcanics, polymictic conglomerate, and tuffaceous sandstone (Drewes, 1971a). These rocks unconformably overlie Triassic-Jurassic Mt. Wrightson Formation volcanics and eolian sandstones in the northern half of the area, and the Jurassic Squaw Gulch Granite and Piper Gulch Monzonite to the south. This unconformity has a rough topography, often showing considerable local relief.
For the purposes of this research, only the northern section, or more specifically, the upper member, of the Temporal Formation was studied.

The upper member of the Temporal Formation can be divided into a lower conglomerate unit and an upper rhyodacite breccia unit. Intercalated within the lower conglomerate unit are small lenses of rhyolite flows and tuff. The conglomerate unit is about 300 m thick north of Gardner Canyon, where it is truncated by faults subparallel to the Sawmill Canyon fault zone, and thins southwestward until it disappears about 1.5 km south of Gardner Canyon. Small lenses of conglomerate are also present within the lower part of the overlying purple rhyodacite breccia, and as much as 120 m of basal conglomerate reappears about 4 km farther south in Temporal Gulch. The rhyodacite breccia is as much as 300 m thick in the northern part of the area and thins southward until it too disappears.

Compositionally, the lower conglomerate is a mixed-clast conglomerate with large amounts of volcanic and granitic clasts and small amounts of quartzite, limestone, and sandstone clasts. Some zones within the member contain volcanic-clast conglomerate with 80-90% red, gray, and purplish red volcanic cobbles and boulders of various sorts. These zones typically contain no granitic clasts. Not more than a few meters away, conglomerate with 50-80% granodiorite porphyry, pink, equigranular granite and dark gray diorite clasts and containing less than 30% volcanic clasts is present. In general, the clast percentages are around 55% volcanic, 35% granitic, and 10% limestone, quartzite, and sandstone clasts (Fig. 28). The unit is typically clast-supported cobble to boulder conglomerate with occasional matrix-supported zones. The matrix is poorly sorted coarse sand, grit, and silt with a range in color from light gray to dark reddish brown. The clasts are subrounded to rounded and may get as large as 1.5 m across (porphyritic granodiorite boulder). No systematic variations in clast composition were noted except that the southern half of the outcrop belt where the upper member conglomerate reappears and thickens to 120 m, the unit is a volcanic-clast conglomerate.

**Bathtub Formation**

Overlying the rhyodacite breccia of the upper member of the Temporal
Figure 28. Mixed-clast conglomerate, upper conglomerate member, Temporal Formation, Gardner Canyon, Santa Rita Mountains.
Formation, with minor disconformity, is a mixed-clast conglomerate unit mapped as the lower member of the Bathtub Formation (Drewes, 1971b). This conglomerate is indistinguishable from the lower conglomerate unit of the upper member of the Temporal Formation that underlies the rhyodacite breccia. The composition and relative abundances of various clast types in the lower member of the Bathtub Formation are identical to those found in the mixed-clast conglomerate of the upper member of the Temporal Formation just 0.5-1.0 km to the north. Typical clast percentages are 50-65% volcanics of various colors and types (derived mainly from the Triassic-Jurassic Mt. Wrightson Formation), 30-40% porphyritic granodiorite and quartz monzonite, equigranular granodiorite and diorite, 5-15% quartzite, limestone, and buff colored sandstone. Typically, the clast sizes range from 5-30 cm in diameter, with occasional boulders 0.8-1.0 m in size. The largest clast found was a pink, equigranular granitic boulder 2.5 m in diameter. Both clast-supported and matrix-supported conglomerate are present (Fig. 29a), with the matrix-supported conglomerate commonly very poorly sorted (Fig. 29b).

The mixed-clast conglomerate of the lower member of the Bathtub Formation is up to 185 m thick near Gardner Canyon but wedges out southward in a similar fashion to the upper member of the Temporal Formation. Far to the south, the lower member of the Temporal reappears as a 200 m thick sequence of volcanic sandstone and minor conglomerate that becomes richer in arkosic detritus in a southerly direction.

Stratigraphically above the conglomerate member is the rhyolitic volcanic middle member and the dacitic volcanic upper member of the Bathtub Formation (Fig. 30). These two volcanic members have a combined thickness of as much as 750 m, with an upper contact that is either an unconformity with overlying Tertiary volcanics or a fault placing the units against Upper Cretaceous sedimentary rocks. The volcanics of the Bathtub Formation have not been radiometrically dated and thus may be younger than presently thought.

As previously mentioned, Drewes (1971b) mapped one locality of Glance Conglomerate south of the Sawmill Canyon fault zone, where the Glance rests unconformably on the volcanic middle member of the Bathtub Formation (Fig. 25).
Figure 29a. Contact between matrix-supported and clast-supported conglomerate, lower conglomerate member, Bathtub Formation, Santa Rita Mountains.

Figure 29b. Massive, poorly sorted, matrix-supported conglomerate with large boulders. Lower conglomerate member, Bathtub Formation, Santa Rita Mountains.
Figure 30. Diagrammatic cross section of the Lower Cretaceous Bathtub and Temporal Formations, south of Sawmill Canyon fault zone, Santa Rita Mountains. Bathtub Formation: Kbu - upper member, Kbm - middle member, Kblc - lower conglomerate member, Kbls - lower sandstone member. Temporal Formation: Ktuc - upper conglomerate member, Ktuv - upper volcanic member, Ktlm - middle and lower members undivided, Ktlc - lower conglomerate member. (Modified from Drewes, 1971)
The Glance is here a mixed-clast conglomerate that is indistinguishable from parts of the conglomerate units in the Temporal and Bathtub Formations to the northwest. This outcrop locality of mixed-clast conglomerate is here considered to be either a slightly deformed conglomerate lens within the middle member of the Bathtub Formation or a fault sliver of lower member Bathtub conglomerate or upper member Temporal conglomerate, both of which are truncated by the same fault farther to the northwest. This conglomerate exposure bears only minor resemblance to any other Glance Conglomerate located elsewhere in the Santa Rita Mountains.

3. Paleocurrent Determinations

In the Santa Rita Mountains, sedimentary structures that indicate sediment transport directions of the Glance Conglomerate and the stratigraphically equivalent Temporal and Bathtub Formations are the same as those present in the Glance Conglomerate of the Mule, Empire, and Huachuca Mountains. Poor exposure, due to the fact that the conglomerate is not very resistant to erosion and local shear deformation, limited the amount of collectible paleocurrent data. A total of 42 paleocurrent determinations were recorded (Table 5), and are plotted as current roses on Figure 31.

North of the Sawmill Canyon fault zone, in the Box Canyon area, the paleocurrent direction within the Glance Conglomerate is to the northeast. This includes data from both the western and eastern outcrop areas. No paleocurrent information could be obtained in the Rosemont mining district to the north.

South of the Sawmill Canyon fault zone, the sediment transport data for the Temporal and Bathtub Formations show three distinct directional modes. Both formations show an explicit south-southwest paleocurrent direction, while the Temporal also displays a secondary northeast direction and the Bathtub a secondary east-southeast direction. This polymodal relationship suggests a mixing of sediments derived from three different source areas. The two data points from the single mapped "Glance" locality suggests a southwesterly source, adding support for an elevated source terrane to the southwest.
Table 5. Distribution of bedding-structure orientation resultants by azimuth classes (in degrees from north) for the Glance Conglomerate, Temporal Formation and Bathtub Formation in the Santa Rita Mountains, Arizona.

<table>
<thead>
<tr>
<th>Azimuth Classes (degrees)</th>
<th>Glance, Box Canyon Area</th>
<th>Southern Glance Outcrop</th>
<th>Temporal Formation</th>
<th>Bathtub Formation</th>
<th>Total</th>
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<td>1</td>
<td>1</td>
<td>3</td>
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<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>8</td>
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<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>91-120</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
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<td>2</td>
<td>2</td>
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<td>2</td>
<td>4</td>
<td>6</td>
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<td></td>
<td>3</td>
<td>5</td>
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<td><strong>Total number of localities</strong></td>
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<td><strong>2</strong></td>
<td><strong>11</strong></td>
<td><strong>19</strong></td>
<td><strong>42</strong></td>
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</table>

Table 5. Distribution of bedding-structure orientation resultants by azimuth classes (in degrees from north) for the Glance Conglomerate, Temporal Formation and Bathtub Formation in the Santa Rita Mountains, Arizona.
Figure 31. Paleocurrent roses for the Glance Conglomerate and equivalent strata in the Santa Rita Mountains. The 3 areas are: Box Canyon (10), Temporal Formation (11) and Bathtub Formation (19).
4. Environment and Mechanism of Deposition

The Glance Conglomerate and its equivalent strata in the Santa Rita Mountains contain the same textural characteristics, contact and lithofacies relationships and wide variety of clast types that are present in the Mule, Empire, and Huachuca Mountains. North of the Sawmill Canyon fault zone, the Glance is basically a coarse, poorly sorted, clast-supported cobble conglomerate with large boulders present only near basement contacts. The coarse arkosic nature of most of the matrix, plus the presence of many sand lenses suggest that here the conglomerate was deposited by fluvial processes. The north-northeast to south-southwest trending limestone-clast conglomerate-filled channel or canyon, located in the subsurface of the Rosemont mining district, the angular and locally sheared Glance/Horquilla Limestone contact in the Box Canyon area, and the recorded paleocurrent directions suggest that transport of the conglomeratic material was to the northeast in an initially incised but eventually buried canyon.

South of the Sawmill Canyon fault zone, the Glance-equivalent Temporal and Bathtub Formations contain poorly sorted, poorly bedded, disorganized matrix-supported conglomerate deposits interbedded with better organized, but still rather poorly sorted, clast-supported conglomerate. Large boulders and fine grained, muddy matrix are commonly associated with the matrix-supported deposits. As discussed in previous chapters, these types of deposits are laid down by subaerial debris-flow processes and are characteristic of alluvial fan depositional environments. Paleocurrent data and the composition of various clast types suggest northern, western, and southwestern source terranes. The porphyritic granodiorite clasts were derived from exposures of Precambrian Continental Granodiorite to the north and northeast. The wide variety of volcanic clasts were derived from the underlying Mt. Wrightson Formation presently exposed to the west and northwest and from intercalated volcanic members in the Temporal and Bathtub Formations. The limestone and quartzite clasts were derived from Paleozoic rocks to the northeast, and some of the pink granitic clasts came from the Jurassic plutons to the south and southwest.
5. Structural Features and Tectonic Implications

The prominent structural features of the Santa Rita Mountains are the northwest-trending Sawmill Canyon fault zone, the north-south trending low angle fault zone located north of the Sawmill Canyon fault zone, and a feature Drewes calls the Santa Rita fault scar (Drewes, 1972), to the south. The Sawmill Canyon fault and the Santa Rita fault scar are structural zones that were active during early to middle Mesozoic time, and the low angle fault zone is a late Mesozoic feature.

The low angle fault zone juxtaposes upper plate Glance Conglomerate, which has similar clast-lithofacies and subjacent contact relationships to Glance farther north in the Empire Mountains area, over lower plate Glance that reflects the autochthonous Precambrian basement upon which its rests unconformably.

This fault zone is probably Early Tertiary (late Laramide) in age, though it may have even younger movement on it. These relationships suggest that the upper plate had a southwest-directed transport direction, in response to Late Cretaceous–Early Tertiary northeast–southwest compressional deformation. Northwest-trending fold axes in the Lower Cretaceous rocks to the northeast support this geometry. The western and eastern outcrop terranes in the Box Canyon area were thus separated by a much greater distance at the time of Glance Conglomerate deposition. The systematic vertical variation of clast lithofacies from limestone-, through quartzite-, and into granitic-clast conglomerate reflects the uplift and sequential erosion of succeedingly older rocks in the source terrane to the southwest. Arkosic Glance Conglomerate resting on Precambrian Continental Granodiorite in the farthest southwest outcrop locality and on steeply dipping Cambrian Bolsa Quartzite and Abrigo Formation to the northeast, further suggests that the underlying basement was part of a tilted fault block creating a northeastern-facing paleoslope feeding sediment into the same restricted basin being fed coarse detritus from the north in the Empire Mountains area.

The Sawmill Canyon fault zone is the structural feature of greatest interest to this study. The marked differences in clast composition, thickness,
lithofacies relationships, paleocurrent directions, and subjacent rock types suggest that this fault zone was a major structural and topographic feature during Early Cretaceous time. The total stratigraphic relief across the Sawmill Canyon fault zone by the end of Glance time, was at least 3000 m, southwest side down. The present complexity of the Sawmill Canyon fault zone with its system of anastomosing fault traces, predominantly trending N50°-55°W, is suggestive of major strike-slip movements and precludes any direct interpretation of possible middle Mesozoic displacements from analysis of the faults themselves. Multiple post-Glance movements along the Sawmill Canyon fault zone are clearly evident, since the fault cuts later Cretaceous formations.

The deposition of a thick, southward-thinning, conglomeratic alluvial fan sequence immediately south of the Sawmill Canyon fault zone, together with the existence of deposits of similar age in the Empire and Mule Mountains where they are related to Early Cretaceous normal fault movements, strongly suggest that the Sawmill Canyon fault zone is also a south-side-down normal fault of mid-Mesozoic age. The presence of minor amounts of Paleozoic limestone detritus and the abundance of Precambrian debris in the Temporal and Bathtub Formations indicates that most of the Paleozoic strata had already been removed from the block north of the fault zone by Glance time. This limestone debris is not found in the exposed Triassic-Jurassic strata of the Santa Rita Mountains and may have been deposed farther to the southeast in possibly older Glance Conglomerate in the Huachuca Mountains.

The third structural feature of interest is the Santa Rita fault scar, a northwest-trending zone indicated by the aligned northeast edges of Jurassic and younger elongate intrusives, by septa in the intrusives, and by striking contrasts in stratigraphic sequences and structural attitudes on either side of the intrusive zone. Drewes (1972) considers that the evidence is sufficient to show that the feature was initially a large, N35°W-trending, early Mesozoic fault zone. The evidence for movement on the fault is sketchy at best, but displacements along faults buried by Cretaceous sedimentation caused uplift of the Jurassic plutons, the Piper Gulch Monzonite (180 ±20 m.y., Pb-α, zircon) and the Squaw Gulch Granite (160 ±20 m.y., Pb-α, zircon and 145 ±6 m.y.,
K-Ar, biotite) (Marvin and others, 1973) and exposed them to erosion during Glance time.
CHAPTER VI

DRAGOON MOUNTAINS-GUNNISON-RED BIRD HILLS

1. Introduction

In the north-central part of the region, the Glance Conglomerate is exposed in four main outcrop localities: (a) the central Dragoon Mountains, (b) the northern Dragoon Mountains, (c) the Gunnison Hills, and (d) the Red Bird Hills (see Fig. 32). In the central Dragoon Mountains, the Glance is exposed along the eastern flank of the range from Middlemarch Pass southward to South Pass as a thin (1-40 m thick) band of basal conglomerate. Conformably overlying the conglomerate is a very thick section of northeast-dipping Bisbee Group rocks. Gilluly (1956) mapped these Lower Cretaceous rocks as the Bisbee Formation with a thickness of over 4500 m, and included the Glance as a basal conglomerate member, though he did not delineate it separately on his map. Post-Early Cretaceous deformation in this part of the Dragoon Mountains, carefully mapped and detailed by Keith and Barrett (1976), has folded and locally overturned much of the section, complicating many of the field relationships. This area has been and will continue to be a structurally controversial locality.

At the north end of the Dragoon Mountains, the Glance is exposed in several north-northwest trending blocks bounded by high angle faults. The bedding dips steeply, and the conglomerate is locally sheared and metamorphosed along many of the bedding contacts. Ten kilometers farther to the north, the Glance Conglomerate is relatively unmetamorphosed and makes up the north end and northeastern flank of the Gunnison Hills. The Red Bird Hills lie about 3 km east of the north end of the Gunnison Hills and are composed almost entirely of Glance Conglomerate. Though high angle faults locally complicate much of the section, the thickness of the Glance here is significantly greater than to the south-southwest in the Dragoon Mountains.
Figure 32. Generalized geologic map of the Dragoon Mountains-Gunnison-Red Bird Hills area. (Modified from Gilluly, 1956; Cooper and Silver, 1964; Cooper, 1960; Keith and Barrett, 1976) Age dates on Tertiary intrusives from Marvin and others (1973).
2. Stratigraphy

(a) Central Dragoon Mountains

In the central Dragoon Mountains, the Glance Conglomerate varies in thickness from zero (locally absent) to about 300 m. Typically, it is about 30-60 m thick and rests unconformably on either Precambrian granitic rocks (quartz monzonite) or upper Paleozoic limestone. A major northwest-trending structure, the Black Diamond fault (Fig. 32) mapped by Keith and Barrett (1976), divides the area into two distinct, pre-Glance structural blocks. Southwest of the Black Diamond fault, the Glance rests unconformably on upper Paleozoic limestone, but to the northeast, the conglomerate unconformably overlies Precambrian and Cambrian rocks. The unconformity shows some local relief, with buried hills of Cambrian strata east of the fault and canyons locally cut down into the Horquilla Limestone on the west side of the fault. Dips in the Lower Cretaceous strata are nearly parallel to those in the Paleozoic rocks on both sides of the fault and suggest that no major diastrophism occurred in post-Paleozoic, pre-Glance time.

Northeast Block

Northeast of the Black Diamond fault, near Middlemarch Pass, the Glance Conglomerate crops out in both limbs of a large open syncline. The thickness of the unit ranges from zero to about 300 m due to relief on the sub-Glance unconformity. At Black Diamond Peak, the Glance is missing due to the presence of a local hill of Cambrian Bolsa Quartzite on the unconformity. About 1 km to the northwest, the Glance unconformably overlies Precambrian quartz monzonite, fills a paleocanyon, and reached 300 m in thickness. Further north, the Glance thins to 120 m and contains many interbedded sandstone lenses near the top of the section.

Compositionally, the Glance Conglomerate is predominantly a limestone-clast conglomerate with local zones of quartzite-clast conglomerate at the base and mixed-clast or limestone-quartzite-volcanic-granitic-clast conglomerate making up large portions of the formation where it is thick. Where the Glance overlies Pinal Schist, the proportion of schist clasts increases, whereas the granitic debris is abundant where it overlies Precambrian quartz
quartz monzonite. Red, pink, and green volcanic clasts locally make up 25% of the clast population. Generally, limestone clasts form more than 50% of the clasts at any given locality, except in a few outcrops of pure quartzite-clast conglomerate exposed at the base of the unit where it overlies Bolsa Quartzite. The maroon matrix is typically arkosic.

Texturally, the Glance is poorly sorted, poorly bedded, clast-supported pebble to cobble conglomerate with boulders up to 1 m in diameter occasionally present. Matrix-supported zones, though present, are rare and have a silty-sandy matrix. The clasts are subrounded to subangular with the granitic pebbles and cobbles being deeply weathered and friable, very similar in appearance to the weathered Precambrian quartz monzonite exposed below the unconformity.

Southwest Block

Southwest of the Black Diamond fault, the Glance Conglomerate is exposed on the crest and lower limb of a northeast-verging, northwest-trending, southeast-plunging overturned anticline (Keith and Barrett, 1976). Typically, the Glance rests unconformably on Permian Colina Limestone, but in two localities it occupies paleocanyons that have been cut down into Pennsylvanian-Permian Earp Formation and Pennsylvanian Horquilla Limestone. The thickness of the unit typically ranges from 30 to 60 m and is nowhere greater than 75 m. North of the Middlemarch Pass road, the Glance is missing, and the finer grained strata of the Bisbee Formation rest directly on Horquilla Limestone.

Compositionally, the Glance Conglomerate southwest of the Black Diamond fault is generally identical to the Glance northeast of the fault. Most of the unit is poorly sorted, mixed-clast or limestone-quartzite-chert-volcanic-granitic-clast conglomerate with limestone making up 50-60% of the total clast population. At the southeastern end of the outcrop band, the lower part of the Glance contains 50-60% granitic and volcanic clasts, 30-35% limestone, and about 10-15% quartzite clasts. About 20 m upsection, near the upper contact, the conglomerate contains about 80-90% limestone clasts. The clasts are subangular to subrounded and form a clast-supported framework with a maroon, arkosic matrix.
(b) Northern Dragoon Mountains

At the northern end of the Dragoon Mountains, the Glance Conglomerate is exposed in narrow, northwest-trending fault blocks bounded by steeply dipping faults. The Glance has been intensely folded, and the beds commonly dip 70°-80° to the northeast or southwest. The conglomerate unconformably overlies Permian Epitaph Dolomite and Pennsylvania Horquilla Limestone, although the contact frequently displays a local shear foliation and may have experienced some bedding-plane slip.

Typically, the Glance is poorly sorted limestone (85%) - sandstone (15%) - clast conglomerate and varies in thickness from 20 to 60 m. No significant variations in clast type were noted either vertically or laterally in the section. Texturally, the Glance is clast-supported with subrounded to angular pebbles and cobbles and only rare clasts over 20 cm in diameter.

(c) Gunnison Hills

The Glance Conglomerate in the Gunnison Hills unconformably overlies Permian Concha Limestone and Scherrer Formation and a local remnant of Triassic(?)-Jurassic volcanics and redbeds named the Walnut Gap Volcanics. The thickness of the Glance is at least 250 m, with the top of the formation not exposed anywhere in the area.

Compositionally, the Glance is very similar to the Glance located at the northern end of the Dragoon Mountains. The unit is strikingly uniform, consisting of poorly sorted, clast-supported, angular to subrounded pebbles, cobbles, and rare boulders of light and dark gray limestone (90-95%), pink and buff sandstone (5-7%), and dark chert (3-5%). Occasional red volcanic clasts and small chips of red shale are present. The matrix is typically pink, sandy, and cemented by calcite. Thin, calcareous buff sandstone lenses are common in the upper parts of the exposed section. The average clast size is greater than that of the Glance found at the northern end of the Dragoon Mountains with many clasts in the 30-50 cm size range.

The small remnant of Triassic(?)-Jurassic Walnut Gap Volcanics is composed of brick-red pebble conglomerate, sandstone, andesitic tuff and andesitic breccia and is approximately 100 m thick (Cooper and Silver, 1964). The
redbeds and volcanics are preserved in a small paleocanyon cut into the sub-
Glance depositional surface, and may be a remnant of a once more widespread
volcanic sequence.

(d) Red Bird Hills

In the Red Bird Hills, the Glance Conglomerate unconformably overlies
the Permian Concha Limestone and local exposures of Triassic(?)-Jurassic
volcanics and redbeds very similar to the Walnut Gap Volcanics 3 km to the
west in the Gunnison Hills. The conglomerate here is identical to that found
in the Gunnison Hills in all respects except for the exposed thickness and max-
imum clast size. Upwards of 1000 m of limestone-clast conglomerate is present
even though the top of the unit is not exposed.

The average clast size of the Glance Conglomerate in the Red Bird Hills
is greater than in the Gunnison Hills. Boulders 1-2 m in diameter are common
within the basal hundred meters of the formation, and boulders 0.5-1.0 m in
diameter are common higher in the section. The conglomerate is poorly sorted,
predominantly clast-supported with rare matrix-supported zones, and contains
occasional pink to buff sandstone lenses. Thick (1-2 m) sandstone beds are
common in the easternmost outcrops. Their presence suggests that the top of
the formation is relatively near.

The underlying Triassic(?)-Jurassic volcanics and redbeds are identical
to the Walnut Gap Volcanics and to the andesitic pyroclastic volcanics and red-
beds reported in the South Pass area of the Dragoon Mountains by Gilluly (1956).
This correlation suggests that these volcanics and redbeds are remnants of a
once much more extensive deposit and may be correlative with the Triassic(?)-
Jurassic volcanics and redbeds located in the Empire, Huachuca, and Santa Rita
Mountains.

3. Paleocurrent Determinations

As in the previous study areas, the direction of sediment transport in
the Glance Conglomerate in the Dragoon Mountains-Gunnison-Red Bird Hills
area can be determined by using clast imbrications, oriented clast fabrics, and
crossbedding in the thicker sand lenses. A total of 61 directional current
structures were recorded (Table 6) and their interval percentages plotted on rose diagrams (Fig. 33).

As a whole, the directional current structures indicate a westerly direction of sediment transport in the Glance Conglomerate. By separating the various observations into three specific localities, local trends become apparent (Fig. 33). In the Red Bird Hills area, the rose diagram shows a rather consistent southwest paleocurrent flow direction. Here the Glance is thicker and coarser than at the other localities in this study area. The paleocurrent direction in the Gunnison Hills and at the northern end of the Dragoon Mountains is bimodal, showing a dominant west-northwest flow direction and a secondary southwest flow direction. Here the Glance is somewhat finer grained than in the Red Bird Hills and definitely much thinner in the northern Dragoon Mountains. Far to the south in the central Dragoon Mountains, the paleoflow directions in the Glance are predominantly to the northwest, with a secondary southwest paleoflow direction. Here the Glance is compositionally different from the conglomerate farther to the north.

4. Environment and Mechanism of Deposition

The Glance Conglomerate in the Dragoon Mountains-Gunnison-Red Bird Hills area is lithologically similar to the Glance present in the other study areas. The Glance in the Red Bird and Gunnison Hills and the northern Dragoon Mountains is poorly sorted, poorly bedded, primarily clast-supported limestone-clast conglomerate with source areas to the east and northeast. The northeastward increase in clast size, the large boulders common in the Red Bird Hills, the northeastward increase in thickness, and the presence of cross-bedded sandstone lenses within the conglomerate indicate that the Glance was deposited on west-southwest facing alluvial fans by predominantly fluvial, braided stream processes. The thick, coarse section in the Red Bird Hills is the proximal facies, deposited near the rising mountain front from which the clastic debris was derived.

In the central Dragoon Mountains, the Glance Conglomerate is composed of mixed-clast conglomerate and was deposited across a wider variety of
Table 6. Distribution of bedding-structure orientation resultants by azimuth classes (in degrees from north) for the Glance Conglomerate in the various localities of the Dragoon Mountains area, Arizona.
Figure 33. Paleocurrent direction roses for the Glance Conglomerate in the Dragoon Mountains-Gunnison-Red Bird Hills area. (23) Red Bird Hills, (18) Gunnison Hills-northern Dragoon Mountains, and (20) central Dragoon Mountains.
subjacent rock types. The coarse character and textural relationships suggest fluvial, braided stream depositional processes. The thickening and thinning nature of the unit and local relief on the sub-Glance unconformity indicate that local incised canyons filled with Glance Conglomerate are present. The paleocurrent data suggest a source to the east-southeast. This source terrane, based on compositional, textural, and some regional considerations, may be located 15-20 km to the east.

5. Structural Features and Tectonic Implications

The rocks exposed in the Dragoon Mountains have undergone intense post-Early Cretaceous (Laramide) compressional deformation and metamorphism related to intrusion of Upper Cretaceous and lower Tertiary igneous rocks. Structural features formed during post-Paleozoic, pre-middle Cretaceous time have been reactivated and obscured or are not exposed. In the central Dragoon Mountains, the northwest-trending Black Diamond fault (Fig. 32) juxtaposes two different basement terranes (Keith and Barrett, 1976) and is overlain by Glance Conglomerate with uniform compositional and textural characteristics. Thus this fault was active in pre-Glance time but was inactive during deposition of the basal Cretaceous conglomerate. By analogy with the other Glance Conglomerate study areas, the Glance here was probably shed from an Early Cretaceous fault-block mountain range rising along northwest-trending normal faults located to the east. The normal faults are located somewhere beneath the presently alluviated valley east of the Dragoon Mountains (see Fig. 36).

The only other direct indication of post-Paleozoic, pre-middle Cretaceous tectonic activity is in the Gunnison Hills where Cooper and Silver (1964) report faults trending N55°E and N75°-90°W that cut the Paleozoic section but are overlain by the Glance Conglomerate. These faults have normal displacements of a hundred meters or less. The major Early Cretaceous fault structure that created the high relief necessary to generate the coarse proximal alluvial fan conglomerates is inferred to lie just to the east of the Red Bird Hills, presently covered by recent alluvial basin fill. The Glance is a minimum
of 1000 m thick and is composed of a large volume of eroded Paleozoic limestone, suggesting that the throw on the syndepositionally active fault is significantly greater than 1000 m.

The post-Paleozoic, pre-middle Cretaceous deformation predominantly involved normal faulting with apparently little folding or compressional deformation, for the angular discordance between the Paleozoic and Mesozoic formation is slight. The presumed northwest orientation of the inferred normal faults of syn-Glance age is based on the paleocurrent clast size data and regional considerations.
CHAPTER VII

DOS CABEZAS-CHIRICAHUA MOUNTAINS

1. Introduction

The Glance Conglomerate exposed in the Dos Cabezas and Chiricahua Mountains varies greatly in thickness, composition, and subjacent rock type. In previously described areas, this characteristic variability provided the key to interpreting the syndepositional tectonic environment of the unit. Unfortunately, in this area, due to the extensive Tertiary volcanic cover, poor exposures, and Late Cretaceous-Early Tertiary (Laramide) and younger deformation, the characteristic variations are nonsystematic and provide only constraints on possible interpretations of the local tectonic setting during middle Mesozoic time.

In the Dos Cabezas and Chiricahua Mountains, the Glance is exposed in many widely distributed localities (Fig. 34). In the Dos Cabezas Mountains, the Glance crops out in a thin, 20 km long belt that extends from just east of the old town of Dos Cabezas to Marble Canyon, southeast of Apache Pass. Further to the southwest, in the northern Chiricahua Mountains, slightly thicker Glance Conglomerate crops out on Wood Mountain and Dunn Springs Mountain. Five to ten kilometers to the south, a thick section of Glance is exposed on Dug Road and Timber Mountain and local exposures of Glance crop out to the northwest and northeast of the town of Paradise. The most southerly exposures of Glance Conglomerate are in the Pedregosa Mountains (southern Chiricahua Mountains), where two thin, northwest-trending bands of basal Cretaceous conglomerate crop out.

2. Stratigraphy

The Dos Cabezas-northern Chiricahua Mountains area is cut by three major fault zones, the high angle, northwest-trending Apache Pass fault zone, the high angle, north-south trending Emigrant Canyon fault, and the low angle,
Figure 34. Generalized geologic map of the Dos Cabezas-Chiricahua Mountains area, Arizona. (Modified from Sabins, 1957b; Cooper 1959, 1960)
east-west trending Wood Mountain fault (Fig. 34). These faults effectively divide the area into structural blocks that contain Glance Conglomerate of distinctly different character. These blocks will be called the northern, southwestern, and eastern structural blocks and will be discussed separately.

**Northern Block**

North of the Apache Canyon fault zone and west of the Emigrant Canyon fault, the Glance Conglomerate is found in two principal outcrop localities. The most extensive outcrop locality comprises a belt 20 km long and extends northwestward from Marble Canyon to near Dos Cabezas (Fig. 34). The Glance in this belt is a nearly pure quartzite-clast conglomerate made up of well rounded, poorly sorted cobbles and small boulders of white to light gray or pink, fine to coarse grained quartzite. A few granitic and schistose clasts are present and are locally abundant in the lower 2-3 m of section. The matrix is typically well cemented fine sand to coarse grit-sized quartz and quartzite fragments.

The Glance ranges in thickness from zero (not present) to 20 m and unconformably overlies, with only minor angular discordance, Paleozoic strata ranging in age from Cambrian to Pennsylvanian. In Marble Canyon, the Glance rests on the Cambrian Bolsa Quartzite and progressively overlies younger Paleozoic strata to the northwest until the Horquilla Limestone is reached. The Glance pinches out at the base of the Bisbee Group at both the northwest and southeast ends of the outcrop belt.

The second outcrop locality is about 10 km northwest of Dos Cabezas. There a predominantly carbonate sedimentary unit rests unconformably on Precambrian Pinal Schist. The calcareous unit is composed of thin beds of limestone-clast pebble conglomerate interstratified with siliceous limestone, siltstone, and sandstone that strikes north-northwest and dips about 20°SSW. The conglomerate is typically, but not always, present at the unconformity. This total section is correlated with the Bisbee Group, in accordance with Cooper (1960) and Erickson (1968), and the limestone-clast conglomerate is thus correlated with the Glance Conglomerate. This conglomerate is distinctly different from the Glance in the main outcrop belt of the northern block located to the southeast.
Southwest Block

The thickest and most extensive exposures of Glance Conglomerate in this study area are southwest of the Apache Pass fault zone on Dug Road and Timber Mountains. The Dug Road Mountain section has been folded with fold axes that trend about N30°-50° W. Due to poor exposure, previous workers failed to recognize the significance of the folding and overestimated the thickness of the unit on cross sections (Sabins, 1957b). Sabins (1957a) reported 300 m of Glance Conglomerate at this locality, even though the cross sections on his map (Sabins, 1957b) show thicknesses in excess of 600 m. The 300 m thickness may be considered an upper limit. The base of the unit is exposed to the east where it unconformably overlies Pennsylvanian Horquilla Limestone, and the top is to the southwest where it grades upward into the sandstone, shale, and limestone of the undivided Bisbee Group. West of Dug Road Mountain, the finer grained strata of the Bisbee Group rest, with no intervening Glance Conglomerate, directly and unconformably on Horquilla Limestone.

Compositionally, the Glance Conglomerate exposed on Dug Road Mountain is a poorly sorted limestone-clast conglomerate containing minor amounts of quartzite, chert, volcanic, and granitic clasts. The volcanic clasts are more abundant in the upper part of the section which also includes local andesitic flows. Large 60 cm size boulders of dark gray to purple andesitic volcanics were observed in the Glance at some outcrops. Even with this increase in the amount of volcanic clasts, the percentage of limestone clasts is rarely less than 80%. The clasts are angular to rounded, but become more rounded higher in the section. Both clast-supported and matrix-supported zones are present, though clast-supported conglomerate makes up most of the total section. Interbedded calcite-cemented sandstone lenses 10-20 cm thick are ubiquitous throughout the unit.

Three kilometers farther southeast, the Glance Conglomerate is exposed in a somewhat thinner (60-150 m) section and is also folded along northwest-trending axes. The southernmost outcrops comprise the southwestern limb of a faulted anticline that verges to the southwest (see Sabin's map, 1957b). The Glance here is compositionally and texturally similar to the Glance at Dug.
Road Mountain, though it contains no recognizable volcanic clasts. The unit is predominantly a poorly sorted, poorly bedded limestone (90%) - sandstone (5-10%) - chert (0-5%) - clast conglomerate and unconformably overlies Permian Concha Limestone.

At one locality, the Glance sharply truncates the Concha and Scherrer Formations and rests directly upon Colina Limestone. This cross-cutting relationship suggests that the Glance fills a local channel or canyon cut into the underlying Paleozoic strata and signifies the presence of local relief on the unconformity. This high local relief at the unconformity is in contrast to the low relief along the unconformity northeast of the Apache Pass fault zone.

Farther to the southeast, in three separate localities, one near the Hilltop Mine, one east of Paradise, and one in the Cave Creek area, thin (3-6 m) limestone-clast conglomerate contains minor amounts of sandstone, chert, and dolomite clasts. At these localities the Glance crops out at the base of a thick section of Bisbee Group strata and unconformably overlies Concha Limestone. The unit is poorly sorted, clast-supported, and contains subrounded to rounded pebbles and cobbles embedded in a matrix of quartz sand and limestone chips well cemented by calcite. This conglomerate is correlated with the Glance Conglomerate to the northwest on Timber and Dug Road Mountains.

Eastern Block

Northeast of the Apache Pass fault zone, east of the Emigrant Canyon fault and south of the east-west trending, south-dipping, low angle Wood Mountain fault, the Glance Conglomerate contains a significant amount of volcanic clasts. The Glance exposed on Wood Mountain is a mixed-clast conglomerate varying from a limestone (65%) - volcanic (35%) - clast conglomerate to a volcanic (70%) - limestone (30%) - clast conglomerate. The volcanic clasts increase in abundance upward in the section and are typically fragments of purple to dark gray andesite very similar to the volcanic rocks in the upper parts of the Dug Road Mountain section. The average clast size ranges from 3 to 10 cm; however, a few cobbles and boulders are as much as 45 cm in maximum diameter. The conglomerate is predominantly clast-supported with a reddish to purplish, medium to coarse grained matrix that contains abundant volcanic detritus. The
Glance is 1-100 m thick and unconformably overlies Pennsylvanian-Permian Earp Formation and Pennsylvanian Horquilla Limestone with somewhat subdued angular discordance.

East of Wood Mountain, on and south of Dunn Springs Mountain, thin (0-20 m) Glance Conglomerate overlies Permian Concha Limestone with minor angular unconformity. The Glance is predominantly a limestone-clast conglomerate with occasional volcanic, sandstone, and chert clasts. Locally, due to channels cut into the underlying Paleozoic section, Glance Conglomerate and Bisbee Group strata rest unconformably on the Scherrer, Colina, and Earp Formations. The clasts are angular to subrounded and comprise a calcite-cemented clast-supported framework.

Southern Outcrops

In the southern Chiricahua Mountains and Pedregosa Mountains, the Glance Conglomerate crops out in two principal localities: Tex Canyon and Walnut Canyon. The Glance in these two areas is primarily composed of limestone-clast conglomerate and resembles the Glance in the Cave Creek and Hilltop Mine areas. The thickness of the unit ranges from 10 to 50 m and unconformably overlies, with little or no angular discordance, the Colina Limestone in Tex Canyon and the Scherrer and Concha Formations in Walnut Canyon. Epis (1956) recognized clasts derived from the Scherrer, Epitaph, Horquilla, Earp, and Escabrosa Formations and possibly from the El Paso and Bolsa Formations. These clasts are subrounded to rounded and typically range in size from 1-30 cm with the largest reaching about 45 cm in diameter. The conglomerate is poorly sorted, clast-supported, and has a matrix of coarse quartzose sand firmly cemented by calcite.

3. Paleocurrent Determinations

In the Dos Cabezas and Chiricahua Mountains, 51 paleocurrent direction determinations were recorded from the Glance Conglomerate (Table 7). The data were divided into four distinct categories based on areal distribution and similarity of outcrop relationships, and plotted on rose diagrams (Fig. 35).

The rose diagrams clearly illustrate that the direction of transport of
Table 7. Distribution of bedding-structure orientation resultants by azimuth classes (in degrees from north) for the Glance Conglomerate in the Dos Cabezas and Chiricahua Mountains, Arizona.

<table>
<thead>
<tr>
<th>Azimuth Classes (degrees)</th>
<th>Northern Block</th>
<th>Dug Road &amp; Timber Mountains</th>
<th>Hilltop Cave Cr. Paradise Wood Cyn.</th>
<th>Tex Canyon &amp; Walnut Canyon</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-30</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>31-60</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>61-90</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>91-120</td>
<td>4</td>
<td>4</td>
<td></td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>121-150</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
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<td>151-180</td>
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</tr>
<tr>
<td>181-210</td>
<td></td>
<td>2</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>211-240</td>
<td></td>
<td>1</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>241-270</td>
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<td></td>
<td>2</td>
<td>2</td>
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<td>271-300</td>
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<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>301-330</td>
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<td>3</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>331-360</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Total number of localities</td>
<td>16</td>
<td>14</td>
<td>13</td>
<td>8</td>
<td>51</td>
</tr>
</tbody>
</table>
Figure 35. Paleocurrent direction roses for the Glance Conglomerate in the Dos Cabezas-Chiricahua Mountains area. The 4 roses represent the following areas: Northern block (16), Dug Road and Timber Mountains (14), Hilltop Mine, Cave Creek, Paradise and Wood Mountain (13) and Tex and Walnut Canyon (8).
the Glance Conglomerate in this area is polymodal. The Glance in the northern structural block exhibits the most consistent paleocurrent directions within the study area. An east-northeast direction of sediment transport is thus indicated for the quartzite-clast conglomerate facies of the Glance Conglomerate. The Glance in the Dug Road and Timber Mountain areas is polymodal with a dominant northwest paleoflow direction and two secondary directions, one to the northeast and one to the south.

The lithology of the Glance Conglomerate in the Hilltop Mine and Cave Creek areas is identical to the lithology of the Glance northeast of the Apache Pass fault zone and southeast of the Emigrant Canyon fault. The combined paleocurrent data from these areas is distinctly bimodal, the Hilltop Mine, Cave Creek, and Paradise area account for the southwest transport directional mode and the Wood Mountain area for the east-southeast transport directional mode. In the southern Chiricahua Mountains and Pedregosa Mountains, the direction of sediment transport in the Glance fans clockwise from west-southwest to north-northeast, resulting in a medial northwest directional trend.

4. Environment and Mechanism of Deposition

The Glance Conglomerate is predominantly a coarse clast-supported conglomerate that resembles the conglomerate of fluvial origin in the other study areas. Only on Dug Road Mountain, where the Glance is relatively thick, is matrix-supported, debris-flow conglomerate evident. Though present, the matrix-supported conglomerate is rare, suggesting that the Glance on Dug Road Mountain is mid-fan facies fanglomerate or a more restricted canyon-fill deposit. The smaller average clast size, the moderate degree of rounding, and the general absence of large boulders also support the interpretation that the Glance has been transported many kilometers and that it is not as proximal as much of the Glance in other study areas.

Where the Glance is thin and mostly a monomictic conglomerate, the fluvial nature of the deposit is evident. The clasts are rounded, framework-supported, and contain many planar bedded and crossbedded sandstone lenses. Even some of the pebble and cobble conglomerate is coarsely crossbedded.
This fluvial conglomerate can either be locally derived, as in the Hilltop Mine, Cave Creek, Paradise, Tex Canyon, and Walnut Canyon areas where limestone-clast conglomerate overlies Paleozoic carbonate strata, or of distal origin, as in the northern structural block where rounded quartzite-clast conglomerate overlies Paleozoic limestone basement.

5. Structural Features and Tectonic Implications

The Glance Conglomerate in the Dos Cabezas and Chiricahua Mountains can be divided into four main types based on clast composition, thickness, and subjacent rock type. These four conglomerate types are located in areas separated by major post-Cretaceous faults. At the northwest end of the Dos Cabezas Mountains, northeast of the Apache Pass fault zone, thin, limestone-clast conglomerate overlies Precambrian Pinal Schist and is gradationally overlain by calcareous sandstone and limestone. About 6.5 km to the southeast, basal Cretaceous quartzite-clast conglomerate overlies various Paleozoic formations, beginning with the Horquilla Limestone to the northwest and eventually resting unconformably on the Bolsa Quartzite far to the southeast near Marble Canyon. Both of these outcrop localities are northeast of the Apache Pass fault zone and are either separated by a post-Early Cretaceous structure which has juxtaposed two diverse Glance terranes or by a pre-Cretaceous structure of unknown trend or origin. A north-south trending fault mapped by Cooper (1960) of post-Cretaceous age lies between the two localities and may be the controlling structure.

Farther to the southeast, the north-trending Emigrant Canyon fault splays from the Apache Pass fault zone and separates the quartzite-clast Glance Conglomerate from the limestone-volcanic-clast Glance Conglomerate on Wood and Dunn Springs Mountains. The limestone-volcanic-clast conglomerate rests unconformably on Paleozoic limestone and is locally cut by a few east-west trending, low angle faults. Southwest of the Apache Pass fault zone, limestone-volcanic-clast conglomerate of moderate thickness, unconformably overlies Paleozoic rocks (Dug Road Mountain section). The presence of this identical limestone-volcanic-clast conglomerate in reasonably close proximity across the Apache Pass fault zone suggests that post-Cretaceous strike-slip movement
on this segment of the fault may not be significant. Pure limestone-clast conglomerate, which makes up the fourth type of Glance, is in the Timber Mountain, Hilltop Mine, Cave Creek, Paradise, Tex Canyon, and Walnut Canyon areas. These are the southernmost outcrops of Glance and are also exposed on both sides of the southeastern part of the Apache Pass fault zone, as mapped by Drewes and Thorman (1979).

Unfortunately, no direct evidence of pre-Glance or syn-Glance movement on the Apache Pass fault zone is known, though post-Glance movement must be present on parts of the system to account for the juxtaposition of the quartzite-clast facies and limestone-volcanic-clast facies Glance Conglomerate across the fault. No structures directly identifiable as being responsible for generating the Glance Conglomerate are exposed in this study area, though some can be suggested (see Fig. 36), based on paleocurrent data, clast compositions, and regional considerations.
CHAPTER VIII

CONCLUSIONS

1. Glance Conglomerate

In each of the areas considered in this study, the Glance Conglomerate is interpreted to have been deposited on or associated with Early Cretaceous alluvial fans shed from rising mountain blocks. Deposition of the Glance on the alluvial fans was by ephemeral streams, sheet floods, and debris flows. Where the Glance is relatively thick (100–2000 m), the conglomerate is an alluvial fan deposit of proximal facies. Where thin (1–30 m), the conglomerate may be either a laterally extensive pediment gravel or a localized channel-lag gravel. In certain areas, the lower parts of the Morita or Willow Canyon Formations interfinger with the Glance and comprise the middle and distal fan facies of the alluvial fan complex.

In three key study areas, the Mule, Empire, and Santa Rita Mountain areas, thick sequences of Glance Conglomerate can be directly related to syn-depositional vertical displacements along high angle normal faults. The overall similarity of the Glance in the Huachuca, Dragoon, and Dos Cabezas-Chiricahua Mountain areas to the Glance in the three key areas suggests that high angle normal faults are also responsible for producing the high relief needed to generate such localized, coarse, clastic deposits. Thus, regionally, the Glance Conglomerate mainly comprises the proximal facies of widely distributed alluvial fan complexes located along the margins of isolated basins, bounded on at least one side by normal faults. The actual and suggested locations of the middle Mesozoic syndepositional normal faults are shown in Figure 36.

2. Local Tectonic Setting

The Early Cretaceous structural setting of southeastern Arizona, indicated by the distribution and syntectonic nature of the Glance Conglomerate, is one of differential vertical movements on various northwest and east-west
trending normal faults (Fig. 36). These differential vertical movements produced an Early Cretaceous paleogeography similar in style to the present-day Basin and Range Province composed of fault-bounded mountain blocks and intervening basins. The absence of features indicative of compressional deformation in Glance or pre-Glance times suggests that southeastern Arizona was a region of continental rifting with associated crustal extension. In the Mule, Santa Rita, and Dragoon Mountains areas, pre-Glance, probably Early Jurassic, differential vertical movements on the Dividend fault, Santa Rita fault scar, and the Black Diamond fault indicate that vertical tectonics were an important part of the pre-Glance, Early Mesozoic tectonic environment. Early Mesozoic igneous intrusive and extrusive activity accompanied the vertical tectonics in the southwestern part of the region. Some of the Jurassic plutons have intruded along northwest-trending faults resulting in distinctly elongated outcrop patterns. Some examples include: Squaw Gulch Granite and Piper Gulch Monzonite trending N35°-40°W, Huachuca Quartz Monzonite at N50°W, and the Juniper Flat Granite at N40°-50°W. The present distribution of Triassic(?)–Jurassic volcanic and plutonic igneous rocks indicates that the northeast flank or back arc side of a magmatic arc trended N50°–60°W across the southwestern corner of the study area during Jurassic time (Bilodeau and Keith, 1979; Coney, 1979).

Local outcrops of Early Mesozoic volcanics and redbeds are present as far east as Walnut Gap, north of the Dragoon Mountains, and suggest that Early Mesozoic volcanics may have covered the entire region but were subsequently eroded before deposition of the Glance Conglomerate. The scattered remnants of these once more extensive deposits proportionally contain large amounts of redbeds. This fact, along with the locally deep erosion along some of the active faults (the Black Diamond fault, for example), and the proximity of the area to the thermotectonically uplifted terrane of the magmatic arc, suggests that this entire region was also elevated and eroding until the Early Cretaceous. Beginning in the Late Jurassic, plutonism ceased in the area, the locus of igneous intrusion was displaced westward, and a new magmatic arc was established along the continental margin, forming the Peninsular Batholith of southern California–northern Baja California (Coney and Reynolds, 1977; Gastil and
others, 1978) (see Fig. 37). By Early Cretaceous time, the area began to subside, perhaps due to crustal cooling, which, due to accompanying northeast-southwest directed extension along northwest-trending normal faults, produced isolated fault-bounded basins. This regional subsidence and extension made use of the pre-existing northwest-trending structural grain of the region and resulted in the topography of high relief needed to produce the alluvial fan environment of the Glance Conglomerate.

3. Regional Tectonics

An Early Cretaceous tectonic environment characterized by east-west and northwest-trending normal faults is strikingly different from the style of deformation farther to the north. During the Early Cretaceous, southeastern Arizona was located completely behind the continental magmatic arc that existed along the west coast of North America. Here, and to the south, the back-arc area was a zone of continental rifting or extensional tectonics, subparallel to the arc. To the north and northwest, in Utah, Nevada, and California, back-arc compression and crustal shortening were generating the fold-thrust structures characteristic of the Sevier Orogenic Belt (Armstrong, 1968). Possible explanations for this striking difference in back-arc tectonic style include (see Fig. 38): A) propagation of a continental rift (aulacogen), related to the Jurassic separation of North America from South America, from the Gulf of Mexico area northwestward across Chihuahua, Mexico to reach southeast Arizona by Early Cretaceous time; B) a steeply dipping subducting slab under southeastern Arizona and a more shallowly dipping slab under Nevada, with either a bend or a tear in the downgoing plate at the latitude of the Colorado Plateau; or C) an apparent anticlockwise rotation of the interior of the North American plate with respect to the continental margin magmatic arc, hinged at a pivot point centered in the Colorado Plateau area.

(A) Aulacogen Model

Rifting in the Gulf of Mexico area began in the Late Triassic-Early Jurassic with the separation of South America from North America. Deposition of clastic redbeds in restricted fault-controlled basins along the Gulf Coast
Figure 37. Early Jurassic-Early Cretaceous paleogeographic map of southwestern North America. Position of South America at 180 m.y.b.p. according to Ladd, 1976.
(Eagle Mills Formation; Scott and others, 1961) and in eastern Mexico (Huayacocotla Formation; Imlay and others, 1948) accompanied the continental break-up. Stratigraphically above the redbeds is a thick evaporite sequence, the Lower Jurassic Louann Salt along the Gulf Coast and the Lower Jurassic Minas Viejas evaporites and Salina Formation in Mexico (Kirkland and Gerhard, 1971). During this time, while southeastern Arizona was a relatively elevated terrain undergoing erosion, marine waters transgressed northwestward from the Gulf of Mexico area, up a linear structural rift basin, referred to by others as the Chihuahua Trough, Mexican Geosyncline or Sonoran Embayment, as far north as the El Paso, Texas area (Fig. 37). This linear basin was flanked by high and dry elevated areas, rimmed and partly floored by coarse, clastic deposits (Lower Jurassic Huizachal Group redbeds and Upper Jurassic La Gloria Formation in the south, and Upper Jurassic Malone Formation in the north) floored by the thick Louann-equivalent evaporites, and filled with Upper Jurassic marine limestone and shale (Zuloaga Limestone(Smackover-equivalent), La Casita Formation, La Caja Formation and Aleja Formation) that thin to the east, west, and eventually to the north (Cordoba and others, 1971; Kirkland and Gerhard, 1971; Imlay, 1943; Imlay and others, 1948; and Ovanki, 1974). This sedimentary trough continued to subside and receive sediment through the middle Cretaceous.

The synchronicity of rifting in the Gulf of Mexico area and the propagation of the Chihuahua Trough rift northwestward suggests a causal relationship between the two events (Fig. 38A). Continental rift basins that intersect the continental margin at high angles are termed aulacogens and form as the failed-arm of a RRR-triple junction (Burke and Dewey, 1973; Hoffman and others, 1974; Burke, 1977).

Following the westward jump of the magmatic arc from the vicinity of southeastern Arizona and northeastern Sonora and the subsequent deposition of the Glance Conglomerate, the marine waters of the Chihuahua Trough aulacogen transgressed west-northwestward into southeastern Arizona (Fig. 37). This transgression occurred in Aptian-Albian time, and deposited the marine parts of the Bisbee Group and correlative rocks in a shallow epicontinental sea.
The normal faults that were active during the Early Cretaceous, just prior to immersion of the area by the marine sea, trend east-southeastward into the northern end of the early-middle Mesozoic aulacogen. This propagation of rift tectonics from the Gulf of Mexico into southeastern Arizona may have been a continuous process from the Early Jurassic through the mid-Cretaceous.

The dominant mechanism or principal cause for the rifting would then originate with a plume-generated(?) RRR-triple junction located to the southeast in the Gulf area. Thus the back-arc compression to the north would have no apparent genetic relationship to any of the back-arc rifting occurring in southeastern Arizona and Mexico (Fig. 38A).

(B) Segmented Slab Model

Recent studies on the lateral segmentation of subducted oceanic plates beneath subduction zones (Carr and others, 1974; Isacks and Barazangi, 1977; Dean and Frake, 1978) have suggested that different styles of deformation within and behind the arc are related to segmentation of the downgoing slab into steep and shallow dipping sections. Generally, the areas studied were undergoing two different styles of compressional deformation behind the arc in a total compressional stress field. But a situation might be possible where the same arc has classic compressional tectonics occurring along one segment but tension or noncompression within a bordering segment. Might not this contrast of tectonic settings be related to differences in the dip of the slab as well?

Two recent papers by Molnar and Atwater (1978) and Uyeda and Kanamori (1979) discuss this important aspect of subduction zone tectonics. Both papers observe that tensional tectonics in the back-arc region is associated with steeply dipping Benioff-Wadati zones and compressional tectonics with shallower dipping zones. Molnar and Atwater correlate the dip of the downgoing plate with the age of the oceanic lithosphere that comprises it. The older lithosphere is colder and denser; thus it sinks faster, and results in a steeper dip with attendant back-arc spreading. Uyeda and Kanamori add the idea of the absolute motion of the landward plate as the controlling factor if the subducted slab is anchored in the mantle. If the absolute motion of the landward plate is away from the trench, there is tension in the back-arc area, and if the motion
Figure 38. Diagram of three different tectonic models for the variable back-arc tectonic settings during Late Jurassic through Early Cretaceous time, southwestern North America. (A) Aulacogen-continental rift model, (B) Variable-dip, segmented slab model, (C) Absolute motion-rotation model. Position of South America in (A) at 180 m.y.b.p. according to Ladd (1976).
is toward the trench, compressional tectonics dominate.

Taking these ideas and applying them to the Late Jurassic-Late Cretaceous continental margin magmatic arc and subduction zone of western North America suggests the following model (Fig. 38B). Subduction of the Farallon plate beneath the North American plate has been going on since the Jurassic and maybe longer. During the Jurassic and Early Cretaceous, shallow dip subduction of the normal style for Cordilleran areas (Coney, 1973) was the subduction mode from the latitude of the Colorado Plateau northward, and produced the Sierra Nevada Batholith (magmatic arc) and the Sevier Orogenic Belt in the back-arc area. South of the Colorado Plateau, steep-dip subduction was accompanied by rifting and crustal extension in the back-arc region. Implicit in this model is a major transverse structure within the subducted slab, at the latitude of the Colorado Plateau. This structure would be either a bend or a tear in the plate, separating the slab into two segments with differing dips. Whether the actual age of the two segments of the Farallon plate could be different enough to allow for this marked change is not, at present, provable. Only three small remnants of the Farallon plate remain, the Gorda, Cocos, and Nazca plates. Any extrapolation of plate age and geometry back to 100-200 m.y.b.p. may thus have limited validity only.

(C) Rotational Model

Studies involving absolute plate motions to explain various styles of deformation at plate margins (Wilson and Burke, 1972; Morgan, 1972; Coney, 1972, 1973) have resolved only one absolute velocity vector per plate and have not addressed the problem of differential convergence rates along a single subduction boundary in an absolute motion context. Coney (1973) suggested that foreland fold-thrust belts are the result of actively advancing continental plates and that extensional back-arc spreading occurs when the continental plate is nearly stationary, moves parallel to the arc, or moves away from the arc.

As previously discussed, two fundamentally different tectonic regimes existed behind the Cordilleran magmatic arc during Late Jurassic to Late Cretaceous time (155-80 m.y.b.p.). In an absolute motion context, if the subducting slab is anchored in the mantle as suggested by Uyeda and Kanamori (1979),
an anticlockwise rotation of the interior of the North American plate with respect to the continental margin magmatic arc, hinged at a pivot point centered in the Colorado Plateau area (Fig. 38C), can account for the diverse back-arc tectonic styles. In this model, the back-arc rifting and tensional tectonics are not directly related to subduction of the slab, as in the segmented slab model (Fig. 38B), or to the rifting in the Gulf of Mexico and Atlantic Ocean (Fig. 38A).

4. Synthesis

The three models just presented for explaining the different tectonic regimes that dominated the back-arc regions of the middle Mesozoic magmatic arc that extended along the entire west coast of North America from Mexico to Alaska are not mutually exclusive. All three are viable as simultaneous phenomena that can be combined to develop a logical tectonic history for the region.

1) In Late Triassic to Early Jurassic time, a magmatic arc existed along the west coast of North America which was, at that time, part of the supercontinent Pangaea. Pangaea was in the early stages of its breakup with the Atlantic rift propagating southwestward across the supercontinent. The magmatic arc trended northwesterly through southern Arizona and had a back-arc area that was in a state of noncompression or slight tension along most of its length.

2) By Early to Middle Jurassic time, the Atlantic rift had reached the Gulf of Mexico area where a RRR-triple junction had formed (Fig. 38A). One arm of the rift, destined to be the third or failed arm (aulacogen), propagated northwestward, behind and subparallel to the west coast magmatic arc, and reached the El Paso, Texas area by the Late Jurassic. This rift became the Chihuahua Trough and continued to subside until the Late Cretaceous.

3) The rifting caused an apparent anticlockwise rotation of the North American plate, which pivoted at a point centered just north of the end of the aulacogen. Northward of the pivot point area, the arc was subjected to compressional tectonics (Sevier Orogeny) and active advancement of the North American plate over the oceanic Farallon plate. This resulted in an apparent shallowing of the slab dip along this segment of the arc, causing a deflection or tear in
the subducting slab. Noncompression within the southern segment of the arc allowed for unrestrained gravitational sinking of the subducted slab and an apparent steepening of the dip. This caused the locus of arc magmatism to jump westward, further accentuating back-arc tensional tectonics.

4) Following the westward jump, the area collapsed along west-northwest trending normal faults, generating the Glance Conglomerate and eventually deepening to allow the influx of marine waters from the Chihuahua Trough aulacogen and deposition of the Bisbee Group sediments.

5) A re-ordering of worldwide plate motions occurred at about 80 m.y. b.p. (Coney, 1972) caused back-arc compressional tectonics to become dominant along the entire length of the arc (Laramide Orogeny). This deformation caused the marine waters to recede back to the Gulf of Mexico, and extensively folded the sedimentary rocks previously deposited in the aulacogen.
APPENDIX 1

GOLD HILL FAULT ZONE

The Gold Hill fault zone was originally mapped and discussed by Ransome (1904), remapped with only minor added detail by Hayes and Landis (1964), and reinterpreted a third time by Jones (1963, 1966). All three interpretations agree on the mapped surface geology but differ on how the structures project at depth and thus on the kinematics and geometric aspects of the faults. The basic disagreement involves the relative importance of large scale thrust faulting along low angle reverse faults (Ransome, Hayes and Landis) versus differential vertical uplift along high angle reverse faults (Jones) in explaining the complex field relations found in the area. The following discussion presents a fourth interpretation that borrows much from the previous work in the area but introduces the ideas of pre-existing fractures, possible strike-slip movement, and a previously unmapped major high angle reverse fault to explain these complex structural relationships.

The Gold Hill fault zone is here considered to include all the faults in the zone that begins just southeast of Black Gap, continues east around both sides of Gold Hill, turns south just southwest of Black Knob (Fig. 39), and is lost in the alluvium near the Christiansen Ranch at the Mexican Border. Westward, the Gold Hill fault may connect with the Abrigo-Bisbee West faults beneath the alluvium near Don Luis to form a lengthy west-northwest to east-southeast fault system (Plate 1).

About 2 km east of the corner in the Gold Hill fault zone is an allochthonous block of Pennsylvanian Horquilla Limestone capped depositionally by Glance Conglomerate and resting tectonically on the Lower Cretaceous Mural Limestone (Fig. 40). This block was designated the "Glance Overthrust" by Ransome. Though the origin and mechanism of emplacement of this block is subject to different interpretations by the three previous worked in the area, they all agree that it is somehow related in time and space to post-Cretaceous
Figure 39. View of Gold Hill fault. Gold Hill in far left background. (Px) Paleozoic undivided, (Km) Morita Formation. Southern Mule Mtns.

Figure 40. View of "Glance Overthrust" outlier. (Ph) Horquilla Limestone, (Kmu) Upper Mural Limestone.
movement on the Gold Hill fault zone.

Ransome (1904) considered the Gold Hill fault to be a low angle thrust fault that dipped south-southwest, flattening with depth. Along this low angle fault, an allochthonous plate of Lower Cretaceous and Paleozoic strata moved northeastward, thrusting Paleozoic rock over Lower Cretaceous Bisbee Group strata. The allochthonous outlier or "Glance Overthrust" block lying to the west, was considered to be part of a separate, westward moving thrust plate which collided with the northeastward directed Gold Hill thrust plate. Hayes and Landis (1964) agreed with Ransome's interpretation of the Gold Hill fault and his suggested minimum 2 miles of horizontal movement of the thrust plate, but differed on the origin of the eastern "Glance Overthrust" outlier. They considered it to be a remnant (klippe) of the northeastward directed Gold Hill thrust plate and thus having a west-to-east direction of movement. The Gold Hill fault has a steep southwestward dip and the low angle fault separating the allochthonous outlier from the underlying Mural Limestone dips 25° to the east. This disparity in dip of the faults is probably what prompted Ransome to suggest the idea of two separate thrust plates, while Hayes and Landis simplified the story to involve only one, somewhat folded, thrust plate.

Jones (1963, 1966) proposed a radically different explanation. Basing his interpretation on the idea that the Gold Hill fault did not flatten with depth but steepened with depth, he suggested that the structures were formed by differential vertical uplift along high angle reverse faults and not by horizontal compression and major crustal shortening along low angle thrust faults. The Paleozoic rocks in the upper plate, uplifted along the Gold Hill fault, thus represent a deeply rooted complex horst with some upper level lateral spreading away from the center of uplift. This lateral spreading was manifested by small scale normal faulting within the horst and the detachment and eastward gravity sliding of the allochthonous "Glance Overthrust" outlier from the structurally uplifted horst. Graben structures and minor east-dipping normal faults found in the slide-block by Jones (1966) support his idea of gravity sliding down an east-dipping paleoslope from the uplifted terrane to the west.

The new interpretation introduced here agrees with various aspects of
the three previous interpretations but with some significant modifications. Some important observations include:

1) The nature of the Gold Hill fault zone is markedly different along the western section (N70°W strike) and the southern section (N30°W strike). The western section is a highly complex zone of high angle and relatively low angle faults which bound a complexly deformed and uplifted block of Paleozoic strata as much as 0.8 km in width. Also included in the fault zone is a fault-bounded wedge of Lower Cretaceous Mural Limestone, quite out of place and exotic to this lower stratigraphic level. The southern section with the N30°W strike is a simple linear fault trace with a steep west-southwest dip. A long, fault-bounded block of Pennsylvanian Horquilla Limestone and limestone-clast facies Glance Conglomerate has been uplifted along the fault.

2) On the south slopes of Gold Hill, a previously unrecognized southwest-striking, northeast-dipping, high angle fault splays off the Gold Hill fault zone and continues south-southeast parallel to the linear southern extension of the Gold Hill zone (Plate 1). This fault is here referred to as the Glance fault. The fault has Glance Conglomerate on both sides and went unmapped until the various clast facies in the Glance were defined and offsets could be recognized. The fault juxtaposes schist-quartzite-clast facies conglomerate on the west side against limestone-clast facies conglomerate on the east side. Along the southernmost stretch of the Glance fault, blocks of Paleozoic basement (Horquilla Limestone) crop out along the east side. The fact that limestone-clast facies conglomerate is the lowest stratigraphic division in the Glance and that it here overlies Paleozoic basement on the eastern side, coupled with the 70°NE dip on the fault, makes this a reverse-slip fault with the likelihood of hundreds of meters of vertical offset.

3) The western section of the Gold Hill fault which strikes N70°W extends westward and links with the Abrigo and Bisbee West faults. This system of faults was active in the Lower Cretaceous during deposition of the Glance Conglomerate. The Bisbee West fault zone was definitely in existence as early as the Early Jurassic as it has been intruded by Jurassic granitic dikes. Thus the post-Early Cretaceous deformation caused reactivation of pre-existing
fault structures.

4) The presence of limestone-clast facies Glance Conglomerate overlying Horquilla Limestone in the "Glance Overthrust" outlier strongly suggests that the large tract of Glance in the southern block to the west is the likely source for the klippe, in agreement with Hayes and Landis (1964) and Jones (1966).

As for the overall structural setting, in disagreement with Jones, it is assumed here that east-northeast compression formed the Mule Mountains anticline, reactivated various northwest-striking, high angle faults during an episode of post-Early Cretaceous "Laramide" deformation. This crustal compression formed the granite cored anticline of the central and northern Mule Mountains, but due to the presence of major pre-existing, west-northwest trending faults south of the granite pluton, the deformation took a different form and style. The Abrigo-western Gold Hill fault system was reactivated with left-lateral strike-slip movement. The direction of compression was not parallel to the old trend of the Abrigo-Gold Hill fault system but at a more northerly strike so that there existed a major component of compression across the fault zone. This type of fault has been called a "transpressional" fault, a term coined by Harland (1971). The oblique compression caused some substantial reverse slip along with the left slip, with the resultant upfaulting of the Paleozoic strata of Gold Hill and northward splay thrusting of the fault wedge at the complicated corner where the fault changes trend. The deformation of the Bisbee Group rocks to the north along the eastward projected strike of the Dividend, suggests that the northeast-verging overturned fold is a result of recurrent movement on the Dividend fault similar but of less magnitude to that on the Gold Hill fault. The straight, southern extension of the Gold Hill fault and the previously unmapped Glance fault broke normal to the direction of maximum compression, uplifting the block of conglomerate and Paleozoic limestone between them. The exotic fault wedge of Mural Limestone in the Gold Hill fault zone is suggestive of strike-slip movement along the fault zone.

The "Glance Overthrust" outlier would have the same origin as put forth by Jones (1966). The major differences between Jones' interpretation
and this one is with the kinematics of the Gold Hill fault zone, the presence of pre-existing major faults, and the formation of these structures by horizontal crustal compression. Some mild flexural folding in the southern block is documented by the southwestern dip of the Glance Conglomerate and other Bisbee Group strata on the western side of the Glance fault and the northeast dip of the Glance Conglomerate to the east of the fault. Whether the Gold Hill fault flattens or steepens with depth is unresolvable with the present field data, and thus this interpretation suggests the third possible case, that the faults maintain their moderately high angle dip to depth.
REFERENCES


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