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UPLIFT AND GRAVITATIONAL ADJUSTMENT RUBY STAR RANCH AREA PIMA MINING DISTRICT, ARIZONA

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INTRODUCTION

The Ruby Star Ranch area lies approximately twenty-five miles southwest of Tucson, Arizona, and is centrally situated in the Pima Mining district (Figure 1). The Pima Mining district is the largest mining district in the Southwest with a potential reserve of about a billion tons of copper and molybdenum, and nearly ten million tons reserve of lead, zinc, and silver.

In spite of the considerable geological and geophysical effort expended in the Pima district, the paucity of outcrop, the complexity of structure, and the complicated igneous activity have led to varied interpretations of the geological relationships and history. The purpose of this paper is to describe and to interpret the tectonic features in the Ruby Star Ranch area, which the writer believes are the result of uplift and gravitational adjustments and are applicable to the district as a whole.

The field work on the area commenced in June, 1960, and continued through December 1962, while the writer was employed by Bear Creek Mining Company. During this interval, detailed surface mapping was carried on and a total of 55,726 feet was drilled in 71 holes. All subsurface work was correlated to surface geology whenever possible.

REGIONAL GEOLOGY

The southwestern part of the Pima Mining district is in foothills which are continuous with the Sierrita Mountain mass and contain the Esperanza Mine. The remainder of the district is a broad, extensive, gravel covered pediment above which project a few isolated hills such as Foy Ridge, Twin Buttes, and Helmet Peak. This gravel cover is from tens of feet thick in the western part of the district to more than 2,000 feet in the eastern section.

Rocks exposed or present in the district range in age from Precambrian (?) to Recent and consist of sediments, intrusive granitic rocks and volcanic flows.

The northern end of the Sierrita Mountains is composed of Tertiary granodiorite. South of a line passing approximately

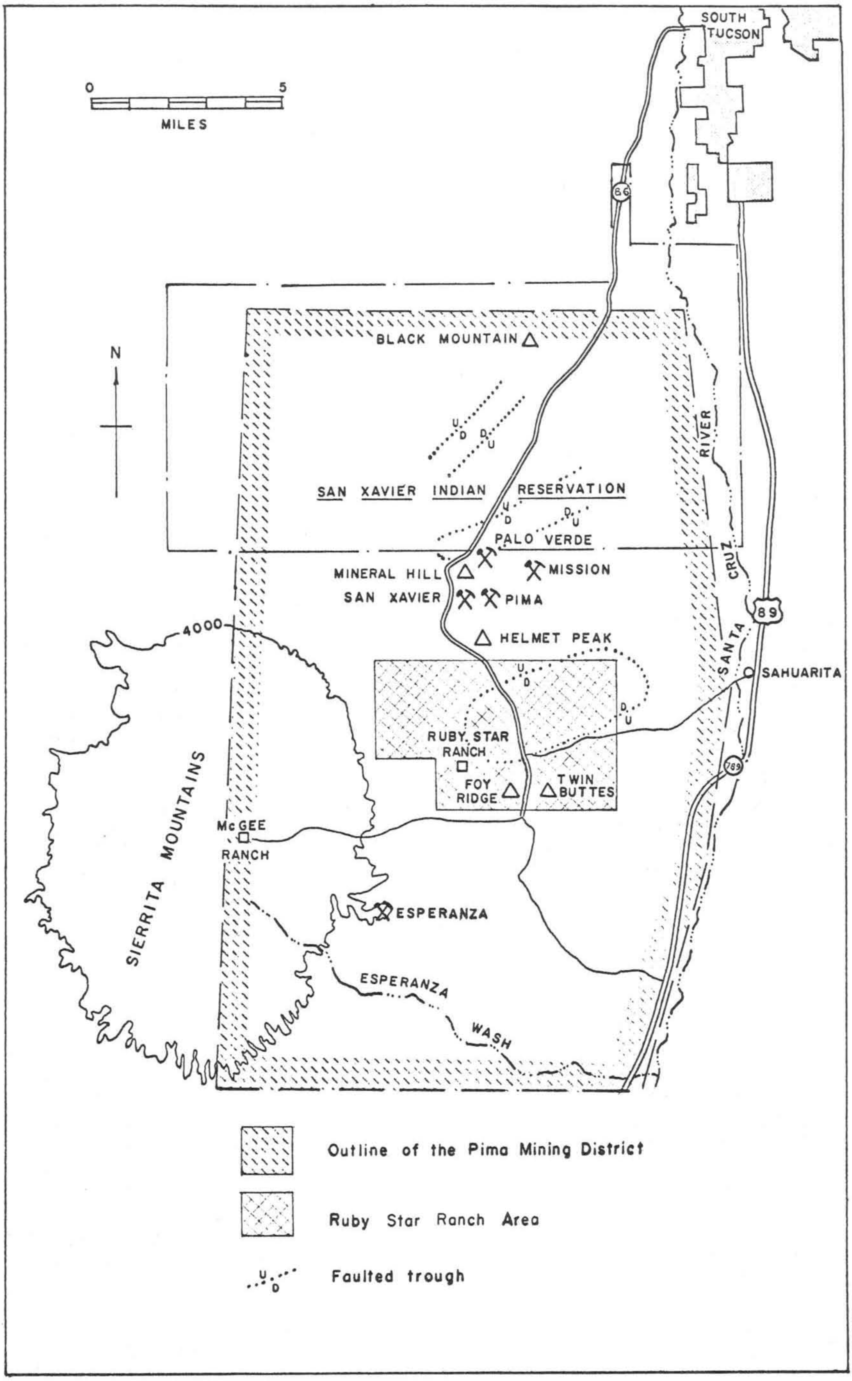

Figure 1.--Index Map of the Pima Mining District.

through the McGee Ranch, the Sierrita Mountains are composed of Cretaceous - Tertiary sediments and volcanics similar to the units in the Esperanza Pit. Southeast of the Esperanza Mine these volcanics are, in turn, overlain by Recent (?) tuffs and rhyolites.

West of a general north-south line, which starts about one and a half miles east of the Esperanza Pit and continues to the gravel covered area on the San Xavier Reservation, the Tertiary granodiorite floors remarkably even pediment surface. East of this line, Cretaceous (?) sediments on the south overlie the folded Paleozoic sediments northward to Twin Buttes.

North of the Twin Buttes, in the Ruby Star Ranch area, a large, deep trough trending northeasterly has been filled with Miocene (?) sediments called by Cooper (1960), Helmet Fanglomerate. This fanglomerate fills the trough and extends northward to a line about one and a half miles south of the San Xavier mine.

Beyond the north edge of the trough to the San Xavier Mine, Cretaceous (?) sediments again overlie Paleozoic units. The basin between the San Xavier Hill and Mineral Hill is partially floored by Cretaceous arkose on the southern side. The arkose covers the Pima-Mission area, overlying Paleozoic sediments to a second northeast-trending trough on the San Xavier Reservation. On the north boundary of the district, in a third northeast-trending trough, the Recent (?) Black Mountain basalt overlies mid-Tertiary gravels and Cretaceous (?) sediments.

Based on drill core data, the southern trough appears to be a hinged structure with the northern edge remaining relatively stationary and forming the hinge line. The middle trough appears to be similar structurally, and little is known of the northernmost one.

A flat-lying fault or sole separates parts of the Paleozoic section, Cretaceous (?) complex, and Tertiary deposits from underlying Precambrian (?) granite and Laramide granodiorite. This sole fault extends from at least the Mission Mine southward through the Palo Verde and Daisy Mines, the Pima Mine, and the San Xavier Mine to just north of Twin Buttes. This is approximately six and one-half miles in a north-south direction, and the total area underlain by the sole fault is at a minimum thirty-four square miles.

STRATIGRAPHY OF SEDIMENTARY ROCKS

Post-Permian metamorphism has complicated the identification of the stratigraphic units in the Ruby Star Ranch area. Recrystallization of the limestones and alteration of the shales and sandstones to hornfels and quartzites obliterated the majority of fossils, except for several reef structures in the Martin Formation and a few brachiopods and gastropods in the Naco Group. The Paleozoic sequence is best represented in the Twin Buttes and Foy Ridge sections.

AGE	UNIT	THICKNESS IN FEET	DESCRIPTION
Pennsylvanian-Permian	Naco Group	600 +	Thin beds of limestones, shale and sandstone. All members metamorphosed. Contains interbeds of gypsum.
Lower Mississippian	Escabrosa Limestone	550	Massive, light gray to white, coarsely crystalline marble.
Upper Devonian	Martin Limestone	440	Light tan to gray, slightly dolomitic limestone with occasional zones of fine-grained marble.
Upper Cambrian	Abrigo Formation	200	Banded limestone with alternating layers of hornfels, quartzite and limestone.
Middle Cambrian	Bolsa Quartzite	500	Fine to medium grained arkosic quartzite.

TABLE 1. Generalized Sequence of the Paleozoic Sediments, Ruby Star Ranch Area.

Unconformably overlying the Paleozoic sequence is a complex of arkose, graywacke, pebble conglomerate, quartzite, shale, pyroclastics and thin beds of limestone. The age of the complex is assigned to the Cretaceous on fossil evidence (Mayuga, 1942), but could be upper Jurassic, lower Cretaceous, or both.

The Helmet Fanglomerate of Miocene age (Cooper, 1960) is the most wide-spread formation in the area, but it is mainly confined to the southernmost trough. It has an average strike of N.60°E. and dips about 55°SE, with dips lessening to approximately 20° in the southern part of the area. The Helmet is a poorly-sorted conglomerate containing cobbles and boulders set in a silty matrix. The conglomerates tend to be finer grained in the eastern section of the area, and tend to be more monomictic and coarser in the western part. This suggests that the source area was located to the west.

MEMBER	LOCATION	DESCRIPTION
Upper Member	Southern Third	Fragments of all rock types found in the lower two members. Monolithologic breccias. Southwest of the Ruby Star Ranch 50% of the fragments are granodiorite.
Middle Member	Central Third	Fragments of the Cretaceous (?) complex and minor granodiorite and Paleozoic rocks, including copper stained tactite. Interbeds of tuff and detached blocks of members of the Naco Group.
Lower Member	Northern Third	Andesite flows Fragments of Cretaceous (?) complex. Few granodiorite fragments. No paleozoic or Precambrian (?) fragments.

TABLE 2. Generalized Stratigraphy of the Helmet Fanglomerate.

IGNEOUS ROCKS

Two periods of igneous activity are recognized in the Ruby Star Ranch area: (1) Precambrian (?) granite and diorite, and (2) Cretaceous-Tertiary intrusions and flows.

Precambrian

The Sierrita granite is of probably Precambrian age (Lacy, 1959) and is found cropping out along the western perimeter of the sole fault, in outcrops west of Foy Ridge, and in drill holes beneath sediment in the northern three-quarters of the area.

A diorite of probable Precambrian age intrudes the Sierrita granite. Surface exposures and drill hole data indicate that the diorite extends from the SE/4, sec. 15, to the S/4, sec. 26, T. 17 S., R. 12 E., a distance of 11,000 feet in a N.15°W trend. It has a minimum width of 2,500 feet.

Cretaceous - Tertiary

Quartz Latite Breccia. A quartz latite breccia is found resting either conformably or unconformably upon the Cretaceous (?) complex in the western part of the area. In part, this unit is a welded tuff. If this quartz latite is a forerunner of the Larimide granodiorite batholith, found in the western part of the district, it is probably of upper Cretaceous age.

Andesite. Andesite is found intruding and lying unconformably on top of the Cretaceous (?) complex and the quartz latite breccia. It is probably of upper Cretaceous in age.

Granodiorite. A granodiorite batholithic complex occurs in the western part of the Pima Mining district, and the easternmost exposures are found in the Ruby Star Ranch area. The Laboratory of Geochemistry of the University of Arizona obtained an age of 58.7 $\pm$ 1.9 million years (Damon, et. al., 1964).

Another granodiorite intrusion forms the core of the Twin Buttes-Foy Ridge anticline, and is probably of the same age and related to the granodiorite batholith.

Quartz Monzonite Porphyry. Small stocks of quartz monzonite porphyry intrude the sole fault and the overlying brecciated formations in the northwestern part of the area. The stocks post date the sole fault, but they are not found cutting the Helmet Fanglomerate. This confines the age to the Eocene or Oligocene Epochs. The stocks are probably late-stage derivatives of the Laramide granodiorite pluton.

Andesite Flows and Dikes. Andesite flows with plagioclase phenocryst attaining one-half inch in length are interbedded with the Helmet Fanglomerate, and separate the lower and middle members of the formation. Similar flows in the Tucson Mountains have been dated at 28 $\pm$ 2.6 million years (Damon, et. al., 1964). The andesite dike cutting the Helmet was dated at 24 million years (Creasy and Kistler, 1962).

STRUCTURE

Introduction

After the emplacement of the Sierrita granite and the intrusion of the diorite in Precambrian times, the district was relatively quiet throughout the Paleozoic Era and the early part of the Mesozoic Era. In the Cretaceous, however, the area became unstable, as shown by the complexity of the Cretaceous strata.

By the end of the Cretaceous a granodiorite batholith began rising in the western sector of the district, causing doming of the whole Sierrita Mountain area. As doming progressed, peripheral stretching in the eastern fringe zone of the dome produced at least three radial troughs. Thus, the consequent increases in relief, produced by doming and crustal sagging in the troughs, set the stage for the gliding of sediments from the roof of the batholith.

Development of the Structural Troughs

In the vicinity of the McGee Ranch (Figure 1) platy flow structures in the Laramide granodiorite batholith have a N.10°-20°W. trend and dip vertically to steeply westward. In the easternmost exposure of the batholith, the same platy flow structure trend is maintained, but the dip is 55°-60° eastward. North of the Esperanza Mine, a more weakly developed flow structure trending N.65°-75°E. and dipping steeply cuts across the stronger N.15°W. trending ones.

Steeply dipping aplite dikes trend N.50°-70°E. across the batholith. Joints parallel to the aplitic dikes are coated with quartz, muscovite, epidote, chlorite, and small amounts of sulfide. They are striated locally. Normal faults within the batholith trend N.65°-75°E. and dip southward 25 - 30 degrees.

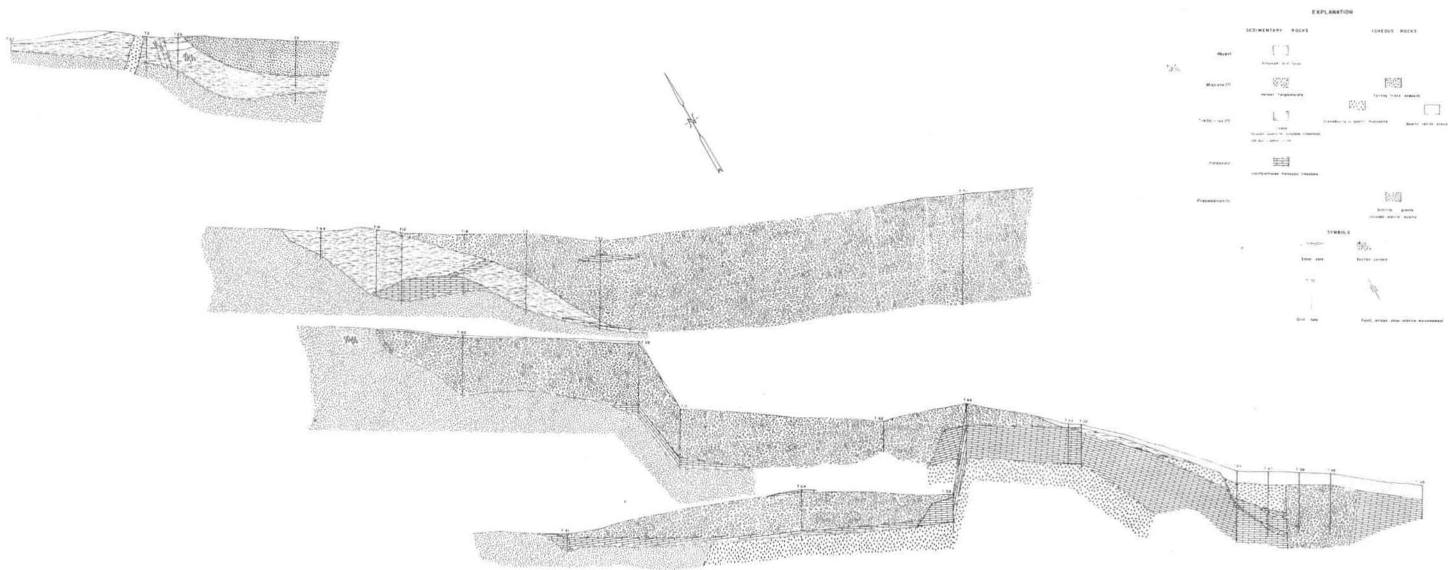

Figure 2.--Geological Cross Section Interpretations Based on Drill Core Data, Ruby Star Ranch Area.

The structural elements in the batholith suggest that the pluton rose as a dome along a N.15°W. trending axis, and as doming progressed the pluton stretched along its northerly trending axis producing tension fractures striking N.50°-70°E.

As suggested by the flow structure in the batholith, the older rocks in the fringe zone not only adjusted to the conformation of the invading pluton by stretching in a vertical direction, but they also adjusted to the longitudinal tensional forces produced by the lengthening of the pluton in a northerly direction. The longitudinal stresses resulted in peripheral stretching around the eastern fringe zone of the batholith. Relief from the peripheral stretching was gained by fracturing in an east to northeast direction as recorded in the Pima Mining district. Stresses resulting from continual uplift and peripheral stretching were relieved by extension on these fracture systems, giving rise to radial sags and troughs.

The three known troughs in the district tend to form a fan-shaped pattern, which converges toward the batholith (Figure 1). The southern trough trends N.60°E. as does the middle one, but where the fringe zone begins to swing northwest around the northeast flank of the Laramide batholith, the northern trough assumes a N.40°E. trend. This radial pattern also suggests that the troughs are related in origin to the domal structure.

After the initial stages in the development of the southern trough, the western end of the trough was invaded and healed by the granodiorite batholith, and may have been somewhat uplifted as doming progressed. The stratigraphy of the Helmet Fanglomerate indicates that the trough probably formed over a considerable length of time; at least from the late Cretaceous through late Miocene times.

Gravitational Gliding

Drill hole data demonstrates that in the southern part of the area, beginning just north of Foy Ridge, members of the Naco Group are in flat fault contact with the underlying Precambrian (?) granite and portions of the Laramide granodiorite. In the northern part of the area, the Cretaceous (?) complex is found separated by a flat fault from the underlying Sierrita granite. This fault contact, or sole, usually dips eastward 10° to 25°, and a black gouge zone from six inches to six feet in thickness separates the granitic rocks from the overlying strata. Both the granitic rocks and the overlying strata are strongly brecciated and sheared. It is upon this fault that the portions of sedimentary and volcanic shell of the domal structure glided eastward to their present position in the trough. Since no formations older than the Naco Group were found while drilling the glide plate, it is proposed that gliding was initiated by failure in the gypsum beds of the Naco.

As the plate of sediments migrated eastward, it rode over the Sierrita Granite in a N.75°-80°E. direction as indicated by the striations in the granite in the western part of the area (Figure 2). Segments of the Naco Group were thinned by frictional drag along the basal shear plane, and some segments became retarded by the lows present in the irregular surface along the sole of the plate.

A good example of retardation of segments of the glide plate, and overriding by younger units, can be seen in the drill hole data

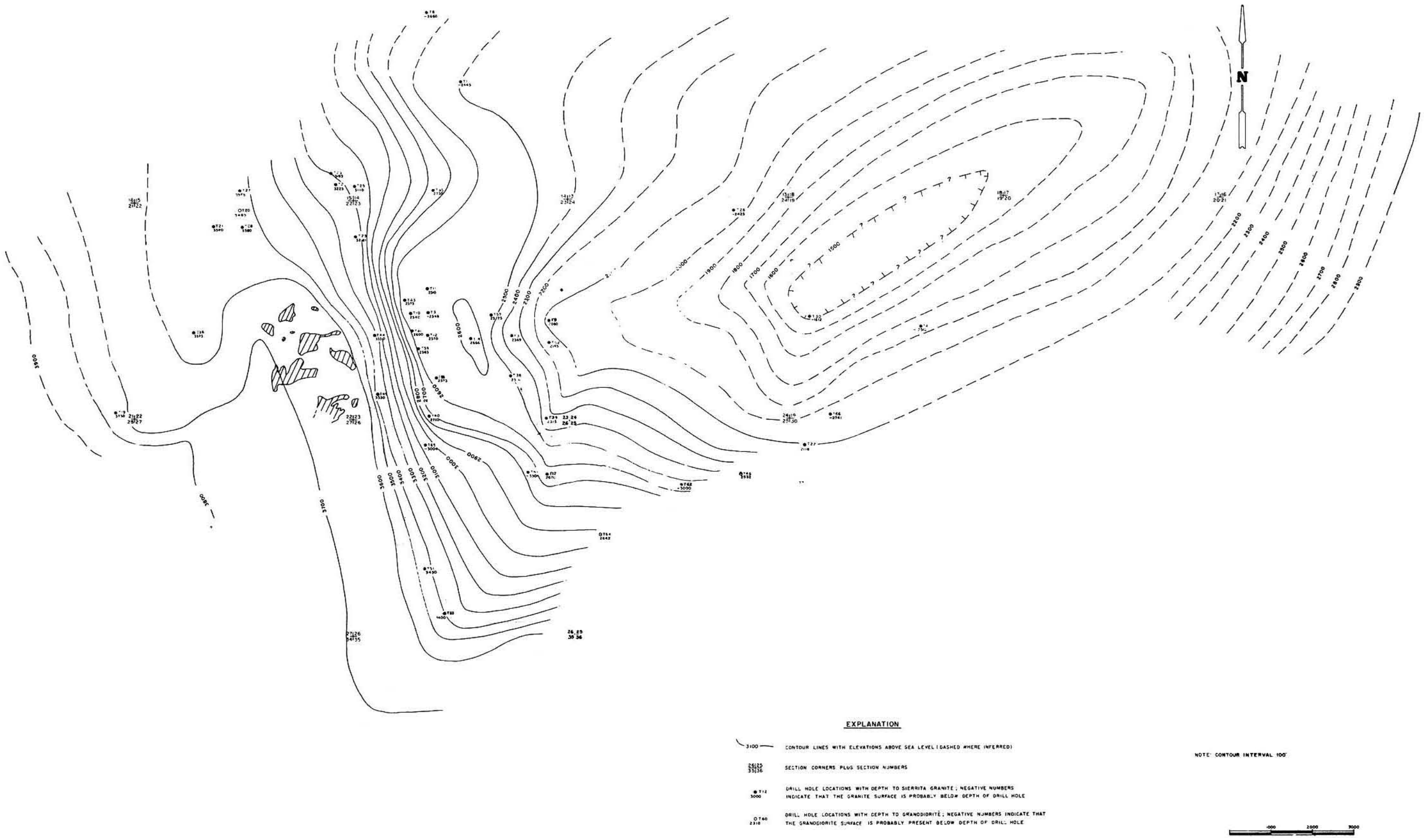

Figure 3.--Structural Contour Map of the Top of the Sierrita Granite, Ruby Star Ranch Area, Pima County, Arizona.

from the western half of sections 23, T. 17 S., R. 12 E. (Figure 2). A configuration resembling a glacial step is present. The closely spaced contour lines in Figure 3 would be the riser, the flat plane to the east would be the tread, and the high that terminates the plane to the east would be the riegel. This riegel in the Sierrita granite acted as a barrier and retarded basal members of the Naco Group as the gliding mass moved across the step.

As this Naco block became arrested and formed the "island" of limestone (Fig. 4), overlying younger units continued to glide east over the retarded block on flat-lying, imbricate, shear planes formed as indicated by slivers of the Naco thrust over Cretaceous units.

As gliding of the whole plate progressed, frictional drag along the sole fault produced north trending tensional faults. The formation of these faults was facilitated by the plate moving over small highs in the underlying granite. Also, local differences in frictional drag along the sole of the plate caused different rates of motion throughout the gliding block. As the differences in velocity of motion increased, the rocks of the plate yielded by shears forming N.70°-80°E. strike-slip or tear faults. Adjustments along these shears opened and caused more movement along the north trending normal faults.

Foy Ridge - Twin Buttes Anticline

The Foy Ridge - Twin Buttes fold is a northwest-plunging anticline, the axis of which strikes N 45°W and plunges 35 to 45 degrees northwest. Beds on both flanks of the fold have a general northwest strike and dip steeply. Part of the succession on the southwest limb of the anticline is repeated and overturned to the northeast, suggesting that thrust faults also developed along the southwest limb of the fold carrying older Paleozoic formations northeastward over younger Paleozoic rocks.

The structure of the anticline is controlled primarily by the emplacement of the Laramide granodiorite stock in the core of the fold. As the stock intruded, it caused doming and breaching of the sedimentary cover. As intrusion into the core progressed the sedimentary shell was also stretched longitudinally. The beds yielded along northeast-trending tensioned faults, perpendicular to the direction of extension. These faults show vertical as well as horizontal movement, indicating adjustments in several directions as doming progressed. This situation is analogous to structural development of troughs in the Pima District, but on a smaller scale.

It is not known if the granodiorite stock in the Foy Ridge-Twin Buttes fold is the same age as the Laramide batholith or is slightly younger. The writer believes that is is slightly younger than the batholith and classifies it as a late stage derivative of the batholith.

Drill information indicates that just north of Twin Buttes in sec. 29 and 30, T. 17 S., R. 13 E., detached blocks of Naco and granodiorite are both interbedded with and overlie the Helmet Fanglomerate beneath the Recent alluvium. Also the limestone hill located about a quarter of a mile northeast of Twin Buttes contains beds that strike parallel to the strata in the Twin Buttes, but dip much more steeply northward. The limestone belongs to the lower Naco Group and thus is out of

Figure 4.--Geologic Map of the Ruby Star Ranch Area, Pima County, Arizona.

stratigraphic position with respect to the surrounding sequence. Perhaps the detached blocks and the limestone hill are parts of slip sheets that glided northward off the Twin Buttes fold.

Tectonic Activity During the Deposition of the Helmet Fanglomerate

Large lentils derived from the Naco Group are found interbedded with the middle and upper members of the Helmet. These units are brecciated and show slippage along their contacts with conglomerate beds and with volcanic ash units. Stratigraphically these lentils are inverted. It does not seem probable that three different lentils scattered throughout the Helmet should break off from larger blocks and be inverted in the process. It is more likely that they were inverted by drape folding before becoming detached or inverted during emplacement. This would mean that uplift and gliding were still in progress while the Helmet was accumulating.

A reversal in age sequence of the fragments composing the fanglomerate--i.e. arkose fragments deposited before Paleozoic fragments--plus lenses composed of rock fragments of one type suggest that the Helmet is at least in part a product of break up and erosion of Paleozoic and Cretaceous (?) slip sheets as they migrated toward the faulted trough. The Naco lentils of the Naco are parts of these slip sheets, but are still intact even though strongly brecciated. Presumably additional fragmentation was inhibited because of the lubricating effect provided by the soft ash beds associated with some of the lentils.

Thus the fanglomerate was not only deposited by mud flows but by migrating slip sheets from the still tectonically active dome in the western part of the district. That this doming was still active during the deposition of the Helmet can also be demonstrated by the fragments present in the upper member of the Helmet; these represent all rock types found in the lower units plus an abundance of granodiorite fragments. These fragments, except for the granodiorite ones, are probably reworked from earlier deposits of fanglomerate in the western part of the area.

The general trend of the Helmet today is N 60° E with dips decreasing to the south. Thus tilting occurred both during and after deposition. The added weight of the Helmet plus continued uplift in the western part of the district caused major adjustments along the southern boundary fault of the trough. The north limb and floor of the trough also dropped but to a lesser extent so that the hinge-line effect along the northern border was retained; hence tilting the Helmet Fanglomerate southward.

CONCLUSIONS

Based on all available surface and subsurface data in the Ruby Star Ranch area, the writer's conclusions are as follows:

1. Beginning in Cretaceous time, as indicated by the deposits of that age, the area became tectonically unstable. The instability may possibly record the first stages of magma emplacement at depth.

2. Uplift was climaxed by the emplacement of a large granodiorite batholith in the western part of the district. A stock of granodiorite was also intruded into the core of the Foy Ridge-Twin Buttes anticline at approximately the same time, and it lifted, overturned and thrust aside its Paleozoic cover.

3. During intrusion, the region rose as a unit, and failed along transverse and radial fractures. Structural sags along these radial fractures gave rise to faulted troughs, thereby increasing and steepening the tectonic relief.

4. Striations, and the presence of an extensive sole fault, as well as the peculiar distribution and variations in thickness of Paleozoic limestones, very strongly suggest that the sedimentary shell of the rising dome slipped off into a large east-northeast-trending trough.

5. Subsequent to the emplacement of the allochthonus strata several small quartz monzonite porphyry stocks intruded them. These stocks are probably structurally controlled and are late derivatives of the granodiorite pluton.

6. The deposition of the Helmet Fanglomerate, with minor Paleozoic slip-sheets, upon the allochthonus rocks was a result of continued upheaval of the domal area.

7. Development of the steep southward dips in the sediments filling the trough was a result of further tensional adjustments and sagging consequent upon continual uplift.

8. The final development of a pediment throughout the area indicates ultimate attainment, or very close approach, to equilibrium.

It is suggested that the concept of uplift (primary tectongensis) and gravitational adjustments (secondary tectongensis) offers the possibility of rational explanation of the otherwise puzzling features of the Ruby Star Ranch area geology.

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