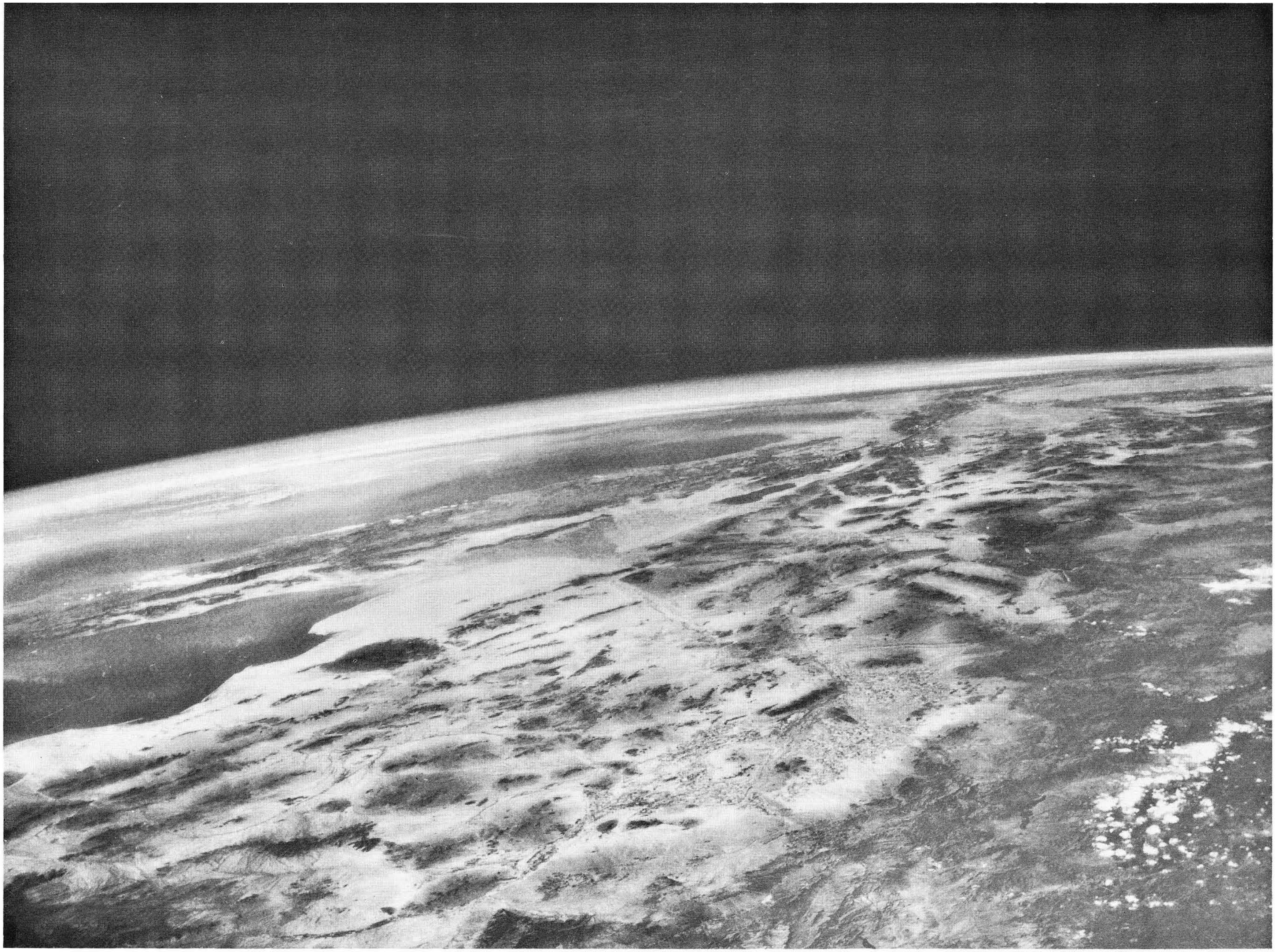

FIGURE 1. U. S. Navy Viking rocket photograph No. 21, Series 12. The exposure, westward across southwestern Arizona, was taken from a point above the White Sands Proving Grounds in New Mexico, at 142.3 miles above sea level. Reproduced with permission of the U. S. Navy Department.

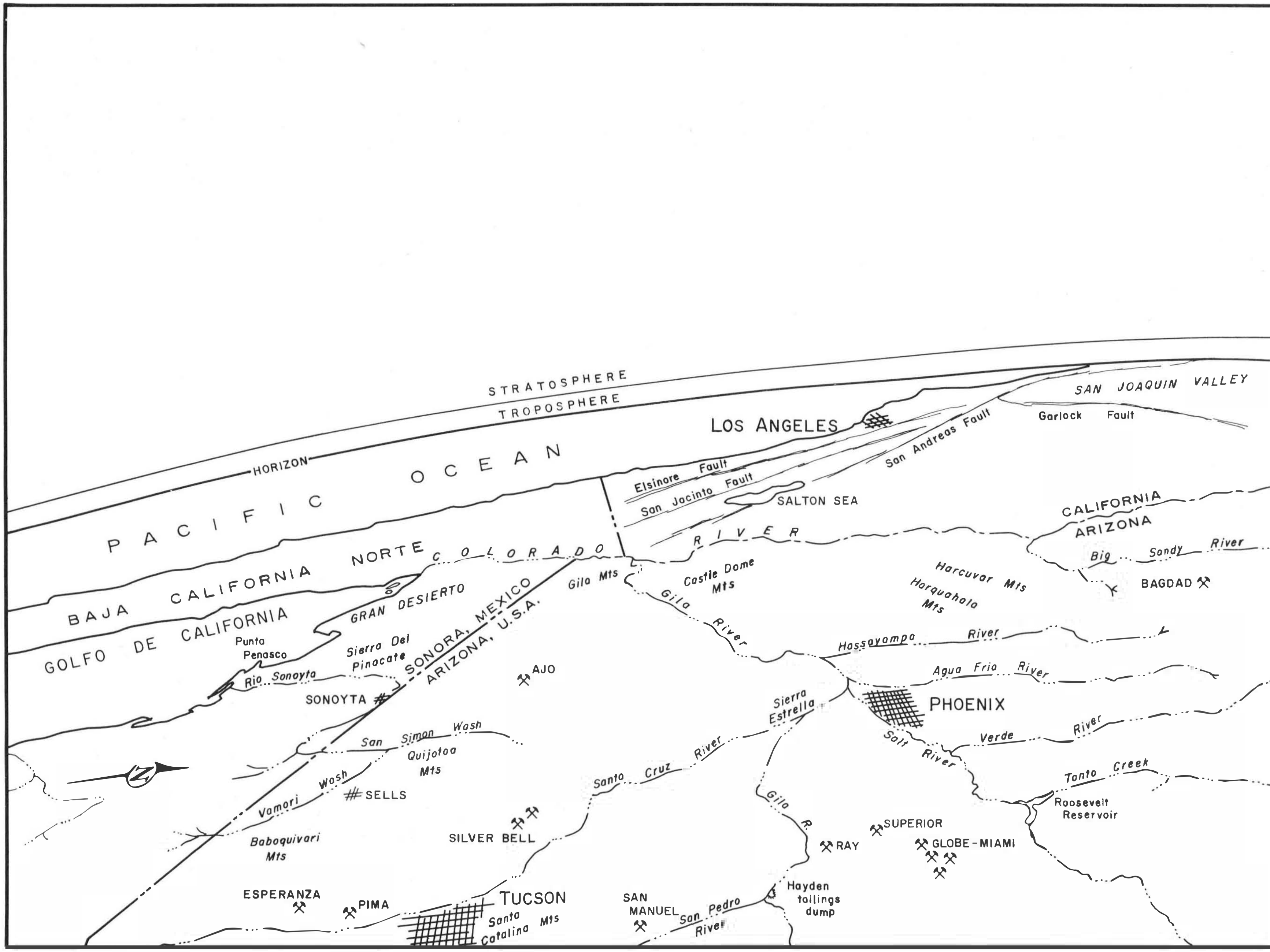

FIGURE 1A. Transferred interpretation of figure 1. This perspective varies in scale from approximately 20 miles to the inch in the immediate foreground to one-third that scale in the vicinity of the Salton Sea. Mine symbols show positions of some of Arizona's major copper ore bodies, labeled by the district name in which they are located.

VIKING ROCKET PHOTOGRAPH OF ARIZONA, CALIFORNIA AND NORTHERN MEXICO WEST OF TUCSON, ARIZONA

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GENERAL

The photograph shown in figure 1 is an exposure across southwestern Arizona from a point over the White Sands area of New Mexico at 142.3 miles above sea level. A modified K-25 camera with a focal length of 163 mm. was used. The area covered by figure 1 is somewhat less than that of the original negative.

GEOGRAPHY

The geography of the sector of the earth shown on the photograph is outlined on figure 1A and a few prominent features are labeled to help orient the reader. Other features can be readily recognized. For example, the snow-capped San Jacinto, San Bernardino, and San Gabriel Mountains, northwest of the Salton Sea, are easily identified and the Sierra Nevada can be seen immediately east of the San Joaquin Valley on the right-hand border of the photograph.

The large farming area of the Gila, Santa Cruz, and Salt River Valleys is identified by its distinctive mosaic pattern. This wide belt extends from Tucson north and west to beyond Phoenix. Small-scale features as detailed as the mill tailings ponds at Ajo, Hayden, and in the Globe-Miami district can be identified.

A few scattered clouds are seen in the right-hand foreground and many are in the distance over the Pacific Ocean. Los Angeles appears to be hidden in smog. The haze zone above the horizon makes a rather sharp contact with the clear (black) area above it. This contact is estimated to be approximately 10 miles above the horizon and is probably the tropopause, i. e., the base of the stratosphere, a layer where dust content drops off sharply.

GEOMORPHOLOGY

In the part of the Sonoran desert which lies within southwestern Arizona, there are no basins of interior drainage and the plains between bajadas are flood plains or adobe flats rather than playas. The broad, cone-like bajadas slope from adjacent mountains to intersect and form a pattern of arcuate intersections, locally marked conspicuously by dark areas or lines of vegetation. The arcuate intersections form almost perfect circles and ellipses around individual ranges or clusters of ranges. Their individual shapes and sizes show the extent of deposition coming from individual ranges and suggest the influence of differences in relief of adjacent ranges and, possibly, their relative ages. Where the intersection forms a straight line, it suggests that the intersecting bajada cones are expanding laterally at about the same rate. Where one bajada front is concave toward or appears to be taking a bite out of another, it represents the dominant source of debris.

The main elements of southwestern Arizona's drainage system are shown on figure 1A. Most of the water supply comes from a mountainous border belt between the Basin and Range province and the Colorado Plateau province. The Gila, Salt, Agua Fria, Hassayampa, Verde, and Big Sandy Rivers, as well as most of their important tributaries, originate in this belt and drain into the Colorado River. Part of this belt, which trends northwest across Arizona and averages about 75 miles in width, is exposed in the lower right-hand corner of the photograph. The drainage from Arizona into the Sonoyta River system in Mexico is clearly seen in the lower left-hand corner below the Sierra del Pinacate.

TECTONIC FEATURES

The general trends of Arizona mountain ranges are shown strikingly on figure 1. A prominent trend of N35°W is well displayed in the extreme southwest corner of Arizona and in northwestern Sonora. The major San Andres fault zone has a similar trend, and its influence on faulting in the southwest corner of Arizona is indicated. The large volcanic field comprising the Sierra del Pinacate mantles the northwest structural trend and appears to be younger than that period of orogeny which formed most of the surrounding ranges. The sharply contrasting trend of the Harcuvar and Harquahala mountains and the lower Gila River channel is noteworthy.

A persistent northerly structural grain in a broad zone between Tucson and Superior is revealed by the photograph. This trend and others, varying from northeast to due east, are additional to the northwest structural trend in this area.

Mayo (1958) has pointed to the lack of basic data which makes our understanding and analysis of lineament tectonics difficult. High altitude photographs will help supply the missing information. This writer is convinced that single photographs covering large regions will directly display some of the major structural zones of the continental framework, which must now be derived, or presumed, from inadequate data.

CONCLUSIONS

Aerial photographs display many features in infinitely more detail than do the best of maps of comparable scales, and geologists are aware of the advantages of using both large-scale maps of local areas and small-scale regional maps. Likewise, the advantages of both low-altitude and high-altitude aerial photographs are recognized.

The few observations discussed here and plotted on figure 1A are only a small percentage of the features displayed on this high-oblique rocket photograph. With each gain of man's ability to obtain photographs from higher positions above the earth, will come new opportunities for man to increase his understanding of the earth. Eventually, it is hoped, a full face of the earth can be exposed on a single photographic negative, i. e., with the horizon exposed as a complete circle.

The measure of man's gain in understanding his home planet with distant space photographs of the earth will rest squarely upon the shoulders of the members of our profession. We must be prepared to meet the challenge of these opportunities which are practically upon us. Full-face earth photographs may become a reality within the next two years. Such photography could be accomplished on 9 x 9-inch film with standard aerial cameras of 6-inch focal length at a distance of 2, 800 miles from the earth. At one-tenth that distance, all of Arizona could be exposed on such a single photograph.

Although photographs from orbiting satellites, considering present limitations of equipment and film, would lack the definition necessary for military inspection (Whitmore, 1958), such photographs will have great potential value in the study of the structure of the earth, our continent, and Arizona.

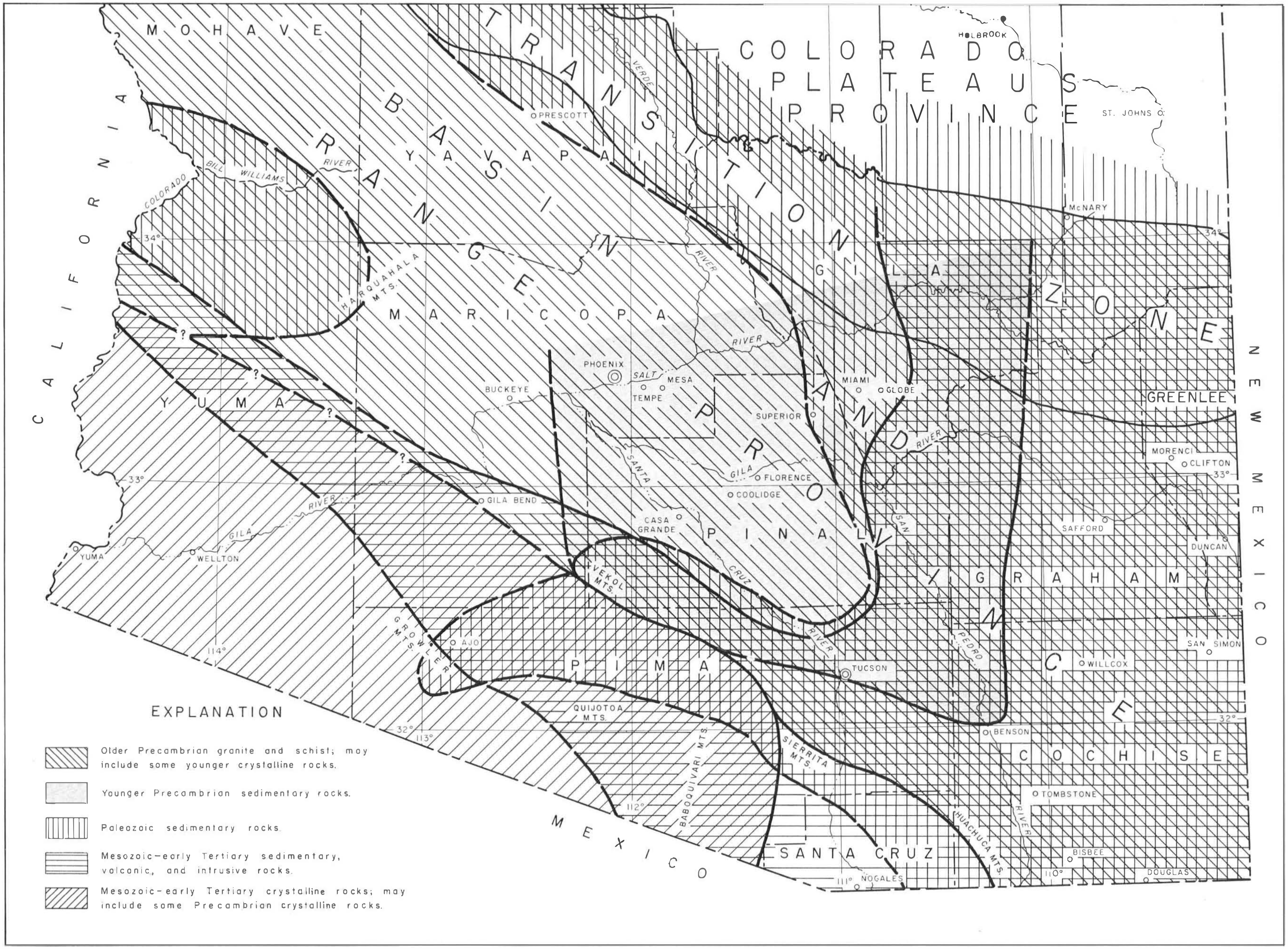

FIGURE 2. Sketch map showing general distribution of Precambrian, Paleozoic, and Mesozoic-early Tertiary rocks in southern Arizona.

INTRODUCTION

L. A. Heindl

Arizona includes parts of the Basin and Range and Colorado Plateaus provinces (fig. 10). The contrast in the physiography of the two provinces is based principally on differences in structural complexity (Wilson and Moore, 18)--rocks of the Colorado Plateaus province are only moderately deformed; the rocks of the Basin and Range province, and particularly those older than late Tertiary, are intensely folded, faulted, and intruded. Although the Basin and Range province is topographically lower than the Colorado Plateaus province, it is structurally higher, and the boundary between the two provinces is the structurally highest part of the State. The boundary forms a comparatively narrow zone of mountainous terrain, along which Precambrian rocks stand up to several thousand feet above Precambrian rocks on either side--a zone that lies like a welt across the face of Arizona. Southern Arizona is generally limited to that part of the State that lies within the Basin and Range province south and west of the boundary, and the distribution and history of the rocks of this region are outlined broadly in this introduction.

Rock Sequences and Their Distribution

The rocks exposed in southern Arizona are here grouped into seven sequences: (1) Older Precambrian granite and schist; (2) younger Precambrian sedimentary rocks; (3) Paleozoic sedimentary rocks; (4) Mesozoic-early Tertiary sedimentary and igneous rocks; (5) Mesozoic-early Tertiary crystalline rocks; (6) Tertiary volcanic and sedimentary rocks; and (7) Tertiary-Quaternary continental deposits. The pattern of outcrop distribution is primarily the result of structural deformation that localized areas of intrusion, erosion, and deposition and most of the rock sequences are distributed in broad, irregular, overlapping belts roughly parallel to the boundary between the provinces (fig. 2). The beltlike pattern is developed better in the southeastern part than in the western part of the State.

Older Precambrian rocks.--Older Precambrian granite and schist lie in a belt along the Colorado Plateaus province north of a general arc from the Huachuca Mountains to northern Yuma County. Within this belt, the older Precambrian age of these rocks is confirmed by stratigraphic relationships or geochemical dating. South of and west of this belt, much of the schist, gneiss, and granite previously assigned a Precambrian age on the basis of lithology may be composed principally of rocks of several different periods of intrusion and metamorphism younger than the Precambrian.

Younger Precambrian rocks.--The younger Precambrian rocks consist predominantly of clastic sedimentary rocks and are restricted to south-central Arizona, forming a wedge that thickens to the west. The thickest sections in the State are exposed in the Slate and Vekol Mountains (McClymonds, 16). No exposures of younger Precambrian rocks are known west of the Vekols, although granitic rocks of presumed Precambrian age locally crop out below Tertiary and Cretaceous (?) rocks.

Paleozoic rocks.--Paleozoic rocks are composed mainly of limy marine deposits and are exposed extensively only in southeastern Arizona. Paleozoic rocks occur in small, widely spaced outcrops in the south-central and northwest parts of southern Arizona, and these rocks are essentially unknown west of the Sierritas except in the vicinities of the Growler and Harquahala Mountains. Conglomerates of post-Paleozoic age, however, containing frequent boulders of Paleozoic rocks crop out as far west as California and Paleozoic rocks must certainly have extended across the southwestern part of the State.

Mesozoic-early Tertiary rocks.--Rocks of known Mesozoic and early Tertiary age in southeastern Arizona are limited to Cretaceous marine and near-shore marine deposits and Miocene continental beds. Rocks of presumed Mesozoic-early Tertiary age include thick sequences of near-shore and continental deposits and volcanic rocks which are exposed in a comparatively narrow west-northwest-trending belt across southwest Arizona. West of Tucson, these rocks include at least two units each of sedimentary, volcanic, and intrusive rocks. Part of the complexity of this succession may be the result of intertonguing of more or less equivalent units from adjacent areas. Almost everywhere the top units are composed of cobble to boulder conglomerate associated with fine-grained volcanic and intrusive rocks. In the southeastern part of the State, Mesozoic-early Tertiary rocks are commonly unmetamorphosed although locally they have been altered to phyllite and schist. Within the belt in southwest Arizona, at least the lower units are metamorphosed almost everywhere.

Mesozoic-early Tertiary crystalline rocks.--Crystalline rocks crop out in a wedge that extends west from the Baboquivari Mountains and south of the Quijotoa Mountains to west of Yuma. These rocks include intrusive bodies ranging in composition from diorite to granite and metamorphosed rocks ranging from phyllite and hornfels to schist and gneiss. Formerly they were considered to be of probable Precambrian age. However, several of the metamorphosed units have been traced into sedimentary and volcanic rocks lithologically similar to those of presumed Mesozoic-early Tertiary age and predominantly these rocks are of probable Mesozoic-early Tertiary age. Locally, these crystalline rocks may include remnants, or metamorphosed equivalents, of Precambrian rocks.

Tertiary volcanic and sedimentary rocks.--The Tertiary volcanic rocks are composed of a succession of andesitic, rhyolitic, and basaltic rocks with some interbedded continental deposits. These rocks crop out widely throughout southern Arizona and do not appear to be restricted to a beltlike zone within this area. The Tertiary rocks included in this sequence are characterized by being broadly warped or tilted. Although most of the volcanic rocks were derived from local sources, the successions of extrusive rocks appear to be similar in many areas.

Tertiary-Quaternary continental deposits.--The continental deposits included in this group, and the volcanic rocks associated with them, were deposited for the most part in the long, narrow structural basins that cut across the beltlike pattern of most of the older rocks. The trends of these basins and their correlative ranges are reflected in the present basin-and-range topography. The continental deposits consist of alluvial, fluvial, flood-plain, adobe-flat, and lake bed deposits, and their exposed portions are of Pliocene and Quaternary ages. The upper deposits in many adjoining basins have coalesced in part to form the nearly continuous cover of continental deposits that blankets more than half of southern Arizona.

Geologic History

During older Precambrian time, clastic and volcanic deposits were laid down in deep troughs and subsequently intruded and metamorphosed. This cycle was probably repeated more than once before the resulting uplifted areas were reduced to a remarkably even surface. Younger Precambrian near-shore and marine deposits were laid down in a wedge that thickened to the west or northwest. Before Middle Cambrian time, these rocks had been broadly uplifted and also eroded to a plain surface.

During Paleozoic time, southern Arizona was covered almost continuously by seas which generally shallowed to the west. The resulting marine deposits have sufficient lithologic and stratigraphic continuity to give a fairly firm sequence of geologic events (Pye, 3). Following the Paleozoic, except for Cretaceous time in southeasternmost Arizona, the sequence of geologic events is generally obscured by (1) a lack of datable fossils and key beds, (2) complex deformation, (3) widespread and repeated local intrusions, and (4) insufficient detailed studies. Nevertheless, enough work has been done to warrant a tentative summary of post-Paleozoic events.

The Triassic and Jurassic periods in southern Arizona were times of uplift and erosion. Locally, there were pre-Cretaceous intrusions and eruptions of volcanic rocks, but, in general, the uplift was epeirogenic. The high area may have been located generally south of and parallel to the Cretaceous Sonoran geosyncline. In Sonora, Mexico, marine deposits of Triassic and Jurassic age were deposited and northern Arizona received sediment from a high located in southern Arizona. The absence of Paleozoic sediments south of an arc drawn through the Growler, Vekol, and Sierrita Mountains may in part be explained by erosion from this high during Triassic and Jurassic time; in part the absence may result from post-Cretaceous erosion or engulfment by post-Paleozoic intrusions.

During late Mesozoic and Cretaceous time, the development of the northeast-trending Sonoran geosyncline was accompanied by orogeny, intrusion, eruption, and continental sedimentation as well as typical marine sedimentation. The destruction of the Sonoran geosyncline in late Cretaceous-early Tertiary time was apparently concomitant with the development of the structural high along the zone between the Basin and Range and Colorado Plateaus provinces. The presence of crystalline rocks of Mesozoic-early Tertiary age suggests, however, that a considerable overburden remained through at least Cretaceous time. The structural high continued to rise and supply debris until, northwest of Superior, much of the Paleozoic strata was removed. The Sonoran geosyncline was deformed into local mountains and basins up to Miocene time and extensive volcanic and continental deposits accumulated. In southeastern Arizona, these basins were destroyed by the principal periods of post-Cretaceous deformation, which occurred in post-early Miocene and pre-middle Pliocene time.

Post-Miocene, pre-Pliocene thrust faulting and associated uplift are the dominant structural features within the present mountain ranges. Although individual faults appear to be local in extent, this late thrusting was widespread and appears to be related unquestionably to the structural trends developed in Mesozoic and possibly Precambrian time. The areas of known thrusts are limited to the belts of Precambrian, Paleozoic, and Cretaceous-Tertiary rocks. Their absence south and west of these belts may result from structural differences between these belts or the evidence for their existence may have been obscured by erosion. Thrusting was in part contemporaneous with and in part followed by the intrusion and extrusion of sequences of igneous material ranging in composition from rhyolite to andesite and by the deposition of sedimentary rocks. Much of the mineralization in this region is associated with the Mesozoic-Tertiary deformation and intrusion.

The last stage of late Tertiary volcanism older than the Tertiary-Quaternary valley fills included the extrusion from local sources of extensive andesitic and basaltic flows, associated with some rhyolitic deposits. The distribution of these late Tertiary volcanic rocks suggests that they were deposited in large valleys. This surface and the volcanic rocks deposited on it were warped into broad crenulated folds. More or less contemporaneously, the high-angle faulting that characterizes the present basin-and-range structure and topography was superposed roughly parallel, or at acute angles, to the trends of the warping.

The deposition of much of the continental material that is called valley fill probably began with the initiation of warping and faulting. Deposition was complicated by contemporaneous local deformation and volcanism. This deposition is known to have continued until early Pleistocene time and to have filled the basins a few tens to a few hundreds of feet above the present surface. Subsequent erosion, locally in two or more stages, reduced the area to its general present configuration. Information is not yet adequate to correlate the Pleistocene deposits and surfaces with the glacial chronology in the Middle West.

The unraveling of the many threads of evidence regarding the history of the area before and after Paleozoic time will depend on detailed stratigraphic work supplemented by geochemical, paleontological, and climatological studies. The Geochronology Laboratories of the University of Arizona are investigating the problems of dating the rocks by several methods, including dendrochronology, palynology, paleontology (Smiley, 1958) and geochemistry (Damon, 1958, 5). The surface and subsurface stratigraphy of the continental deposits within the basins is being studied by the U. S. Geological Survey and the University of Arizona. The geology of the consolidated rocks below the valley fills is being investigated by drilling and geophysical methods by mining and oil companies, the U. S. Geological Survey, and the University of Arizona. General geological studies, of course, are continuing by all groups.