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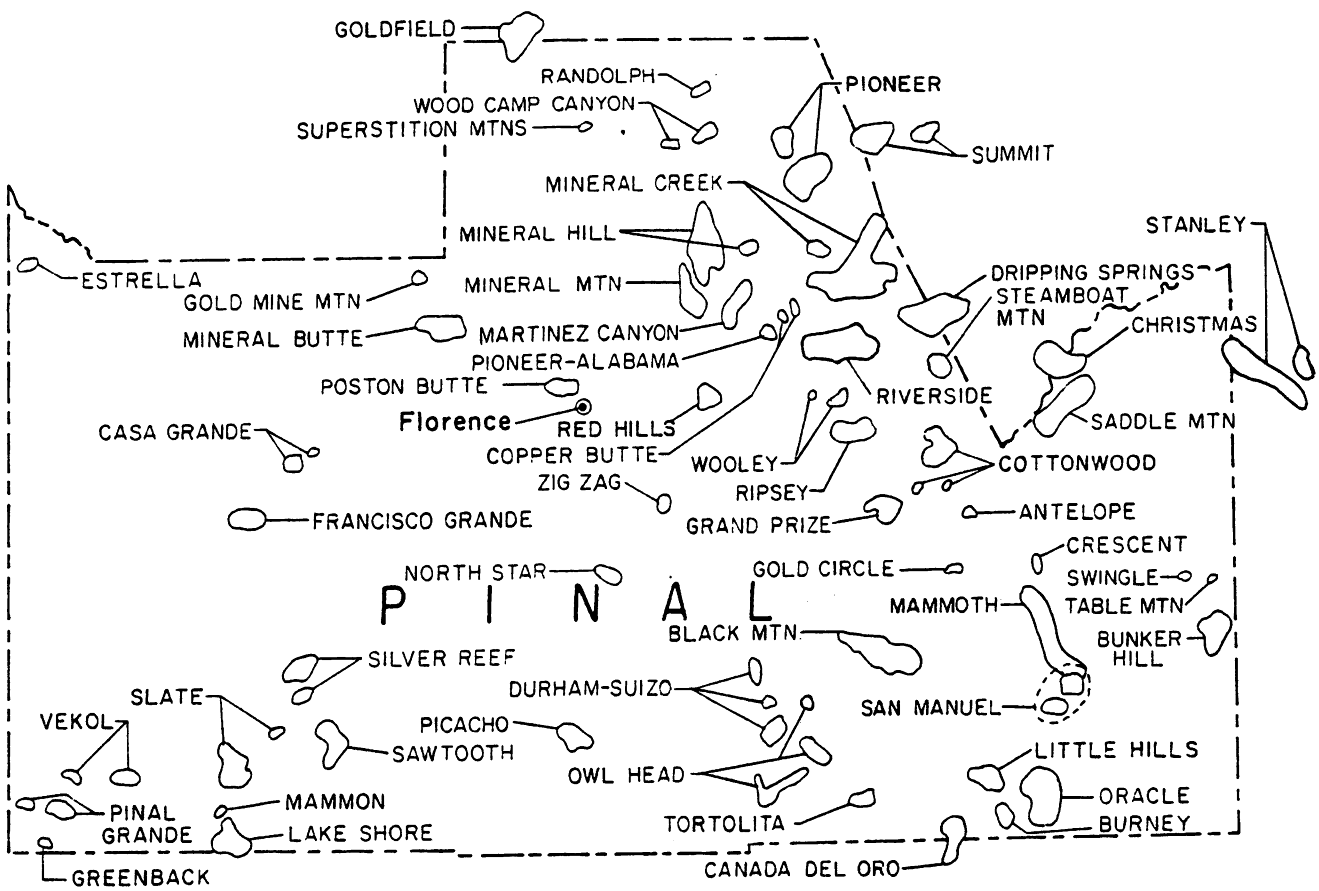
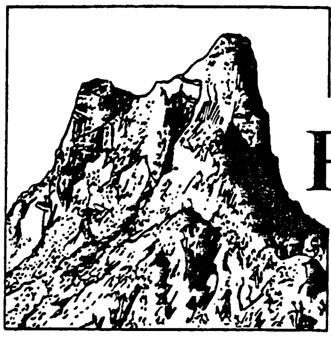
1979
MAP
OF
PINAL COUNTY
ARIZONA
SCALE IN MILES
LEGEND
TOWNSHIP LINE
SECTION LINE
DIVIDED HIGHWAY
PAVED ROAD
IMPROVED ROAD
UNIMPROVED ROAD
RESERVATION BNDRY.
WILDERNESS AREA
CANAL
AIRFIELD
AREA 5,386 Sq. Mi.
POPULATION 90,000
COUNTY SEAT FLORENCE
STATE
FOREST
PATENT
PINAL COUNTY
INDIAN RESERVATION
BUREAU OF LAND MANAGEMENT
TOWNSHIP INDEX
MARICOPA COUNTY
GILA COUNTY
GRAHAM COUNTY
PIMA COUNTY
TONTO NATIONAL FOREST
SUPERSTITION MOUNTAINS
GILA RIVER INDIAN RESERVATION
MARICOPA INDIAN RESERVATION
PAPAGO INDIAN RESERVATION
SAN CARLOS INDIAN RESERVATION
CORONADO NATIONAL FOREST
SANTA CATALINA MOUNTAINS
TABLE TOP MOUNTAINS
FLORENCE MILITARY RESERVATION
APACHE JCT.
FLORENCE JUNCTION
FLORENCE
COOLIDGE
CASA GRANDE
STANFIELD
MARICOPA
SACATON
ELOY
PICACHO
RED ROCK
KEARNY
KELVIN
WINKELMAN
DUDLEYVILLE
MAMMOTH
ORACLE
SAN MANUEL
GALIURO MOUNTAINS
PREPARED AND DESIGNED BY PINAL COUNTY ENGINEER'S OFFICE



Mineral districts in PINAL County, Arizona.

mi 0 10 20
km 0 10 20 30



Pinal County

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GENERALIZED GEOLOGY AND STRUCTURE OF THE WINKELMAN 15-MINUTE QUADRANGLE AND VICINITY, PINAL AND GILA COUNTIES, ARIZONA

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Abstract.—A northwest-trending belt of steeply east-dipping Precambrian and Paleozoic sedimentary rocks extends across the Winkelman 15-minute quadrangle and separates areas of contrasting structures. To the southwest for 60 mi is an expanse of Precambrian basement, largely granite; to the northeast the Precambrian and Paleozoic sedimentary rocks are gently tilted and intricately faulted. The structure within the Winkelman 15-minute quadrangle is interpreted as a monocline separated into en echelon segments by strike-slip and normal faults. Other monoclines lie to the north and northwest. Most of the tilting that formed the monoclines occurred after deposition of the early(?) Miocene San Manuel Formation. Structural features that repeat the Precambrian and Paleozoic sedimentary rocks within the area and that resemble high-angle faults are believed to have formed as low-angle thrusts, tilted to their present nearly vertical position during development of the monoclines. Structural features that are younger than the monoclines include low angle gravity slide surfaces which are older than the high-angle normal faults that formed the basin-and-range topography on which the Pliocene sediments were deposited.

This paper describes and interprets the geologic structure within and adjacent to the Winkelman 15-minute quadrangle (fig. 1). The four 7½-minute quadrangles that make up the 15-minute quadrangle are being published in the quadrangle-map series at a scale of 1:24,000 (Krieger, 1974a-d). The interested reader is referred to these maps for more details on the structure and for fuller descriptions of the stratigraphy of the area. The most obvious structural features are en echelon belts of steeply dipping Precambrian and Paleozoic sedimentary rocks that contrast with structural features to the northeast and southwest. Southwest of the 15-minute quadrangle, Precambrian basement rocks are extensively exposed; northeast of it, Precambrian and Paleozoic sedimentary rocks are gently tilted and intricately faulted. The northwest-trending en echelon belts within the 15-minute quadrangle are interpreted as a single monocline later separated into segments by strike-slip and high-angle normal faults.

Acknowledgments.—I thank my colleagues in the U.S. Geological Survey, particularly Max D. Crittenden, Jr., and Norman G. Banks, for stimulating discussion, for many suggestions concerning the structural interpretations, and for critical review of the manuscript.

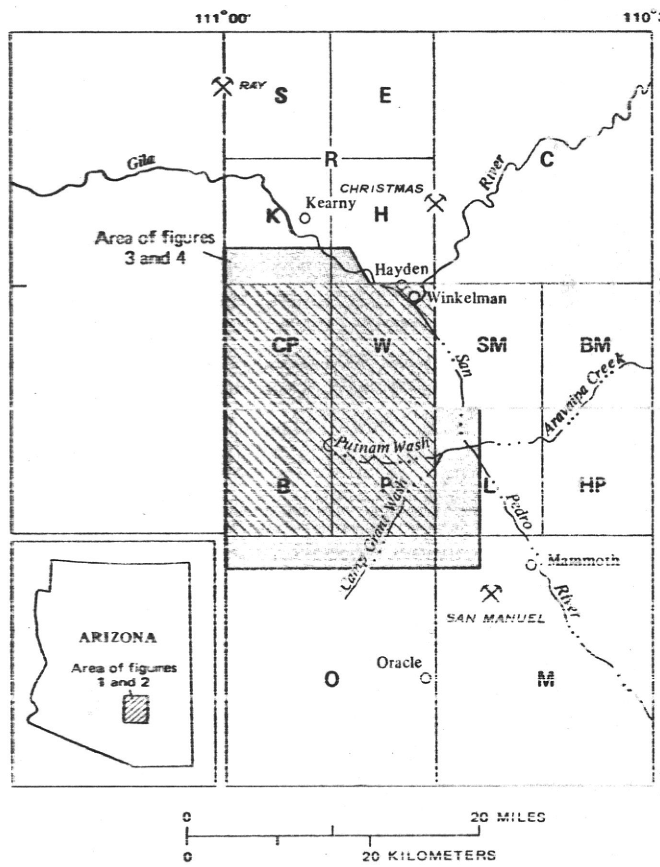


Figure 1.—Index map showing location of the Winkelman 15-minute quadrangle (hatched and shaded) and other quadrangles in southeastern Arizona, and showing location of features referred to in text. Quadrangle names and published data identified as follows: B, Black Mountain (Krieger, 1974c); BM, Brandenburg Mountain (Krieger, 1968a); C, Christmas (Willden, 1964); CP, Crozier Peak (Krieger, 1974b); E, El Capitan; H. Hayden (Ransome, 1919; N. G. Banks and M. H. Krieger, unpub. data, 1973); HP, Holy Joe Peak (Krieger, 1968b); K, Kearny, (Cornwall and Krieger, 1974); L. Lookout Mountain (Krieger, 1968c); M, Mammoth (Creasey, 1965, 1967); O, Oracle (from aerial photographs by U.S. Soil Conservation Service and from Creasey and others, 1961); P, Putnam Wash (Krieger, 1974d); R, Ray (Ransome, 1919); S, Sonora (Cornwall and others, 1971); SM, Saddle Mountain (Krieger, 1968d); W, Winkelman 7½-minute (Krieger, 1974a).

STRATIGRAPHY

Rocks in the area discussed (figs. 2,3) range in age from Precambrian to Holocene. The oldest Precambrian rocks are the Pinal Schist and intrusive rocks, mostly the Ruin Granite (Oracle Granite of Peterson, 1938). Batholithic masses of Ruin Granite, dated at about 1,430 m.y., by Silver, (1968) and Damon, Livingston, and Erickson (1962), were intruded after a period of intense deformation that produced nearly vertical east-trending foliation and bedding in the schist. The schist and granite are overlain with profound angular unconformity by unmetamorphosed Precambrian sedimentary rocks of the Apache Group and the disconformably overlying Troy Quartzite. Diabase, about 1,200 m.y. old (Silver, 1960; Damon and others, 1962), forms dikes and sills in the Apache Group and Troy Quartzite and sill-like masses in the schist and granite parallel to the pre-Apache erosion surface. The sills inflated the Precambrian sedimentary section but apparently did not perceptibly tilt the strata. Because of their abundance and narrow outcrop width due to steep dips, diabase sills in sedimentary rocks are not shown in figure 3. Sills in granite and schist are shown with exaggerated width to illustrate their relation to the pre-Apache erosion surface.

After a long period of erosion, Cambrian formations were deposited disconformably on the Precambrian sedimentary rocks and diabase. Devonian, Mississippian, and Pennsylvanian rocks overlie the Cambrian strata.

Volcanic rocks of Late Cretaceous age that disconformably overlie older rocks in the area are (1) the Williamson Canyon Volcanics (fig. 3) of andesitic composition, most abundant northeast of the Winkelman quadrangle, (2) the Cloudburst Formation, composed of volcanic rocks of probable latitic composition, fanglomerate, and sedimentary breccias in the southern part of the area and now standing nearly vertically and underlain by a gently dipping gravity slide surface, and (3) a rhyodacitic to quartz latitic pyroclastic unit, found only

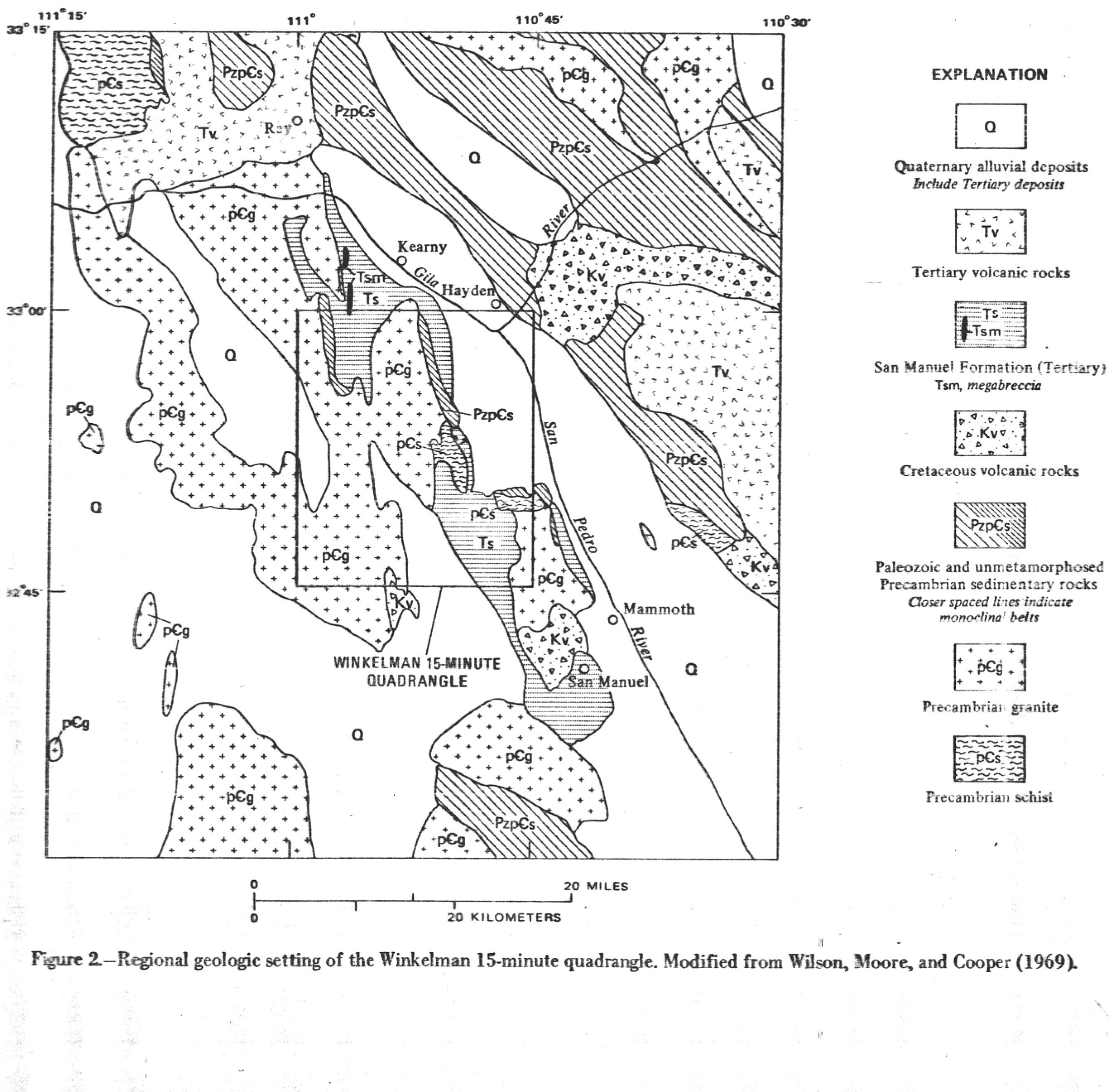


Figure 2.–Regional geologic setting of the Winkelman 15-minute quadrangle. Modified from Wilson, Moore, and Cooper (1969).

in the northwest part of the Crozier Peak quadrangle. The Williamson Canyon Volcanics was considered to be Late Cretaceous by Willden (1964) and Late Cretaceous or early Tertiary by Creasey (1965, 1967). It is now considered to be Late Cretaceous because in the Crozier Peak quadrangle it is intruded by Late Cretaceous diorite (Krieger, 1974b). The Cloudburst Formation is also designated as Late Cretaceous because Creasey (1965, 1967) considered it to be probably the same age as the Williamson Canyon Volcanics in the Christmas quadrangle. The rhyodacitic to quartz latitic volcanic rocks are considered to be Late Cretaceous in age because some of them resemble the Glory Hole Volcanics (east of the area of fig. 3), which is intruded by 69-m.y.-old granodiorite (Simons, 1964; Creasey, 1967).

Late Cretaceous diorite and granodiorite and Late Cretaceous and (or) early Tertiary (Laramide) porphyry masses and dikes of several lithologic types, but largely rhyodacite porphyry, intrude the older rocks. Only the diorite is shown in figure 3. Many of the porphyry dikes and masses are east trending, but older porphyry masses, some possibly of Early Cretaceous age, are conformable and probably were intruded as sills in the Precambrian sedimentary rocks before tilting.

According to the new nomenclature for Cenozoic stratigraphy in eastern Pinal County (Krieger and others, 1974), Tertiary sedimentary deposits in the area (fig. 3), formerly called the Gila Conglomerate or Group, are now divided into the San Manuel Formation (oldest), the Big Dome Formation, and the Quiburis Formation (youngest). Pleistocene and Holocene alluvial deposits, also formerly included in the Gila Conglomerate or Group, overlie these formations.

The San Manuel Formation consists of alluvial and playa deposits and interbedded andesite and megabreccias (not shown separately in fig. 3). The playa deposits and megabreccias are well developed in the Kearny quadrangle (Cornwall and Krieger, 1974). The San Manuel is Miocene (probably early Miocene) in age. Discordant dates on biotite and sanidine from a rhyodacite tuff bed in the upper part of the formation in the Crozier Peak quadrangle are 18 and 24 m.y., respectively. The San Manuel Formation is overlain unconformably by the alluvial Big Dome Formation in the Kearny and Crozier Peak quadrangles. In the Kearny quadrangle, north of the map area, a nonwelded ash-flow tuff in the Big Dome Formation yielded late Miocene K-Ar ages of 14 m.y. on biotite and 17 m.y. on hornblende (Banks and others, 1972). The Quiburis Formation consists of both alluvial and lakebed facies and was deposited in the basin now occupied by the San Pedro River. It contains Hemphillian vertebrate fossils, indicating a middle Pliocene age (John Lance, oral commun., 1963, in Krieger, 1974a). Tertiary volcanic rocks shown in figure 2 include the Galiuro Volcanics (Krieger, 1968, a-d) east of the San Pedro River and the volcanic rocks in the Ray-Superior area. The Galiuro Volcanics has been dated at 22-26 m.y. and probably is about the same age as the San Manuel Formation. The Apache Leap Tuff (part of the volcanic rocks shown in the northwest part of fig. 2) has been dated at 20 m.y. It is older than the Big Dome Formation and probably younger than the San Manuel Formation. Beneath the Apache Leap Tuff is the Whitetail Conglomerate, which contains near its top in the Ray area (Cornwall and others, 1971) a rhyolite tuff bed dated at 32 m.y. (Oligocene).

STRUCTURE

The most obvious structural features in the area are belts of steeply dipping Precambrian and Paleozoic sedimentary rocks that form a series of en echelon ridges separating extensive exposures of Precambrian granite and minor schist on the west from tilted Tertiary sedimentary rocks and gently tilted and intricately faulted Precambrian and Paleozoic sedimentary rocks on the east (figs. 3,4). The steeply dipping belts formed as monoclines, not as the eastern limbs of anticlines. The belts within the Winkelman 15-minute quadrangle are interpreted as parts of a single monocline, later separated by strike-slip and high-angle normal faults. Monoclinal folding commenced before, but continued during and after, deposition of the early(?) Miocene San Manuel Formation.

Within the steeply dipping belts, the section is locally repeated by faults with steep dips which are considered to have formed as low-angle thrusts and to have been tilted to their present nearly vertical position during monoclinal folding. These thrusts and related tears are the oldest structures recognized. They are intruded by Laramide porphyries that are older than the San Manuel Formation. All the other structures are mainly younger than the San Manuel. Possibly some movement on strike-slip faults that segmented the monocline commenced before San Manuel time, but much of it was later. Low-angle gravity slide surfaces underlie the Cloudburst Formation and part of the San Manuel Formation. North-trending high-angle normal faults cut older structural features; some are younger than the Big Dome Formation.

Structural Features Older Than The San Manuel Formation

Thrusts

Faults interpreted to be tilted thrusts (fig. 4) include (1) Ripsey Wash fault, an imbricate structure in the Crozier Peak and southwestern Kearny quadrangles, (2) Romero Wash fault in the Winkelman 7½-minute quadrangle, (3) a thrust extending southward from the Crozier Peak into the Black Mountain quadrangle, and (4) possibly a thrust in the northwestern part of the Lookout Mountain quadrangle. All now have steeply dipping attitudes that closely follow beds of the monoclinal fold. The Ripsey Wash and Romero Wash faults are intruded by Cretaceous porphyries (not shown in fig. 3). Because the folding occurred largely after deposition of the San Manuel Formation, as shown by steep dips in that formation, and because the San Manuel contains clasts of the porphyries, the structural features cannot have formed as high-angle normal or strikeslip faults after formation of the monocline. The Ripsey Wash and Romero Wash faults may

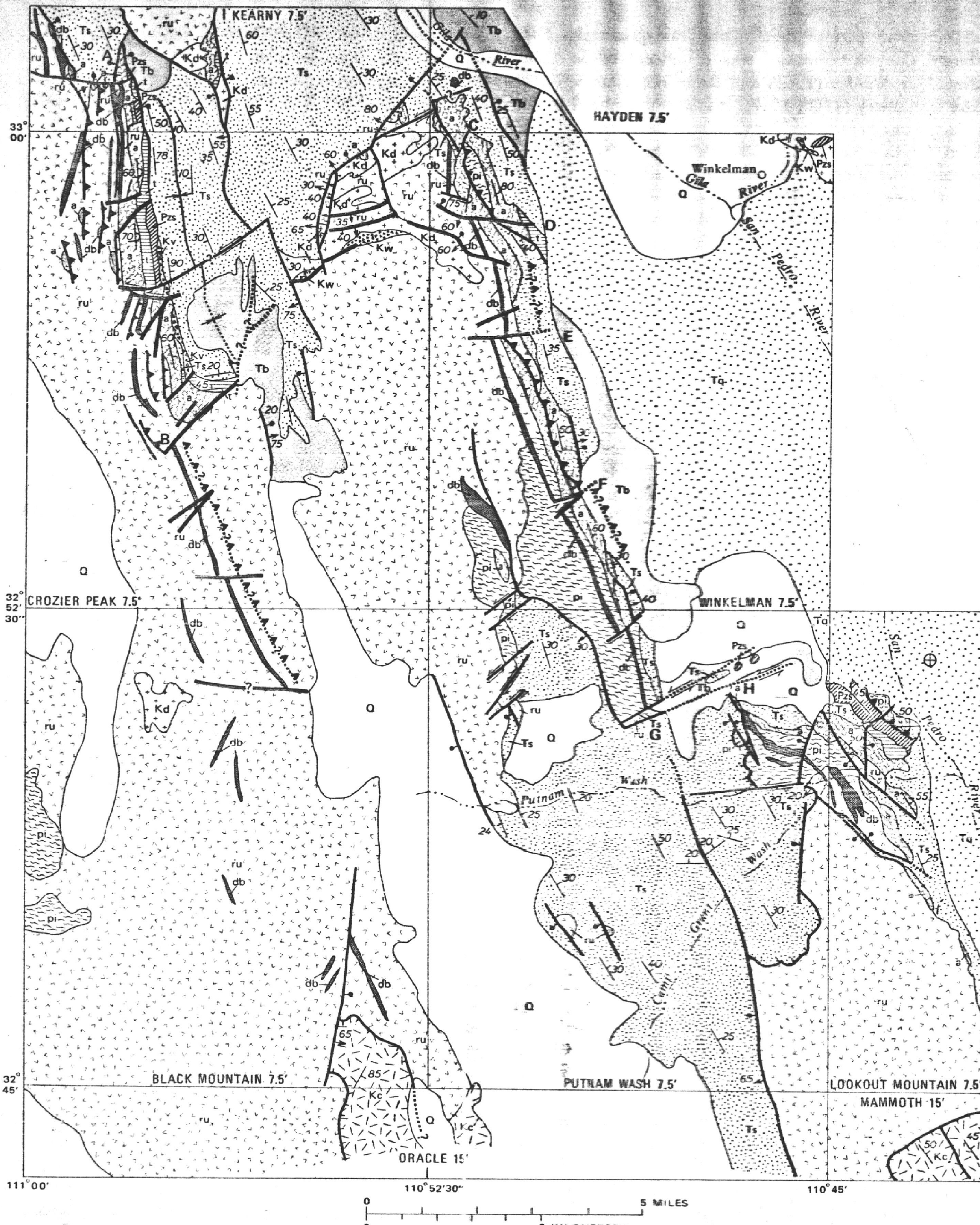
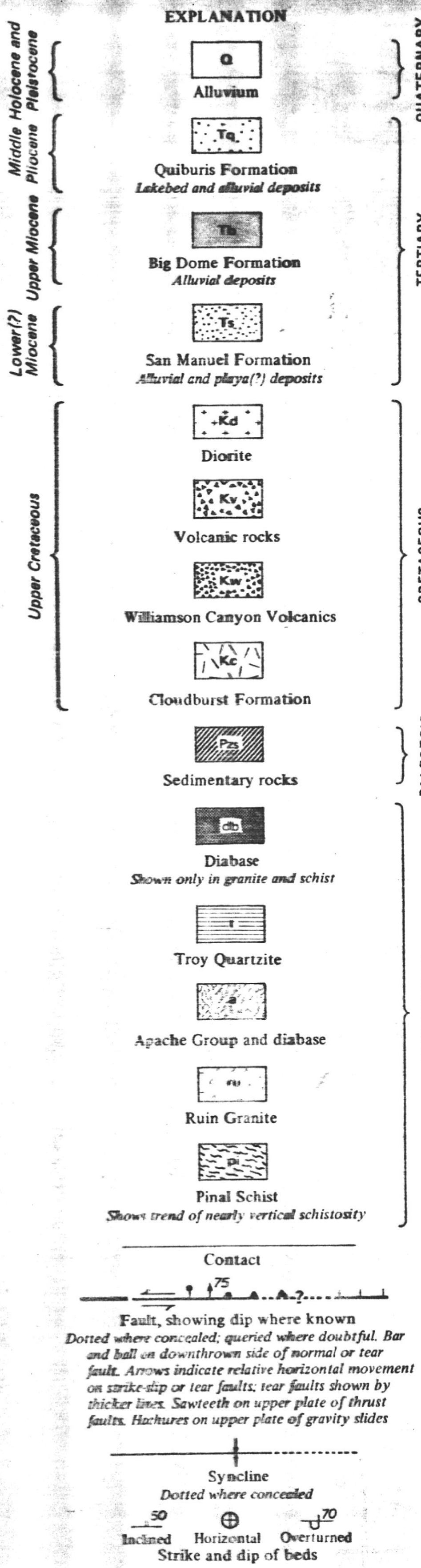


Figure 3.–Generalized geologic map of the Winkelman 15-minute quadrangle and adjacent areas.



have been part of a single thrust zone, cut and displaced by strike-slip and high-angle normal faults that segmented the monocline.

Ripsey Wash fault.—A north-trending belt of nearly vertical faults that extends from the southwestern part of the Kearny quadrangle (point A, fig. 4) to the central part of the Crozier Peak quadrangle (point B, fig. 4). This zone consists of several fault strands that separate thin east-facing slices of the basal part of the Apache Group, resting with sedimentary contact on the underlying basement (Ruin Granite), from similar slices to the west. Just north of point B at least three such slices, too small and too poorly exposed to show even on the detailed map (Krieger, 1974b), are spaced at distances of 50–100 ft. It is difficult to interpret this series of faults as anything other than a zone of imbricate thrusts that was later tilted. If the monocline extended upward indefinitely, high-angle normal faults could have downdropped the tilted slivers, but the presence of Cretaceous porphyries in some of the faults proves that faulting preceded tilting. If the monocline flattened upward, as it must have and as is suggested for the separate monocline in the Kearny quadrangle discussed below, the slivers should be nearly horizontal or tilted in discordant directions. Figure 5 represents diagrammatic sections across the fault zone, showing relations before and after tilting.

Romero Wash fault.—This fault (fig. 4) is exposed in two segments, a northern segment from south of point C (Hayden quadrangle) to west of point D (Winkelman quadrangle) and a southern segment from west of point E to west of point F. In the northern segment east of the fault the Apache Group rests on the Pinal Schist, and the beds dip steeply east; west of the fault the Apache rests on granite, and the beds are overturned but still occur in normal sequence, except where broken by small faults, most of which are not shown in figures 3 or 4. Some of these faults may be imbricate structures related to the major thrust, not younger high-angle faults as shown on the detailed map (Krieger, 1974a). In the southern segment the beds both east and west of the fault dip steeply east. West of the fault the Apache rests on granite to the north and schist to the south. East of the fault it rests on granite, except at the southern end, where the section is repeated without intervening granite. At the southern end of this segment (point F), two strands of the fault repeat the Apache Group. The southern segment of the fault (points E to F) is occupied by a tabular body of Cretaceous porphyry, whose nearly vertical dip and concordant relations show that the fault formed before or during Cretaceous time. Figure 6 represents a diagrammatic section across the fault, showing relations before and after tilting.

Other thrusts.—The occurrence of diabase as sill-like masses in granite and schist parallel to, and generally not more than 500 ft below, the pre-Apache erosion surface is well illustrated in the Winkelman and parts of the Crozier Peak and Putnam Wash 7½-minute quadrangles (fig. 3). This relationship was recognized by Shride (1967, p. 56), who stated that at depths

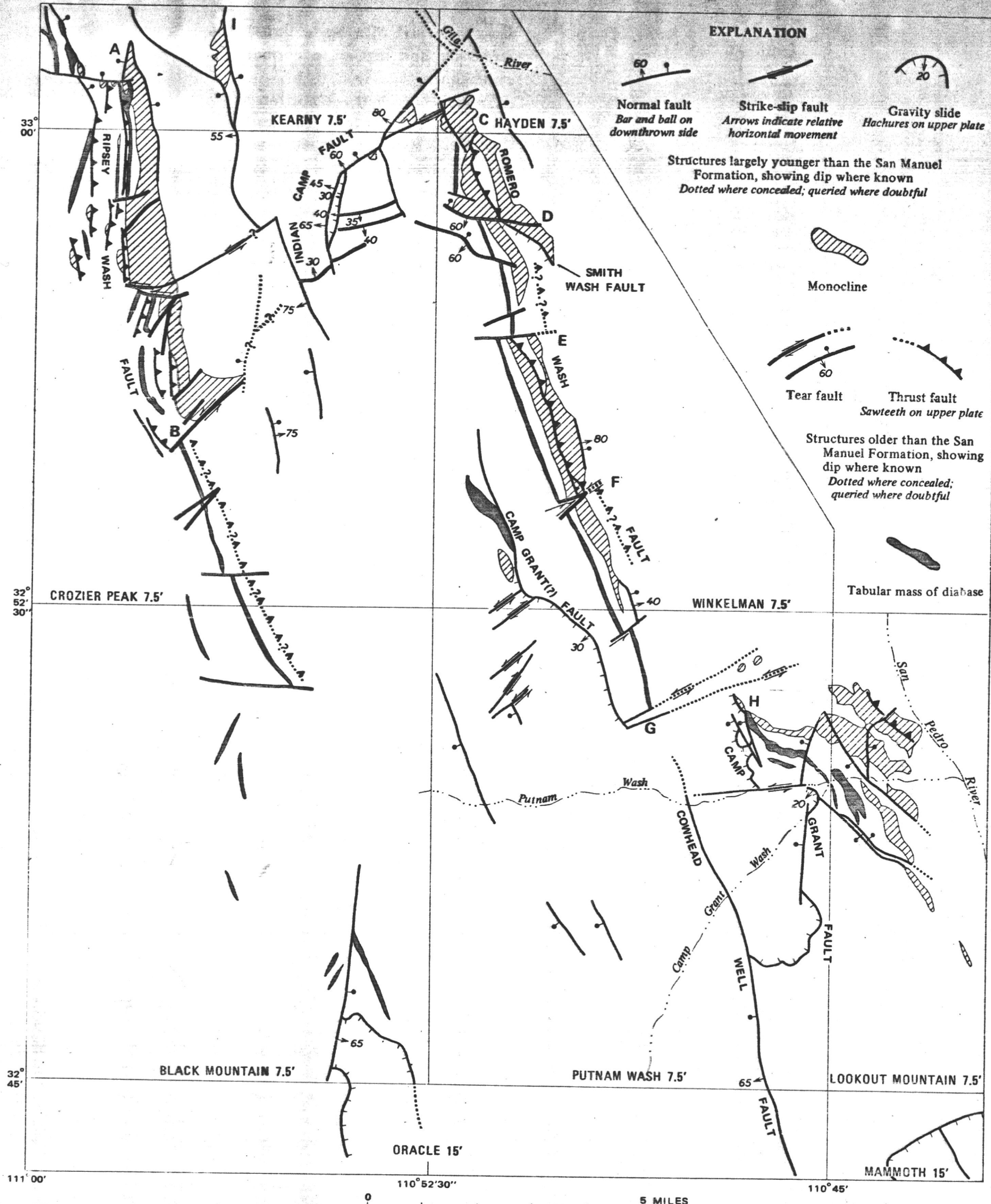


Figure 4.–Generalized structure map of the Winkelman 15-minute quadrangle and adjacent areas.

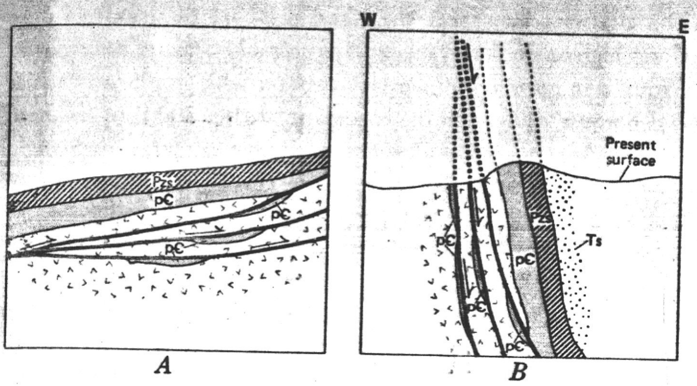


Figure 5.—Diagrammatic sections across Ripsey Wash fault showing suggested relations (*A*) before, and (*B*) after tilting. Ts, sedimentary strata; Pzs, Paleozoic strata; p€, Precambrian sedimentary strata.

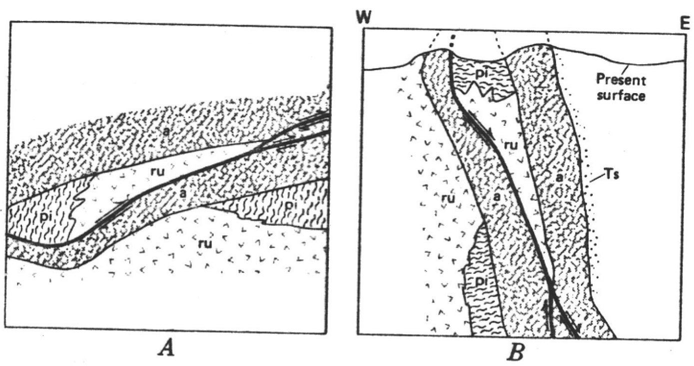


Figure 6.—Diagrammatic sections across Romero Wash fault showing suggested relations (*A*) before, and (*B*) after tilting. Ts, sedimentary strata; a, Apache Group; ru, Ruin Granite; pi, Pinal Schist.

of more than 500 ft below the base of the Apache Group extensive intrusions of diabase are practically nonexistent. It seems likely that the tabular mass of diabase that extends south of point B into the Black Mountain quadrangle may be such a sill originally intruded into the Ruin Granite within 500 ft of the pre-Apache surface. I explain its presence here, apparently miles "below" the nearest Apache Group, as the result of a thrust (fig. 4) perhaps related to a deeper strand of the Ripsey Wash fault; unrecognized normal faults in the granite may complicate the structure. Other tabular masses of diabase, mostly in the Black Mountain quadrangle, may owe their position to unrecognized tilted thrusts, or they may represent feeders to the diabase sills and sill-like masses.

In the northwestern part of the Lookout Mountain quadrangle, the section of steeply dipping Precambrian and Paleozoic rocks is repeated by a series of faults. Some of these faults cut the San Manuel Formation and therefore cannot be thrusts similar to the Ripsey Wash and Romero Wash faults. The beds face east and become progressiely younger, except in the northeasternmost exposures where the beds are overturned and face west or south. This was shown on the map of the Lookout Mountain quadrangle (Krieger, 1968c, sec. *AA'*) as a steeply east-dipping thrust that moved from east to west, or as a high-angle reverse fault. The structure was throught to represent the east limb of a tight syncline in which the west limb had been sheared out. Its relation to the thrusts to the northwest is unknown.

Tears

Numerous northeast-, east-, and southeast-trending, steeply dipping cross faults cut Precambrian and Paleozoic rocks. Some of them exhibit features characteristic of tear faults related to thrusting; they terminate at a thrust or transfer movement from one thrust surface to another. If they are tears that have been rotated almost 90° during development of the monocline, the typical tear-type displacement, which originally would have been strike slip, may now appear as high-angle dip-slip movement. Examples of this are two east-southeast-trending high-angle faults with apparent reverse movement in the northwest part of the Winkelman quadrangle, west and southwest of point D. They dip about 60° to the south, and both show relative uplift on the south. These same relations may also be obtained by strike-slip or oblique-slip, rather than reverse movement. The northern fault appears to offset the Romero Wash fault but not enough to account for the offset of the Apache Group. Where the fault offsets the San Manuel Formation, the south side has been relatively downdropped; that is, the movement is in the opposite sense.

Structural Features Younger Than the San Manuel Formation

Structural features that are mostly younger than the San Manuel Formation include (1) folds that tilted the thrusts and the Precambrian and Paleozoic sedimentary rocks to form north-trending, steeply dipping, east-facing monoclines, (2) east- to northeast-trending strike-slip faults that separate the major monocline into en echelon segments, (3) gently dipping gravity slides that placed tilted Cretaceous and Tertiary rocks on the Ruin Granite, and (4) north-trending high-angle normal faults. Folding may have commenced before, but much of it occurred during and after deposition of the San Manuel. Movement on some of the strike-slip faults may also have commenced before, but most of it ocurred after San Manuel time, and some of it is younger than the gravity sliding that postdates the San Manuel. High-angle normal faults are mostly related to deformation that produced the basin and ranges; one of these basins was filled with the Pliocene Quiburis Formation on which the San Pedro River now flows.

Monoclines

Three north-northwest-trending, en echelon belts of steeply dipping to overturned Precambrian and Paleozoic sedimentary rocks (figs. 3, 4) extend from the Lookout Mountain to the southwest part of the Kearny quadrangle. A remnant of another belt is exposed in the south-central part of the Kearny quadrangle (figs. 2, 3, and Cornwall and Krieger, 1974). A fourth belt of tilted Precambrian sedimentary rocks is found 15–20 mi northwest of the Kearny quadrangle (fig. 2, and Schmidt, 1966).

The belts that lie mainly within the Winkelman 15-minute quadrangle (from points A to B, points C to G, and southeast of point H, fig. 4) are interpreted to have originally been part of a single monocline later segmented by strike-slip and high-angle normal faults. The steeply dipping Apache Group rocks are not exposed continuously in the middle segment (points C to G). Their presence beneath the San Manuel Formation, however, is suggested by the tabular mass of diabase in granite and schist, which elsewhere lies within 500 ft of the pre-Apache surface; it is also confirmed by small patches of Apache Group (not shown in fig. 3), north of point G.

The monocline near point I is a separate but probably contemporaneous feature. This monocline extends from southwest of point I northward across the Kearny quadrangle (Cornwall and Krieger, 1974) for over 6 mi. Remnants of Precambrian sedimentary rocks resting on granite lie west of the steeply dipping San Manuel Formation near point I. North of point I nearly vertical tabular masses of diabase lie a short distance west of the fault that separates Ruin Granite from the San Manuel Formation and indicate the northward extension of the monocline. The suggestion is untenable that the monocline was originally part of the monocline in the Winkelman 15-minute quadrangle and was moved from point A to south of point I along a southeast-trending strike-slip fault. Two belts of east-trending porphyry dike swarms show no evidence of offset. One belt extends from the northwest part of the Kearny quadrangle (Cornwall and Krieger, 1974), westward across the northeast part of the adjacent Grayback Mountain quadrangle (H. R. Cornwall and M. H. Krieger, unpub. data, 1973); the other extends from the southwestern part of the Kearny quadrangle into the southeast part of the Grayback Mountain quadrangle. The apparent strike-slip fault is a high-angle normal fault that bounds the southwest side of a younger horst block.

These tilted belts are interpreted as the eroded remnants of east-facing monoclinal folds that separate vast areas of granite on the west from Tertiary sediments on the east. The almost complete absence of west-facing beds, as well as the absence of Precambrian or Paleozoic sedimentary rocks for more than 60 mi to the southwest, appear to rule out the possibility that the monocline is the east limb of an anticline. Isolated examples of west-facing beds—southwest part of the Winkelman quadrangle (Krieger, 1974a), northwest part of the Lookout Mountain quadrangle, (Krieger, 1968c), and northwest part of the Crozier Peak quadrangle (Krieger, 1974b, sec 23, T. 5 S., R. 13 E.)—are interpreted as the result of drag or later deformation.

The alternate view that the tilted belts are the result of drag along high-angle faults appears improbable because the Apache Group is in normal sedimentary contact with granite and schist and because diabase in the basement, within 500 ft of the base of the Apache, precludes the existence of large high-angle faults west of the belts. In the west-central part of the Kearny quadrangle (Cornwall and Krieger, 1974), a nearly horizontal mass of diabase trends westward from a north-trending diabase mass that marks the trend of the monocline in this area. It is interpreted as a sill intruded not more than 500 ft below the pre-Apache surface and representing the area where the monocline flattened westward. The overlying Precambrian and Paleozoic sedimentary rocks were eroded after formation of the monocline.

The folding occurred before and continued after deposition of the San Manuel Formation because, adjacent to the monoclinal ridges, the San Manuel Formation also dips steeply, though generally 20°–30° less than the older rocks. Although some of the tilting of the San Manuel Formation could have been caused by drag along the faults that separate the San Manuel from older rocks, the extensive areas of tilted San Manuel east of the faults could not have been formed by drag. Deposits of claystone and mudstone with abundant mud cracks and curled mud chips indicate deposition of part of the San Manuel Formation in a flat playa environment. In the Kearny quadrangle (Cornwall and Krieger, 1974), megabreccias (landslide blocks) slid from the west or southwest out onto interfingering playa and alluvial deposits and were immediately buried by additional playa and alluvial deposits. The sediments and interbedded megabreccias now dip steeply to almost vertically east. Away from the monocline the San Manuel Formation dips less steeply because of the eastward flattening of the monocline. Attitudes of the San Manuel Formation away from the monocline may be partly due to later structural features. The fact that the oldest unit in the San Manuel in the Putnam Wash quadrangle is composed largely of clasts of Ruin Granite indicates that Precambrian basement was exposed, before San Manuel time, somewhere west and southwest of the Winkelman 15-minute quadrangle. Likewise, much of the San Manuel Formation in the northwestern half of the Kearny quadrangle is composed of granitic clasts, derived from the northwest and west. However, Paleozoic and Precambrian sedimentary rock clasts are abundant in the San Manuel Formation and form extensive megabreccias, especially in the Kearny quadrangle (Cornwall and Krieger, 1974), proving that these sedimentary rocks had not been entirely stripped from the granite and schist basement by San Manuel time.

Strike-slip faults

Two major left-lateral strike-slip faults appear to separate into segments what is interpreted to have been a single monoclinal ridge (fig. 4). The northern fault moved the monoclinal ridge from points B to C, and the southern one moved it from point G to east of point H.

Although conclusive proof is lacking that the northern and middle segments were originally continuous, the following evidence suggests this interpretation: (1) In the Crozier Peak quadrangle, east of point B (fig.3) the strike of vertical to steeply overturned strata changes abruptly from a north to an east-west trend with a gentler northward dip, suggesting drag, and (2) The small patches of Apache Group, not entirely in normal stratigraphic sequence, west of point C (southeast corner of Kearny quadrangle and northeast part of Crozier Peak quadrangle), may have been dragged into their present position by the fault. In this area the fractured condition of granite and diorite bedrock may have been caused by the strike-slip fault. The position of the strike-slip fault across or beneath the San Manuel Formation, northeast of point B, is uncertain because of concealement both by the Big Dome Formation and by colluvial slumping of the San Manuel Formation and because of offset by younger north-northwest-trending high-angle faults. How much of the movement on the strike-slip fault is older than the San Manuel Formation and how much is younger is uncertain. The fold in the older rocks is reflected in the younger deposits, which also swing east.

The following evidence supports a southern strike-slip fault: (1) Small exposures of Paleozoic rocks north of point H lie considerably west of the main outcrops in the northwest part of the Lookout Mountain quadrangle (fig. 3), (2) Apache Group, assumed to be buried beneath the San Manuel Formation, north of point G, is west of the Apache Group near point H, and (3) what is interpreted to be the continuation of the post-San Manuel Camp Grant fault (fig. 4), northwest of point G, is offset westward from the northern exposure of Camp Grant fault near point H. Movement on this strike-slip fault appears to be younger than the Camp Grant fault, which cuts the San Manuel Formation.

Gravity slides

Gravity slides–décollements or detachments–are concave-upward surfaces that separate sedimentary or volcanic rocks from older rocks. The younger rocks generally dip in the opposite direction from the fault surface. The best example of a gravity slide in the Winkelman 15-minute quadrangle is Camp Grant fault in the Putnam Wash quadrangle. Other probable gravity slides are beneath the Cloudburst Formation (fig. 3) in the Black Mountain and Mammoth quadrangles and involve San Manuel Formation in the northern part of the Winkelman 15-minute quadrangle. The Cloudburst Formation in the southeast part of the Black Mountain quadrangle is nearly vertical and is surrounded on at least the west, north, and east sides by the Ruin Granite. The contact between the Cloudburst and granite is concealed by alluvium, except on the west where it is an east-dipping normal fault. The gravity slide is assumed to be a nearly horizontal concave-upward surface (Krieger, 1974c, sec. *AA'*). In the Mammoth quadrangle, Creasey (1965, 1967) interpreted the structure as a gently east-dipping thrust; the overlying Cloudburst Formation dips mostly 35°–65° eastward. The Indian Camp fault in the northeastern part of the Crozier Peak quadrangle and the Smith Wash fault in the northwest part of the Winkelman 7½-minute quadrangle are questionably interpreted as gravity slides.

A low-dipping gently curved fault surface (fig. 7) is well exposed on the north side of Camp Grant Wash about 2,000 ft southwest of its junction (at the quadrangle boundary) with Putnam Wash. This surface, interpreted as a gravity slide plane, dips 20° west and separates Ruin Granite on the east from the San Manuel Formation on the west. The surface on granite is remarkably smooth. Conglomeratic gouge a few inches thick separates the granite from the overlying conglomerate. Fracture cleavage in the gouge indicates that the upper block moved from east to west. The conglomerate dips about 35° northeast and is cut by by subparallel cycloidal (in section) faults and by steeper west-dipping faults. The steeper faults end downward at the gravity slide plane or at the cycloidal faults. These features are similar to what Anderson (1971, p. 43) has called "thin-skinned distension" in Tertiary rocks in Nevada in which Tertiary volcanic rocks are cut by "a system of closely spaced north- to northwest-striking shingling normal faults (many of which are low angle) that displace younger over older rocks in a west to southwest direction * . * . * . The structural units are floored at or near the present level of exposure by complex low-angle zones of detachment or decollement into which the numerous shingling normal faults merge." Absence of recognizable small stratigraphic units and difficulty in tracing faults in the San Manuel Formation make it impossible to determine whether or not the apparently great thickness of the formation in the Putnam Wash quadrangle is caused by repeated low-angle slicing and rotation.

Camp Grant fault is offset to the west by an eastward-trending strike-slip fault along Putnam Wash and probably by a major strike-slip fault near point G; it is cut by north-trending normal faults (discussed below). What is interpreted to be the offset part of the Camp Grant fault is exposed in the northwest part of the Putnam Wash quadrangle. It separates Pinal Schist on the east from northeast-dipping San Manuel Formation on the west. The fault dips about 30° west. Camp Grant fault was questionably extended into the southwestern part of the Winkelman quadrangle. If the fault in that area is part of the Camp Grant fault, it is unusual in that it involves Precambrian rocks. Most of the gravity slides are believed to flatten downward and for the most part not to extend far into the basement. The attitude of the small mass of Apache Group suggests drag that might accompany faulting or gravity sliding. The Apache is cut by a north-trending fault (not shown in figs. 3, 4). West of the fault the Apache dips steeply eastward; east of the fault it also dips steeply eastward, but the dip flattens

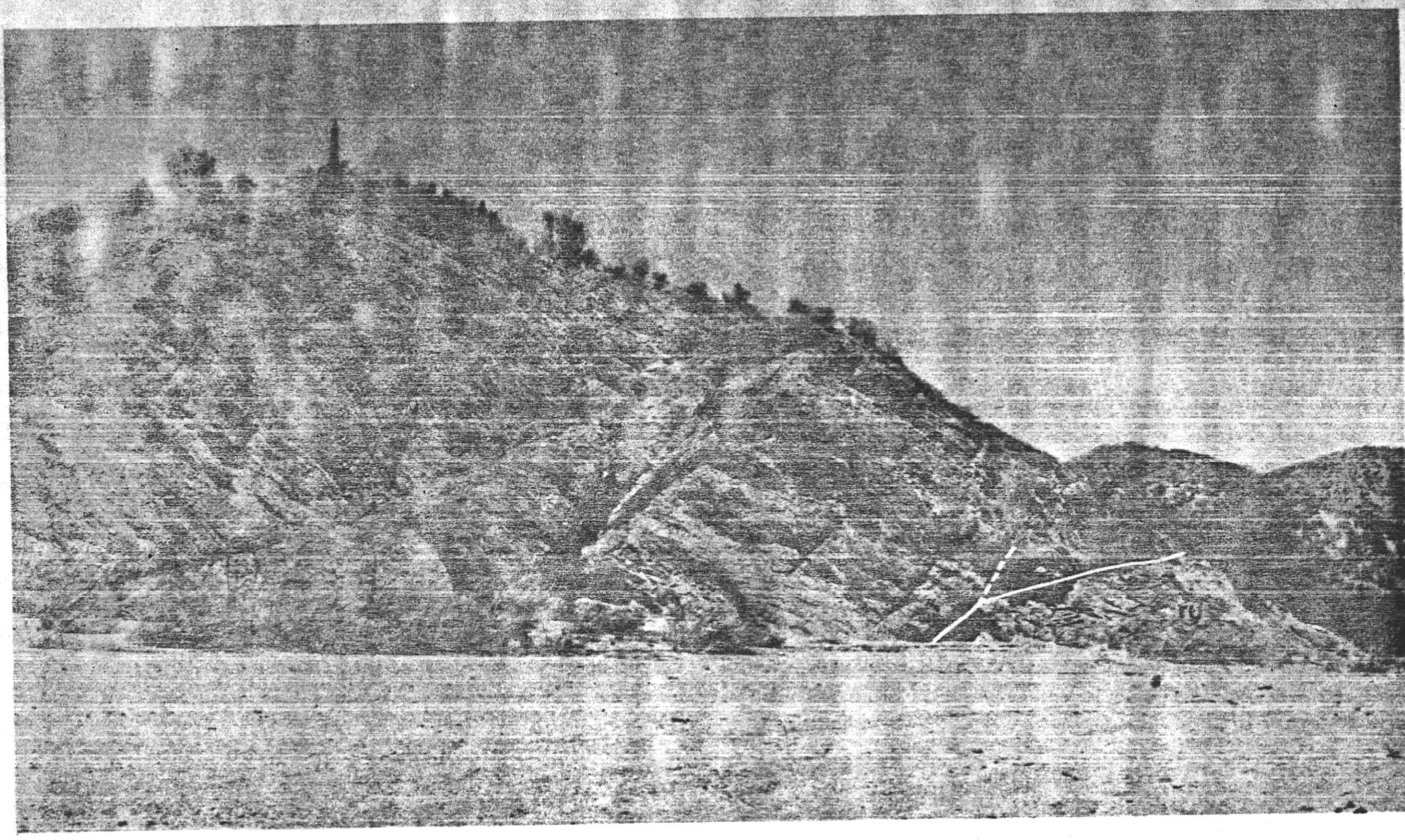


Figure 7.–Camp Grant fault, exposed on north side of Camp Grant Wash, about 2,000 ft southwest of junction of Camp Grant and Putnam Washes. Light-colored outcrop at right is Ruin Granite (ru). Fault surface here dips about 20° west. Overlying conglomerate of San Manuel Formation dips about 35° northeast and is cut by subparallel cycloidal faults and by steeper west-dipping faults that end downward at the cycloidal faults. The fault surface appears to steepen where it approaches the wash, but this is an optical illusion due to foreshortening because of the angle at which it is viewed and to removal of some of the younger rocks, where cut by one of the more steeply dipping small faults at the creek level.

rapidly (Krieger, 1974d, sec. *DD'*), and along the eastern margin of the outcrop, beds dip gently westward.

High-angle normal faults

High-angle, mostly north-northwest-trending normal faults cut the San Manuel Formation and older rocks. Renewed movement has also occurred since deposition of the Big Dome Formation, and some has occurred since deposition of the Quiburis Formation (east of the San Pedro River). Some of these faults are downthrown on the east, and some on the west. A few of these faults deserve special mention.

The Cowhead Well fault (fig. 4) extends for at least 12 mi, from north of Putnam Wash into the western part of the Mammoth quadrangle (south of the map area). It is younger than both the San Manuel Formation and the Camp Grant fault.

The fault that cuts off the Cloudburst Formation and the thrust that underlies the Cloudburst in the Southeastern part of the Black Mountain quadrangle may also be younger than the San Manuel Formation.

Faults occur between the San Manuel Formation and Precambrian and Paleozoic bedrock in many places, but the amount of displacement within the Winkelman 15-minute quadrangle in most places is believed to be small. The attitude of the San Manuel Formation, therefore, is likely due to folding (tilting), not to drag on the faults. In the Kearny quadrangle, however, considerable post-San Manuel displacement has occurred on the bounding faults. The bedrock mass west of point I is clearly a horst. Uplift on this block may have been responsible for development of the syncline in the San Manuel Formation that extends from the Crozier Peak quadrangle into the southwest part of the Kearny quadrangle. Playa deposits on the east side of the syncline are identical with those east of point I and at one time extended across at least the southern end of the block.

These high-angle normal faults are part of the Basin and Range fault system. Major faults, at least on the east side of the San Pedro River (fig. 2), produced the basin in which the Pliocene Quiburis Formation was deposited. This faulting took place largely after deposition of the San Manuel Formation, and some of it occurred after deposition of the Big Dome

Formation. The early Miocene Galiuro Volcanics east of the San Pedro River has been downdropped at least 5,000 ft from its position at the northern end of the Galiuro Mountains and was later buried by the Quiburis Formation (Krieger, 1968b,c). The change from low-angle gravity sliding and associated low-angle normal faults indicating major extension to high-angle normal faults indicating predominantly vertical displacement took place in the late Tertiary, as noted in Anderson (1971, p. 3534), in southwestern Nevada.

CONCLUSIONS

Structural features in the Winkelman 15-minute quadrangle are believed to have developed in the following sequence: Imbricate thrusts and related tears were formed in a flat environment and were later tilted, when an east-facing monoclinal fold developed a linear belt of steeply dipping to overturned Precambrian and Paleozoic sedimentary rocks. This folding, which began before but continued after deposition of the Miocene San Manuel Formation, developed other monoclinal folds to the north and northwest of the quadrangle. East-trending strike-slip faults separated the monocline in the Winkelman quadrangle into three en echelon segments. Some of this faulting apparently occurred after large areas of the San Manuel Formation became detached and moved over basement rocks on a low-angle gravity slide surface. All these structures are broken by north-trending high-angle normal faults.

The structural complexity of the area contrasts markedly with the structural features northeast of the Gila and San Pedro Rivers, as was noted by Ransome (1919, p. 82) and as can be seen in figure 2 and by examining published geologic maps of the area (see fig. 1 for references; also Wilson and others, 1969). Northeast of the rivers the beds are mainly gently tilted and intricately faulted; monoclinal flexures, where present, face both east and west. A major northwest-trending fault, approximately beneath the Gila and San Pedro Rivers, follows the boundary between the two blocks.

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PINAL COUNTY
LEGEND
Paved Road
Unpaved Road
River
Creek
Federal Boundary
Town
SCALE
MILES
INTERSTATE MAP CO.
118 NORTH BROWN ST.
SCOTTSDALE, ARIZ.
TONTO NATIONAL FOREST
CROOK NATIONAL FOREST
GILA COUNTY
MARICOPA COUNTY
PIMA COUNTY
GRAHAM COUNTY
SAN CARLOS INDIAN RES.
GILA RIVER INDIAN RESERVATION
PAPAGO INDIAN RESERVATION
PAPAGO INDIAN RESERVATION
CORONADO NATIONAL FOREST
SUPERSTITION MTNS.
SIERRA ESTRELLA
PALO VERDE MTNS.
SANTAN MTNS.
SACATON MTNS.
MESCAL MTNS.
TORTILLA MTNS.
GALIURO RANGE
BLACK HILLS
PICACHO MTNS.
SILVER REEF MTNS.
SAWTOOTH MTNS.
SIERRITA PRIETA
BITTER WELL MTNS.
TORTILLITA MTNS.
SANTA CATALINA MTNS.
APACHE JCT.
FLORENCE JCT.
SUPERIOR
SONORA
SNAKETOWN
MAGMA
SANTAN
SACATON
MARICOPA
FLORENCE
COOLIDGE
HAYDEN
WINKELMAN
DUDLEYVILLE
RANDOLPH
LA PALMA
STANFIELD
CASA GRANDE
NUNEZ
TOLTEC
ELOY
PICACHO
CHUICHU
WYMOLA
MONTROSE
RED ROCK
SASCO
FRIENDLY COR.
JACKRABBIT
COPPEROSITY
QU KOMELIK
ORACLE
ORACLE JCT.
MAMMOTH
TIGER
SAN MANUEL
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Drafted by FRANK GETSCHER

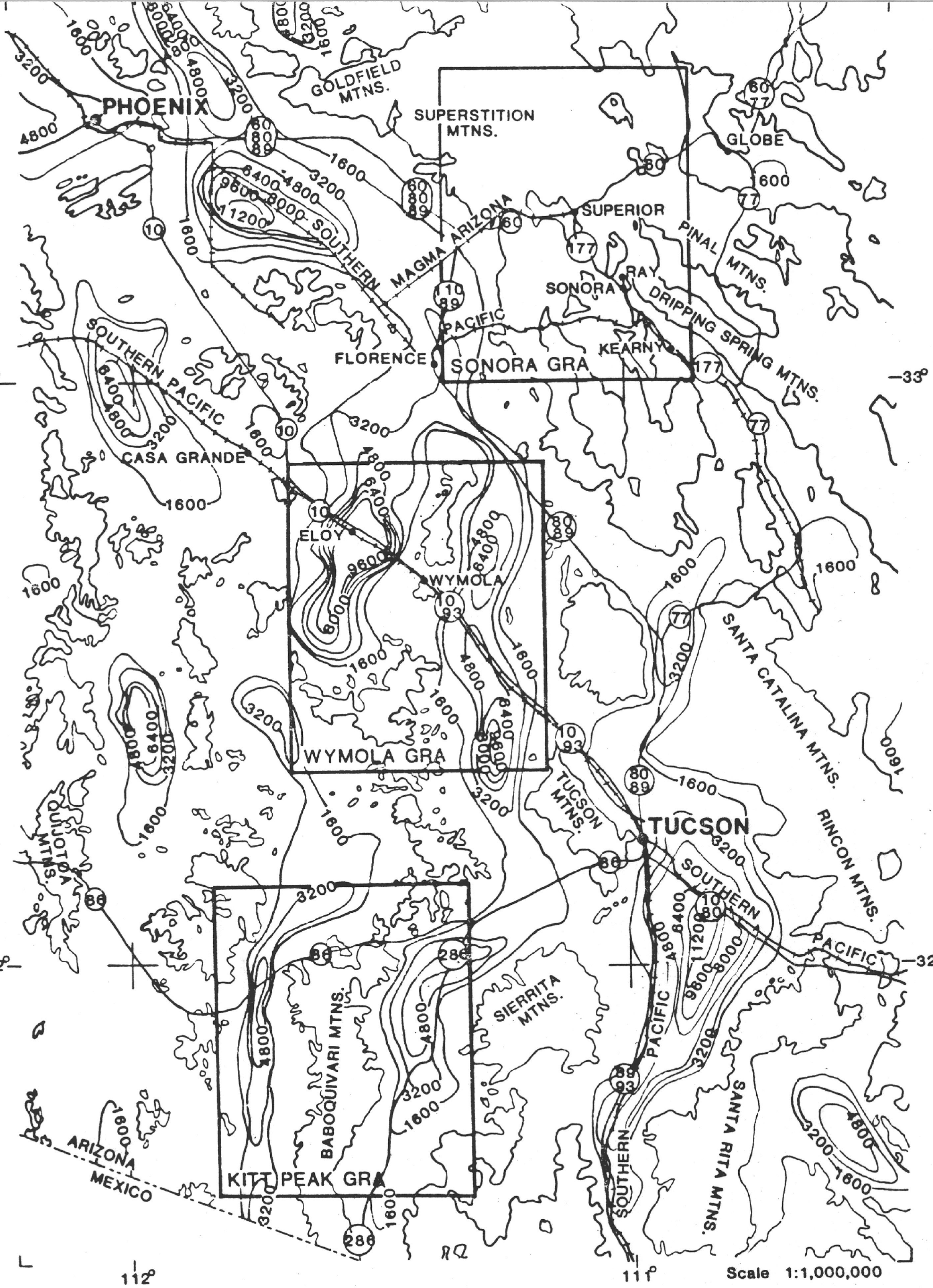

FIG. 1. **PHYSIOGRAPHIC MAP OF SOUTH-CENTRAL ARIZONA SHOWING LOCATION OF SONORA, WYMOLA AND KITT PEAK AREAS. Depth to bedrock contours, interval = 1600 ft., from Oppenheimer and Sumner (1980).**

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