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STRUCTURAL RECONNAISSANCE OF THE RED ROCK QUADRANGLE, ARIZONA

By

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Tucson, Arizona
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ILLUSTRATIONS

ABSTRACT

Geologic structures of the Red Rock Quadrangle, south-central Arizona, and their relation to the occurrence of ground water are discussed in this paper.

Lithologic units involved range in age from metamorphic rocks of possible pre-Cambrian age to Quaternary alluvium. The most prominent units consist of volcanic flows and clastic rocks of probable Cretaceous and Tertiary age.

A northwest-trending structural pattern, prominent in southeastern Arizona, is recognized in the Red Rock quadrangle. High-angle normal faults, possibly accompanied by gentle anticlinal arching or by over-thrusting, are believed to govern the outlines of the principal valleys. Where measured, the faults dip toward valley axes at angles up to 85°. Formation of three earth fissures in 1949 is described and hypotheses of their origin are cited.

Picacho Peak, a prominent landmark, is interpreted on petrographic evidence as a plug of Quaternary (?) basalt piercing volcanic rocks of probable Cretaceous and Tertiary age.

Occurrence of pediment areas carved on pre-Cambrian (?) metamorphic rocks and pre-Cambrian (?) granite is discussed in relation to occurrence of ground water. Supplies of ground water in quantities large enough to permit irrigation are believed to be present only in the valley of the Santa Cruz River, where Quaternary alluvium is the chief aquifer.

INTRODUCTION

Location

The Red Rock quadrangle includes the area between longitudes $111^{\circ}15'$ and $111^{\circ}30'$ west, and latitudes $32^{\circ}30'$ and $32^{\circ}45'$ north, approximately 250 square miles. The southeastern corner of the quadrangle is 28 miles northwest of Tucson, Arizona. State Highway 84 which approximately bisects the quadrangle from northwest to southeast, and a graded, unsurfaced road between the hamlet of Red Rock and the southwest corner of the quadrangle are the only well-maintained automobile routes within the area other than short paved or graded roads to military installations no longer in use. Ranch roads furnish access to most of the areas of rock outcrop within the quadrangle.

Irrigated farms are scattered along the Santa Cruz River Valley, and the remainder of the quadrangle is range land. Red Rock, Picacho, and the Marana Housing Unit are the only settlements with more than one or two families. Marana Basic Flying School (inactive in 1949) and two auxiliary fields are within the quadrangle.

Previous Investigations

There are only three published records of previous geologic investigation of this quadrangle: Reconnaissance mapping done by Carl Lausen and E. D. Wilson for the Geologic Map of the State of Arizona (1924); brief notes by G. A. Waring, published in a mimeographed bulletin, "Ground-water resources of the Santa Cruz Basin, Ariz.," by S. F. Turner and others, U. S. Geological Survey, Tucson, 1943; and "An earth fissure in southern Arizona," by R. J. Leonard, Journal of Geology, vol. 37, no. 8, pp. 765-774, 1929.

Purpose and Scope of this Investigation

Most of the field work upon which this report is based was done during July and August 1948 as part of a geologic study of the Eloy ground-water subbasin of the Santa Cruz River basin. Geologic work was carried on simultaneously with hydrologic studies of the irrigated areas, but the hydrologic data are not given in this paper.

The principal object of the investigation was to map contacts between rock outcrops and the unconsolidated alluvium of the valley areas, and major structural features that might bear on the ground-water problem. An attempt was made concurrently to obtain an over-all view of the geology of the area.

Physiography and Drainage

Unconsolidated alluvium blankets all but 30 square miles of the quadrangle. The highest part of the valley lands lies along the eastern boundary of the quadrangle, about 2,125 feet above mean sea level. The valley floor slopes gradually and uniformly to the west and northwest, and the extreme northwest corner of the quadrangle is slightly less than 1,600 feet above sea level.

The regularity of this pattern is interrupted by the Picacho Mountains, which rise precipitously from the valley floor to a maximum altitude of 4,508 feet at Newman Peak. Within the Red Rock quadrangle these mountains extend 4 miles almost due south from the northern boundary of the quadrangle. North of the quadrangle they continue for about 7 miles, narrowing in width and decreasing in altitude to a range of hills at their northern extremity. Slopes in the southern portion are steep, descending from 3,600 feet to 1,800 feet in about 1½ miles.

Some 2 miles farther south and just west of the center of the quadrangle, a range of hills about 3 miles long and half a mile to nearly 2 miles wide is dominated by Picacho Peak, a small angular volcanic neck that reaches an altitude of 3,382 feet. Owing to its relative isolation from other high land and to its bold and distinctive topography, Picacho Peak was a landmark before the Spanish conquest. It is recognizable from distances of 40 to 45 miles.

The southwestern corner of the quadrangle is occupied by irregularly scattered hills of which Cerro Prieto[1] is the highest (2,689 feet). These

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1/ This appears as "Cierro Prieto" on the topographic map. According to Dr. John Brooks, Department of Spanish, University of Arizona, there is no justification for the use of "Cierro" (an enclosure). It appears that the Spanish word "Cerro" (hill) was intended. "Cerro Prieto" signifies a black hill.

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hills are the northeastern outliers of the Silverbell Mountains, which extend about 15 miles southwest of the southern limits of the Red Rock quadrangle.

Four small isolated hills adjacent to the Picacho Mountains and Picacho Peak, and a range of low hills about a mile long and a quarter of a mile wide that lie athwart the eastern boundary of the quadrangle, make up the remaining known rock outcrops.

There are no permanent streams in the area nor, so far as is known, any springs that can be depended upon in periods of even moderate drought.

Drainage of the area is by a few intermittent streams whose courses are incised a few feet to 10 or 20 feet below the general ground level. The northeast part of the quadrangle is drained by McClellans Wash, which here flows from north to south. McClellans Wash turns sharply at the railroad and from that point flows northwest. It appears that the wash once flowed farther south, rounded the southeastern slopes of Picacho Peak, and then turned northwest along the line of the axis of the Santa Cruz River Valley. The change appears to have resulted from construction of the railroad embankment.

The Santa Cruz River enters the quadrangle along its southern boundary at about latitude 111°20' W. Although the river channel is shown on the quadrangle sheet as continuous, the river actually fingers out into distributaries that cross the Silverbell Road, interrupting traffic for several days at a time during periods of heavy rainfall. Los Robles Wash, parallel to and about a mile west of the Santa Cruz River at the southern boundary of the map is similarly erratic in channel and equally subject to intermittent flooding. Los Robles Wash drains the Avra-Altar Valley. This valley lies south of the Red Rock quadrangle, and west of the valley of the Santa Cruz River, from which it is separated by the Tucson Mountains.

Acknowledgments

The writer acknowledges with appreciation the company of H. N. Wolcott during 6 weeks of the field investigation. His stimulating companionship and helpful advice were of immeasurable value. The writer, however, assumes responsibility for the conclusions drawn and for whatever inaccuracies may appear in the text. Louis Watson assisted the writer for 2 weeks in the field. Ranchers and farmers in the area proved cooperative in every respect.

T. S. Lovering, Geologic Division, U. S. Geological Survey, interrupted a busy schedule to study and interpret thin sections from the Picacho Peak intrusive.

S. F. Turner, district engineer, Ground Water Branch, had general supervision over field work and with a party ran an electrical-resistivity probe to check an assumed fault.

The author is indebted to B. S. Butler, University of Arizona, E. D. Wilson, Arizona Bureau of Mines, Mr. Wolcott, and a committee of his colleagues for reading the manuscript. Their helpful suggestions have been incorporated in the final draft.

John P. Martin prepared the map and other figures accompanying the text. Other acknowledgments are made in the text.

ROCK UNITS

Sedimentary Rocks

Paleozoic (?) Rocks

Some mineral prospects along the base of Picacho Peak are in or adjacent to irregular, partly metamorphosed blocks of limestone in outcrops too small to map on the scale employed. The lithology of the limestone and the presence of numerous chert nodules, apparently original in it, suggest that the blocks are Paleozoic limestone broken from strata at depth and carried upward by rising magmas to their present position within the lavas.

Cretaceous (?) and Tertiary (?) Rocks, Undifferentiated

Near the southeastern tip of Picacho Peak is a small area of conglomerate and sandstone, apparently conformably interbedded with volcanic rocks. The beds consist of pebble and cobble conglomerates and arkosic sandstones. Their total thickness is approximately 300 feet. About 80 percent of these pebbles and cobbles consist of volcanic fragments that range in size from chips less than 1 inch in diameter to cobbles about 12 inches in diameter, and in shape from angular to well rounded. The remaining 20 percent of the fragments is made up of partly rounded slabs of micaceous schist 1 to 4 inches in diameter, brown or reddish-brown laminated quartzite similar to and perhaps belonging to the Bolsa quartzite (Middle Cambrian), scattered pebbles of coarse-grained pink granite, and laminated brown limestone.

Because the volcanic rocks are believed to be of Cretaceous and Tertiary age, the sedimentary beds are similarly designated. There is indication in drillers' logs of some of the wells in Santa Cruz River Valley that sedimentary rocks, tentatively assigned to the Tertiary system, lie below the valley alluvium. The well logs show that these strata consist of a few feet to a little more than 100 feet of hard clay, brown shale, or conglomerate. Records kept by the drillers are not sufficiently complete to reveal the stratigraphic sequence or to permit correlation of beds from one well to another. It is possible, however, that the sediments that crop out on Picacho Peak may be directly related to those encountered in wells beneath unconsolidated Quaternary alluvium.

Quaternary (?) Rocks

Two sequences of sediments tentatively assigned Quaternary age occur within the quadrangle. The older is a series of gray or buff sandstones with lenses of conglomerate, ranging in thickness from 4 to an estimated 200 feet. These sediments are exposed in a comparatively small area at the northeastern end of the Silverbell Mountains (fig. 2). A separate unit consisting of reddish conglomerate about 20 feet in maximum thickness overlies the sandstone. Locally the entire sedimentary sequence is represented by 4 to 10 feet of residual soil developed by weathering of underlying (Tertiary ?) volcanic rocks, and overlain by a basaltic flow breccia of probable Quaternary age. Their stratigraphic position leads to tentative assignment of the strata to the Quaternary, probably the Pleistocene.

~~It is believed that these strata~~ developed during a pause in volcanic activity in the area, during which an erosion surface of considerable relief was formed on the underlying volcanic rocks. In localities where the sedimentary section is thickest the base is not exposed; hence, exact relationships have not been determined. It is possible that raising of small blocks of volcanic terrain along fault zones during the assumed erosion interval contributed to the variations in thickness among the several exposures. Detailed study may show their equivalence to lake beds of Pliocene age that occur in the San Pedro River Valley (Moore and Tolman[2]).

2/ See references at end of paper.

Two specimens from these strata were examined under a binocular microscope. One sample, taken about 50 feet below the top of the section, showed an estimated 95 percent of quartz, mostly colorless, and 5 percent of biotite, magnetite, and limonitic grains. The larger grains (about 2 mm.), in general, are subangular to well rounded, whereas the smaller grains are consistently angular. A considerable part of the sample was silty. No reaction with dilute hydrochloric acid was detected.

The second sample examined was from the conglomeratic phase about 10 feet from the top of the section. Grains larger than 2 mm. are, in general, rounded to subangular and consist mainly of quartz. Some fragments of granite and of various volcanic rocks were found within the 2-mm. range, but for the most part rock fragments were limited to the pebble range. Calcareous cement was present.

Accurate determination was not attempted, but the appearance of these sediment suggests that some of the fine-grained angular material identified as quartz in both specimens actually consists of shards of clear volcanic glass.

The younger sequence of Quaternary sediments includes the unconsolidated or poorly consolidated alluvium that mantles the major part of the Red Rock quadrangle. The maximum thickness of the material is not known. Available well records indicate, however, that the younger Quaternary alluvium reaches a depth of about 400 feet a mile northeast of the Silverbell Mountains, in the SE¼SE¼ sec. 12, T. 10 S., R. 8 E.,[3] where the driller reported "porous rock" at 377

[3] Township and range designations are referred to the Gila and Salt River Base line and meridian.

feet, and "malpais" at 400 feet. At Marana Basic Flying School, in the NW¼SE¼ sec. 34, T. 10 S., R. 10 E., a well was completed at 506 feet without passing out of alluvium. At Eloy Farms, in the SE¼SE¼ sec. 25, T. 9 S., R. 8 E., the log showed alluvium to the bottom of the hole at 600 feet. No records of deeper wells in the quadrangle are known.

Igneous Rocks

Intrusive Rocks

Pre-Cambrian (?) rocks.--The extreme southwestern corner of the Red Rock quadrangle is occupied in part by a pediment surface of pink or, locally, gray porphyritic granite. The ground mass is coarse-grained normal granite in which appear orthoclase phenocrysts about an inch in diameter. No apparent difference in structure or texture of the rock accompanies the color changes. Aplitic phases were observed, but they are small in area. This granite extends for several miles to the south and southeast.

The geologic map of Arizona does not show granite cropping out at the northeastern margin of the Silverbell Mountains. The map does, however, show a granite assigned pre-Cambrian age farther south in the Silverbell Range. No relationships were observed in the Red Rock quadrangle that would establish the age of the granite, but it is assigned to the pre-Cambrian (?).

Quaternary (?) rocks.--There are three types of small intrusive bodies in the quadrangle that are tentatively assigned Quaternary age. At the southwestern corner of the quadrangle a dike of gray andesite porphyry has been intruded into Quaternary (?) volcanic rocks. The dike ranges from 50 to 75 feet in width, strikes about N. 45° W., and is vertical. It has not been traced from the lavas into the granitic pediment, but is known to continue southeast, off the limits of the Red Rock quadrangle, for at least a mile.

Several outcrops of diabase, too small to map on the scale used, are exposed in gullies that cut back into the Silverbell Mountains, notably in the S½ sec. 29, T. 10 S., R. 9 E. The rock weathers rapidly and exposures are poor.

Numerous dikes and small intrusions of basalt and diabase occur in the

Picacho Mountains, though only a few are found within the quadrangle. In several areas north of the quadrangle, basalt dikes were observed to continue as flows over an erosion surface developed upon metamorphic rocks.

The central spire of Picacho Peak is a small angular mass of olivine basalt, apparently a volcanic plug. It is about 1,000 by 2,000 feet in horizontal dimensions and 500 feet high.

Extrusive Rocks

Cretaceous (?) and Tertiary (?) rocks, undifferentiated.--The larger part of Picacho Peak consists of a series of basic to intermediate lava flows, tuffs, and agglomerates. A thickness of 1,200 feet was estimated for the exposed part of a series of flows occurring between unconsolidated alluvium at the base of the peak and the base of the central intrusive spire on the south flank of the peak.

Tentative assignment of Cretaceous and Tertiary age for these rocks is made by analogy with similar rock series in southern Arizona. Schrader (1915, pp. 70-75) described lavas of both Cretaceous and Tertiary (Miocene ?) age, characterized, in general, by increasingly acidic composition upward in the column. Quaternary volcanics of southern Arizona are generally andesitic or basaltic.

Brown (1939, pp. 713-714 and 729-738) described an estimated 4,000 to 4,500 feet of volcanic rocks in the Tucson Mountains, almost equally divided between the Cretaceous and Tertiary systems. The Cretaceous sequence includes intermediate flows, principally andesite, and andesitic tuffs and agglomerates, which resemble the volcanic materials that form most of Picacho Peak. It appears, however, that the volcanic sequence of Picacho Peak is, on the average, somewhat more basic in composition than are the rocks in the Tucson Mountains. The analogy does not appear to warrant more than tentative assignment to the Cretaceous or Tertiary, or both.

Quaternary (?) rocks.--An estimated 900-1,000 feet of Quaternary (?) volcanic rocks is exposed in the northeastern part of the Silverbell Mountains, overlying the Quaternary (?) sediments described earlier in this paper. This sequence consists for the most part of basic to intermediate flow material with only minor amounts of fragmental rock. The sequence as it appears on Cerro Prieto is illustrated in figure 2. In the hills west of Cerro Prieto the lower part of the flows is not exposed. Instead, overlying a basalt that is correlated with the flow that tops Cerro Prieto, there is an alternating series of three red scoriaceous layers and three black basalt layers approximately 200 feet in total thickness (fig. 3). Owing to the rapid erosion of the scoria and the greater resistance of the basalts, a knob topography is created that, from a distance, suggests intricate structure. Actually the structure is simple.

The volcanic section is not uniform throughout the part of the Silverbell Mountains that lies within the area are discussed. North of the Silverbell Road (fig. 1) a black basaltic flow breccia directly overlies the sediments. South of the road the sediments are directly overlain in most outcrops by about 250 feet of red basalt and scoria. The scoria, in turn, is overlain by a black flow breccia that appears to be identical with that at the base of the volcanic sequence in the hills north of the road. The scoria that underlies the flow breccia south of the road is distinguised by the presence of almost perfectly spherical vesicles, with a diameter of at least 1 inch in numerous observed examples.

The presence of spherical vesicles in the red scoria and absence of red basalt north of the road suggest the possibility that, at the time the red basalt and scoria were extruded, the area north of the road stood higher than that south of the road. Approximately on the line of the present road there was perhaps a scarp toward which the red basalt advanced from the south. The flow, dammed against that scarp, ceased moving before cooling of the flow, and permitted gas bubbles to assume spherical form.

Three small areas of basaltic flow material between Picacho Peak and the Picacho Mountains are probably Quaternary. The northernmost of the outcrops occurs as a small platter at the crest of a spur of metamorphic rocks projecting southwest from the Picacho Mountains in the SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 36, T. 8 S., R. 9 E., at an altitude of about 2,400 feet above sea level. A mile and a half southwest, an isolated hillock stands about 50 feet above the surrounding alluvial plain, straddling the 1,800-foot contour. A somewhat larger hill rises about 150 feet above its surroundings, likewise on the 1,800-foot contour near the northernmost tip of Picacho Peak, in the NW$\frac{1}{4}$ sec. 9, T. 9 S., R. 9 E.

The rocks composing the three outcrops are impressively similar. Included are both flow material of basaltic composition and basaltic flow breccia. They are almost identical in appearance and probably are equivalent in age to basic flow breccias occurring farther north at the base of the Quaternary (?) volcanic series.

Metamorphic Rocks

Pre-Cambrian or Tertiary (?) rocks

Outcrops of metamorphic rocks, other than limited contact-metamorphic zones occur only in the Picacho Mountains and outliers. Granitic gneiss, much of it high in biotite, forms the main mass of the mountains with small areas of more acidic gneiss, almost lacking in dark minerals. An occasional band of micaceous schist was observed.

Rocks of similar character make up the hill that lies off the southeast corner of the Picacho Mountains about a mile from the main range. Approximately 7 miles southeast of this outlier, on the eastern boundary of the quadrangle, there is another low range of hills of similar but somewhat more acidic composition. Small dikes of pegmatite occur, trending approximately east.

The sedimentary origin of these metamorphic rocks is indicated by bands of white quartzite and a clearly defined zonal sequence of hard and soft, coarse-grained and fine-grained layers analagous to original bedding. There is a suggestion of relict cross-lamination on some weathered surfaces.

The prevaling strike of schistosity ranges from north along the backbone of the ridge to N. 20° E. at the north end. The dip of the schistosity ranges from 60° to 80° W. or NW.

No evidence is available as to the age of the metamorphic rocks in the Red Rock quadrangle. Most of the metamorphic rocks in central and southern Arizona are considered to belong to the Pinal schist and related rocks of pre-Cambrian age, probably equivalent to the Vishnu schist of the Grand Canyon. On the other hand, Moore (Moore and Tolman, op. cit.) assigned many of the gneisses and schists of the Tortolita and Santa Catalina Mountains, the next two ranges southeast of the Picacho Mountains, to the Tertiary (?) system.

STRUCTURE

General*

The pattern of dominant structures striking approximately northwest, now familiar to geologists working in southern and central Arizona, is well displayed in the Red Rock quadrangle. The trend finds expression in a number of high-angle faults that are believed to govern to an important degree the physiography of the area. The pattern is modified and complicated by numerous high-angle faults that strike about normal to the dominant northwest trend. A few of the faults show displacement measurable in hundreds of feet but most are of smaller displacement. Other faults of small to moderate displacement are variously oriented, especially in the Silverbell Mountains. Only a part of the faults observed in the field have been plotted, owing to the reconnaissence nature of the investigation and the small scale of the base map.

The lowest dip angle measured on a fault was 50°. This was in the Silverbell Mountains on a fault of small displacement striking N. 15° E. and dipping to the southeast. The lowest dip angle measured on Picacho Peak was near the northwestern end where a prominent break strikes N. 15° W., and dips 73° SW. All the faults of larger displacement appear to be within a few degrees of vertical.

A fault of at least 650 feet of throw is believed to account for the presence of a platter of Quaternary (?) basalt on the outlying hill near the southeast tip of the Picacho Mountains. These relationships are illustrated in cross section A-A' (fig. 4) and on plate 1, A.

Picacho Mountains

The northwest regional trend is reflected in the strike of two mineralized veins in secs. 21 and 24, T. 8 S., R. 9 E., the latter at the Gold Bell Mine. The same trend appears in much of the schistosity of the metamorphic rocks in the Picacho Mountains, though complex local variations in schistosity were noted.

The topography of the Picacho Mountains suggests that their structural development may diverge markedly from the regional pattern. The comparatively straight east and west margins of the mountains suggest the possibility of strong controlling structures bounding the range and striking roughly north. The strike of the fault referred to earlier, section A-A', (fig. 4), was not determined. One strong suggestion of a northwest fault structure is found in a pair of reentrant valleys that have northwest-trending axes and that separate the hill, lying mainly in sec. 28, T. 8 S., R. 9 E., from the main mass of the mountains.

Various joint patterns appear in the Picacho Mountains. The most striking is a horizontal set that affect many of the exposures of metamorphic rocks on the steep southern face of the range. Viewed from some distance, the jointing is so pronounced as to give the impression that the mountains are composed either of horizontally bedded sedimentary rocks or of a series of thin horizontal lava flows. So far as is known, all rocks affected by the horizontal joint set are metamorphic, and the jointing has no direct relation to original structures.

It is probable that there were earlier periods of deformation than that which displaces the Quaternary basalt of the Picacho Mountains, but the present investigation was not sufficiently detailed to reveal the older structures.

<u>Picacho Peak</u>

Because of petrographic evidence, a part of Picacho Peak is interpreted as a basalt mass intruded into a sequence of intermediate to basic flows that dip 20° to 30° toward the intrusive mass (fig. 5, A, B,). Perhaps the most unusual feature of the relationship lies in the strongly angular shape (in plan) of the intrusive (fig. 1). Field relationships and evidence suggestive of faulting led to the author's original interpretation of the structure as a small block of flow material lifted above the level of surrounding flows along four bounding faults. The presence of a basalt breccia separating the central spire of Picacho Peak from the flows, and slickensiding on the near-vertical face of the spire, supported this interpretation.

An oriented specimen was taken in the field from a niche in the vertical face of the central mass and oriented thin sections were prepared (fig. 5, B). These were examined only for evidence of movement by T. S. Lovering,[4] to whom

[4] Lovering, T. S., oral communication, March 1949.

the author is indebted for the interpretation here presented.

Thin sections 1, 2, and 3 (fig. 5, B) were first prepared. Lineation of feldspar laths throughout these slides indicated that the movement of basaltic magma in the volcanic vent, just prior to consolidation of the rock in the vent, was such that the plane of flow would strike about N. 65° E. and dip about 85° NW. The figure for dip was derived by resolution of the dip components shown on the south and east faces of the sawed block. This relationship was later essentially confirmed by preparation and examination of two additional slides, nos. 4 and 5. Slide 4 was cut as nearly as possible to the plane of flow as interpreted from the first three slides examined. Slide no. 5 was taken in a horizontal plane. Allowing 10° for field error, it is believed that, at the point where the hand specimen was taken, movement of magma in the dying volcanic vent was oriented along a plane striking N. 60°-70° E. and dipping 80°-85° NW.

The rock composing the central spire of Picacho Peak is a nearly aphanitic dark greenish-gray basalt. No phenocrysts were seen and only a few amygdules of soft white calcite were observed.

Under the microscope the rock was identified as an olivine basalt consisting of a mass of small plagioclase laths that show pronounced flow orientation, interstitial mafic minerals in minute grains, and subhedral to euhedral phenocrysts of olivine. Olivine grains make up only about 1 percent of the rock. The feldspar laths have been sericitized to such an extent that specific identification was not possible.

Irregular masses of calcite reaching diameters of 1 to 2 millimeters occur throughout the slides. These calcite masses are partly replaced by quartz. Quartz is also found in veinlets that, in general, trend within 10° of due east, although this relationship is not rigidly constant. Several veinlets were observed to terminate against masses of calcite in which partial replacement of calcite by quartz had taken place.

No fresh olivine grains were found. The original olivine is identifiable primarily from the characteristic shape of the grains.

It has largely been replaced by a quartz mosaic, although rims of original olivine or of olivine altered to iddingsite remain about the quartz in some grains.

In general, the rock shows the effect of considerable alteration. The outlines of feldspar laths remain clear despite the fact that the feldspar for the most part has been altered to sericite. A distinctly lesser amount of alteration to chlorite was observed. There are local areas, many of them adjacent to masses of calcite, where the rock has weathered to clay. No clay masses with a diameter of more than about 1 millimeter were observed.

The relationships described above suggest the following sequence of events: solidification of basalt in the volcanic vent; sericitization and chloritization; introduction of calcite; introduction of quartz; weathering, including formation of clay.

The sharply ridged and serrated topography of the group of hills referred to at Picacho Peak is believed to be governed by two major fault sets. The faults with greater displacement trend approximately N. 45° W. and are almost vertical. Five step faults have been mapped, two on the southwest and three on the northeast side of the peak, and they have raised a central block at least 1,400 feet above most of the surrounding terrain.

The relation between faulting and the basalt plug discussed above is not clear. It may be that the scarp faces bounding the intrusive result entirely from removal of the dipping flows that originally constituted the cone. It may be that the original cone extended somewhat higher than the present summit of the spire, and that subsidence of the area immediately surrounding the solid basalt plug took place at some time after cessation of volcanic activity, the walls of the former vent providing zones of weakness along which the rocks yielded. This follows the general pattern of a small collapse caldera, except for the presence of a stable central mass of solid basalt. This hypothesis is supported by the fact that flows on at least two sides of the central spire dip inward toward the spire. By tracing the oxidized tops of flows, it becomes apparent that the block immediately southeast of the intrusive stands about

200 feet higher, relatively, than the block immediately southwest of the spire, the two being separated by a vertical fault that strikes N. 20° E. On the southeast block the flows strike N. 20° E. and dip 30° NW. On the adjacent (southwest) block, flows strike N. 50° W. and dip 20° NE.

Another explanation for the central spire may be considered. It is conceivable that the basalt solidified in the vent during the dying stages of activity of the volcano and was then partly extruded as a solid spine. The formation of spines of this nature is normally associated with acid volcanic rocks rather than with rock as basic as that of Picacho Peak. Day and Allen (1925, pp. 33, 34, 40), however, discuss the possibility of a comparable but less extreme movement of a solid andesite plug in the main crater of Mt. Lassen during the eruptions of 1915.

A second, and probably later, series of faults strikes from N. 15° W. to N. 30° E. These faults are greater in number but smaller in throw than those which trend northwest. The second set of faults is believed to govern the sharp serration of the ridge. They are too numerous to map on the scale employed in this investigation. Only the most prominent are shown. Most of these faults are vertical. One, however, was observed to dip about 75° SW.

An electrical-resistivity probe was run by S. F. Turner and party in the SW¼ sec. 22, T. 9 S., R. 9 E., beginning on the edge of lava outcrop and extending southwestward across valley fill. The effective depth of penetration was 600 feet. The resulting curves indicate a sharp change in resistivity at about the point where an assumed fault had been mapped on physiographic evidence. It is believed that, so far as the geophysical data go, they support the concept of a fault striking approximately N. 45° W., which bounds the range on the Santa Cruz Valley side.

On the assumption that the youngest rocks affected by faulting are Quaternary, structural movement must have taken place in Quaternary time. The assumption of late Pleistocene or Recent movement finds support in the little-dissected fault scarps visible at several points along the ridge.

Silverbell Mountains

A complex fault patterncan be traced throughout the Silverbell foothills. It affects all rocks in the area and some movement must, therefore, have taken place in Pleistocene or Recent time.

With one possible exception discussed below, all faults noted dip at angles ranging from 50° to vertical. Two strong faults trend generally northwest. One marks the southwest boundary of the range of hills north of the road, the other, perhaps continuous with the first, controls the steep northeast slope of Cerro Prieto and probably forms the northeast boundary of the hills that lie just east of Cerro Prieto. A second set of faults trends northeast. These are more numerous than the northwest-trending faults but appear to be of smaller throw. They are clearly marked by displacement of recognizable units in the volcanic sequence, by zones of brecciation exposed in small gullies, and by the physiography.

In the southwest corner of the area, granite crops out in the valleys and volcanic rocks form the higher country. The volcanic rocks show much sheeting brecciation, and oxidation, especially within a flat-lying zone about 10 feet thick that is exposed in some of the washes in the area. A dip of 10° to 15° SW. is suggested. Exposures are so discontinuous and small, however, that detailed study was not possible.

The red basalt forming most of the southwesternmost hill shown on the geologic map has been sheeted, the partings dipping southwest from 15° to 55°. The crest of the same hill is marked by a vertical dike of gray andesite porphyry about 50 to 75 feet wide. The dike has been offset horizontally in several places, but in only one place on a scale large enough to show on the map (fig. 1; width of dike exaggerated on map to show structure). Each successive block has been moved toward the northeast relative to its neighboring block on the northwest.

In the valley immediately east of the hill just described, granite is exposed from the base of the hill to the axis of the valley. Granitic material appears locally as cliffs, each about 5 feet high. These outcrops are crumbly and show irregular bands, about half an inch thick, that are parallel in strike to the upper margin of the outcrop. Flat surfaces dip about 50° SW. The mineral grains composing the rock are notably angular and little decomposed. It is not clear whether these outcrops represent blocks of granite picked up with the surrounding volcanic materials during overthrusting, or whether the rock results from slope deposition and cementation of mineral grains derived by weathering from underlying granite. In some localities basalt appears on the slope above the granitic cliffs and basalt of a different aspect is present in pockets below. Granitic material can be traced, with interruptions due to overwash of volcanic debris, from a low hill of solid granite in the center of the SE¼ sec. 36 to a point well around the south slope of the hill, outside the map area. A comparable low granite hill lies in the NE¼SE¼ sec. 35. At the northern end of the hill a nearly vertical fault strikes about northwest. The southwestern block is downthrown. Along this fault, granite on the northeast is in contact, at the present ground surface, with volcanic rocks on the southwest block.

Relationships outlined in the preceding paragraphs suggest two possible interpretations. One is that an erosion surface of relatively low relief was created on granite of pre-Cambrian (?) age. Debris accumulated on slopes close to its place of origin in fragments approximating single mineral grains in size and was cemented into a slope deposit displaying a generally sheeted texture. Early basalt flows filled hollows on the granite landscape but left some hills of granite exposed. These granite hills were covered by later basalt flows that spread across the surface of both the hills and the basalt-filled pockets. Such a sequence of events would account for those localities where "sheeted granite" lies on slopes with volcanic material both above and below. At some still later time, high-angle faulting brought fresh granite into contact with volcanic rocks, as described earlier.

Another possibility is that some of the volcanic rocks in the southwestern corner of the Red Rock quadrangle have been overthrust upon a granite basement, and that the low cliffs of "sheeted granite" are imbricate blocks incorporated within the lower zones of the volcanic sequence during overthrusting. Under this interpretation, the consistent trend of dips of sheeting planes in the volcanic rocks toward the southwest suggest overthrusting from the southwest toward the northeast. The hypothesis would explain the horizontal displacement of the vertical andesite porphyry dike by tear-faulting in the overthrust block, and the flat-lying zone of brecciation and oxidation, described earlier would be the sole of the overthrust.

Extension of reconnaissance mapping south and southwest of the Red Rock quadrangle by H. N. Wolcott and F. L. Turner[5] has not disclosed any evidence

5/ Oral communication, 1948.

of overthrusting in the part of the Silverbell Mountains north of the El Tiro Mine.

Indications of Valley Structure

The northwest trend of major high-angle faults at Picacho Peak and in the Silverbell foothills coincides with an apparent regional structure pattern that is displayed on the geologic map of Arizona by marked northwest alignment of mountain ranges and major valleys. It is probable that in the Red Rock quadrangle such faults determine the margins of the Santa Cruz Valley both on the southwest and, in part, on the northeast. The inference is that the broad intermontane valley is, in part, a stepped graben trough or a ramp valley, depending on whether the undetermined absolute movement involved dropping of the valley blocks or raising of the bordering mountain masses.

The relationship between the hills at the northeastern tip of the Silverbell Mountains and Picacho Peak requires more study. If additional investigation makes possible a correlation of some of the volcanic flows in the two localities, then several structural possibilities may be postulated. It is noteworthy that on the southwestern side of Picacho Peak most of the volcanic rocks, and the interbedded sedimentary strata as well, strike about N. 50° W. and dip northeast. In the Silverbell foothills, although the structure of the rocks is complicated by intricate faulting, it can be seen that the over-all trend is toward northwest strikes, and dips at relatively low angles, averaging about 20° SW.

Assuming that the sequence in the Silverbell foothills can be correlated with some of the flows of Picacho Peak, three possibilities may be advanced to explain the relationships. These are represented in figure 6, A, B, C, as structure sections along the line B-B' on figure 1, matching key flows being assumed.

Figure 6, A, diagrams the possibility that Picacho Peak is a remnant of a once-continuous volcanic sheet overthrust upon a granite basement, and subsequently broken by high-angle northwest-trending faults, to produce a stepped graben or ramp valley.

A second possibility is diagrammed in figure 6, B. Here Picacho Peak is pictured as a remnant of the northeast limb of a broad faulted anticline, the Silverbell foothills representing the southwest limb of the arch. The broad valley through, in this hypothesis, occupies the area where erosion has removed the crest of the anticline. It is highly probable that northwest-trending faults in part govern the location of the valley margins and make possible the known thickness, in excess of 600 feet, of unconsolidated valley alluvium.

A third possibility is that the divergent dips in the Silverbell Mountains and on Picacho Peak result from rotation on high-angle faults bounding what is essentially a simple stepped graben or ramp valley. This interpretation is illustrated diagrammatically in figure 6, C.

Each of the three interpretations offered above includes as an important factor high-angle northwest-trending faults, the presence of which is established. The reconnaissance nature of the investigation here reported leaves the remainder of the structural interpretation within the realm of speculation.

Recent Earth Fissures

On the night of September 14-15, 1949, a 3-mile-long series of earth fissures formed about 2 miles west-southwest of the Picacho Mountains. The trend of the fissures was generally parallel to the west front of the mountains. The occurrence was first reported by the Arizona State Highway Department when a crack 3 to 6 inches wide opened across State Highway 84. The break in the highway asphalt was part of the central one of three subparallel, discontinuous earth cracks.

The occurrence was examined on September 20 by E. D. Wilson, Arizona Bureau of Mines, on September 30 by L. A. Heindl and O. B. Coulson, Ground

Water Branch, U. S. Geological Survey, and on October 27 by B. S. Butler, University of Arizona, and the writer. The following description combines the results of the three observations.

The southwest end of the trace of the fissures was found about 0.3 mile south of the center of sec. 31, T. 8 S., R. 9 E. (fig. 1). Here the crack was 0.15 mile long, striking N. 37° E.

The central trace began at a point 0.25 mile north of the center of sec. 31 and extended about a mile to a point a little north of the center of the east boundary of sec. 30, T. 8 S., R. 9 E. The average strike was N. 25° E. The third fissure trace began 0.2 mile south of the General Land Office quarter-corner monument on the line between secs. 18 and 19, T. 8 S., R. 9 E., and trended N. 8° E. for 0.9 mile.

As may be seen (fig. 1), the result is a rude en echelon arrangement of three subparallel traces, two about a mile long, the third only 0.15 mile long. Toward the west the over-all pattern is slightly concave; toward the north, it shows a tendency toward increasing parallelism between the trace of the fissures and the western margin of the Picacho Mountains. The course of each fissure was zig-zag and irregular in detail, but the general trend was quite constant.

The fissured zones are closely similar in appearance and, typically, trend nearly at right angles to the drainage. The area is one of little relief and is mantled with fine-grained flood-deposited sediments. Vegetation is sparse and consists of low-growing grasses, weeds, and bushes characteristic of the southern Arizona desert.

No vertical or horizontal displacement could be detected at any point along the fissures. Locally, however, blocks of earth as much as 10 feet long and a few inches to about 2 feet wide were dropped vertically into the openings to a depth of 6 inches to about 4 feet. Slumping was common along both margins of the fissures. Irregularly semicircular areas of slumping, $1\frac{1}{2}$ to 6 feet wide, were depressed a few inches to about a foot, the outlines of the semicircles being marked by scalloped patterns and vertical walls (pl. 2, C).

So far as could be observed, the fissures were vertical. The deepest probing by Wilson, went to 10 feet on September 20 (Arizona Daily Star, 1949, p. 2A). It is probable, however, that examination immediately after the fissures opened would have resulted in deeper penetration. On October 27, after two heavy rains had fallen over the area, there were indications that locally the fissures were acting as sinkholes, conducting surface runoff to a considerable depth. At other points along the fissures the outlines were becoming blurred and the bottom was beginning to fill with sediments washed in or slumped in from the walls.

The fissures ranged from simple open cracks a quarter of an inch to 36 inches wide to zones of fracture as much as 6 feet wide and containing as many as 15 individual cracks, which in most places coalesced to form a reticulated pattern (pl. 2, A and B). Three cracks were observed transverse to the central fissure, two trending southeast and the third northwest. These cracks ranged from 25 to 40 feet in length and near the junction with the main fissure showed a fracture zone and network of intersecting cracks comparable to those of the main fissure.

The fissures died out in a similar manner; central fissures became narrower, and secondary cracks disappeared. Finally the main cracks disappeared in the mud-crack pattern of the playalike deposits.

It is noteworthy that in 1927 a comparable fissure opened in what is thought to be the same place as the central one of the three fissures that appeared in 1949. R. J. Leonard (1929) reported that the earlier fissure was 1,000 feet long, 1 to 6 inches wide when newly formed, 2 to 3 feet wide after slumping had occurred, and up to 15 feet deep. The coincidence of location of the 1927 fissure with that of 1949 where it crosses the highway and railroad is indicated by Leonard's statement (p. 765) that the locality was 3 miles southeast of Picacho station on the Southern Pacific Railroad. The statement was confirmed from memory by Wilson and Butler[6] who saw both the 1927 and 1949

[6] Wilson, E. D., and Butler, B. S., oral communication, 1949.

earth cracks.

Basing his conclusions on the record of an earth tremor centered 170 miles from Tucson on the night of September 11, 1927, when the fissure opened, on simultaneous development of cracks underground at El Tiro Mine, Silverbell Mountains, about 20 miles from the fissure, and on the absence of evidence pointing toward another origin, Leonard (pp. 769-770) concluded that the fissure of 1927 opened as a result of structural strain in partly consolidated basin-fill material induced by vibrations set up by an earthquake at some distant point. Other possible causes of fissuring, considered unlikely by Leonard, were: (1) subsidence over a cavity and (2) readjustment of underlying rock. He tentatively adopted the possibility of earth vibrations, caused by a distant earthquake that occurred at the time the fissure appeared, in combination with stresses hypothetically preexistent in the valley fill.

William K. Cloud, Seismological Field Survey, U. S. Coast and Geodetic Survey, examined the 1949 fissure in the field, and examined seismograph records for the period during which fissuring might have occurred. He concluded[7] that seismic origin for the 1949 crack apparently could be ruled

[7] Cloud, William K., personal communications, 1949

out, and suggested that fluctuation of the water table might be the cause.

S. F. Turner[8] suggests the possibility that the fissuring resulted from

8/ Oral communication, 1949.

strains set up by subsidence of unconsolidated and weakly consolidated valley-fill materials off the edge of the buried pediment. He hopes, as time permits, to make a series of geophysical probes across the fissures near Picacho, and across comparable cracks in alluvium discovered near Pomerene and Willcox, Ariz. in 1948. It is possible that this type of investigation will yield definitive results in the search for an explanation of the earth fissures.

The absence of any detectable displacement, vertically or horizontally appears to rule out the probability of fault movement, at least on any significant scale, in the underlying bedrock. The rude en echelon arrangement of the fissures would, however, favor a fault interpretation. It is possible that gentle doming of the area would result in tensions that might cause fissures such as appeared in 1927 and 1949.

OCCURRENCE OF GROUND WATER

Favorable localities for the development of appreciable supplies of ground water indicated by the geologic reconnaissance of the Red Rock quadrangle are those relatively near the axis of the Santa Cruz River Valley and those in the northwest corner of the quadrangle north of Highway 84 and west of the line of earth cracks (fig. 1). The important aquifer is unconsolidated alluvium, presumably of late Tertiary and, at the surface, of Quaternary age.

According to records in the office of the Ground Water Branch, U. S. Geological Survey, Tucson, Ariz., and information obtained from ranch and farm owners during the investigation, alluvium has been penetrated by wells to depths of 600 feet. Individual wells in the Santa Cruz Valley ranging in depth from 400 to 600 feet produce an early-season maximum of about 3,000 gallons per minute and an annual irrigating-season average approaching 2,500 gallons per minute.

Too few wells have been drilled in the area north of the highway and east of Picacho Mountains to provide definitive date on production possibilities for that section of the Red Rock quadrangle. However, wells of the Clemens Cattle Co., east of Picacho Mountains, yield only small quantities of water from depths of as much as 600 feet. The main supply of stock and ranch water in this area comes from wet-weather springs on the lower mountain slopes, and from catchment of surface runoff in earth tanks. At the time this investigation was made (July-August 1948) runoff had been below normal. Most of the tanks were dry, and the range had been temporarily abandoned, except for a few head of cattle and horses in the foothills of the Picacho Mountains and in the areas immediately adjacent to range camps where small supplies were pumped from wells.

Eleven miles north of the railroad, in the extreme northern foothills of the Picacho Mountains, a pediment formed on granite and metamorphic rocks extends for about 1½ miles from the base of the mountains to the contact with the valley fill. The smoothly sloping contours extending east, south, and west from the base of the Picacho Mountains within the Red Rock quadrangle suggest the possibility that a rock pediment may exist continuously around the exposed mountain mass. Existing wells have not penetrated deeply enough to reach bedrock if it is present as a suballuvial platform. If such a rock slope exists, it should logically limit the depth of effective drilling for water, for the rock making up the Picacho Mountains is poorly suited to receive or yield water in quantity. The pediment surface would probably control a local perched water table, concentrating what water is present in overlying sand and gravel along the rock-alluvium contact.

Owing to drought, there was no opportunity for observation of temporary seeps and springs in the mountains.

The easternmost well of the Clemens Cattle Co. lies about 4 miles from the Picacho Mountains. From that point to the eastern boundary of the map, in the area north of the highway, few wells have been constructed. There is a hole, apparently intended as a dug well, at the northeast tip of the low hills that straddle the eastern boundary line. The hole reached an estimated depth of 50 feet and encountered metamorphic rock. The hole was dry when visited.

The hills just mentioned may be high points on an ancient erosion surface carved on metamorphic rock and extending continuously from the Picacho Mountains east and southeast to the Tortolita Mountains. The Tortolita Mountains are composed largely of metamorphic rocks comparable to those of the Picacho Mountains and the low hills. Wells in the valley extend 600 feet into the unconsolidated alluvium, as noted earlier, without bottoming in solid rock. At least 800 or 1,000 feet of relief is suggested, partly erosional and partly structural.

There is record of only one well within a mile or two of hard-rock outcrop adjacent to Picacho Peak. This well is at the Arizona State Highway Department camp on the highway, about at the midpoint along the peak. Highway Department records[9] show:

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[9] Layn, M., Arizona State Highway Dept., personal communication, 1948.

Total depth of well	220 feet
Depth to standing water level	186 feet
Capacity	no drawdown with bailer (no record of pumping tests)

"The well is lava rock at bottom. The water was in volcanic cinder formation."

Although small permanent supplies appear, from this information, to be available adjacent to Picacho Peak, it is unlikely that large amounts will be encountered at comparable shallow depth in the volcanic sequence, which extends to an unknown depth and over an unknown area. Bounding faults, downthrown on the valley sides, probably exist at no great distance from exposed rock, and thicknesses of valley fill of at least several hundred feet may occur within a mile of the outermost rock outcrops.

Approximately a mile northeast of the Silverbell foothills, volcanic rock is indicated by well records at depths of about 400 feet. Farther out in the Santa Cruz Valley, wells 500 to 600 feet deep, entirely in valley fill, are recorded. Whether the alluvium thickens gradually over a continuously sloping rock platform or abruptly at fault-controlled drops in the rock floor is not known from existing data.

It is probable that only along the axis of the Santa Cruz Valley and in the northwest corner of the quadrangle is the ground-water supply sufficient for irrigation. Local runoff from the Picacho Mountains and from Picacho Peak is rapid during times of heavy precipitation. Steep slopes and much bare rock contribute to the speed of runoff. The gravel and sand at the foot of the rock slopes, or at the margin of the pediment if one exists, are favorable for rapid infiltration of the runoff waters. Except along the axis of the valley, however, the tributary drainage area appears to be too small to provide more than domestic and stock water supplies in the underground reservoir.

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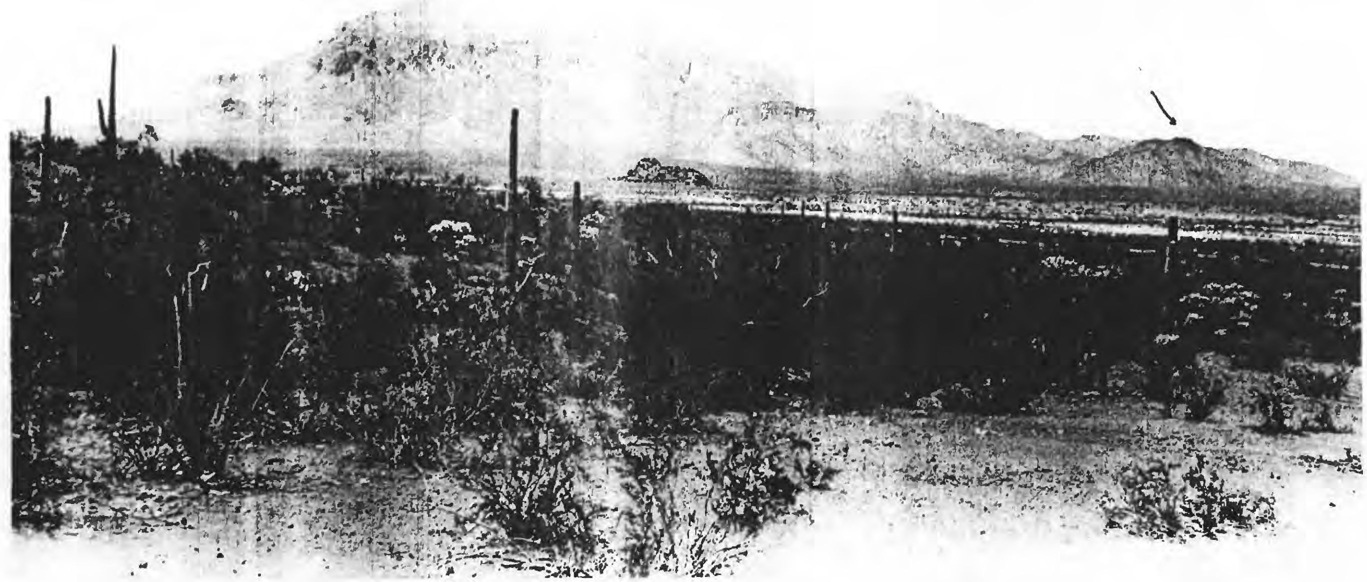


PLATE 1 A.

Picacho Mountains from foot of Picacho Peak. Low basalt hill (center) and basalt platter (arrow) on hill of metamoprhic rocks suggest fault of about 650-foot throw between.

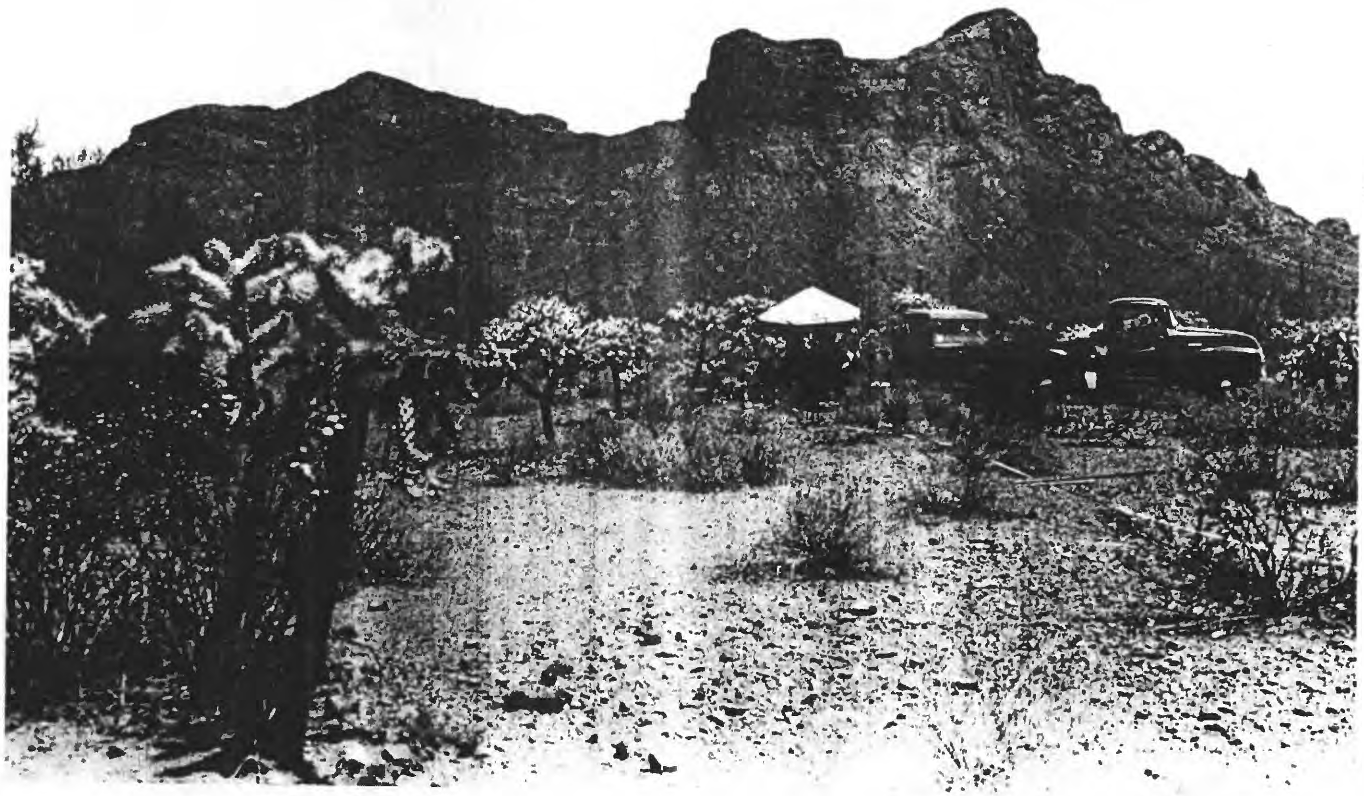


PLATE 1 B.

Picacho Peak (right) from west-southwest showing bounding scarps on west and north faces of intrusive plug. Geophysical party in foreground.

PLATE 1 C.

Picacho Peak from southeast. Note dip of flows, approximately northeast, in foreground.

(Photos by S.F. Turner)

PLATE 2 A.

Portion of the central earth fissure of September 1949. Note fine-grained materials at surface and transition from single wide fissure to double narrow fissure (background).

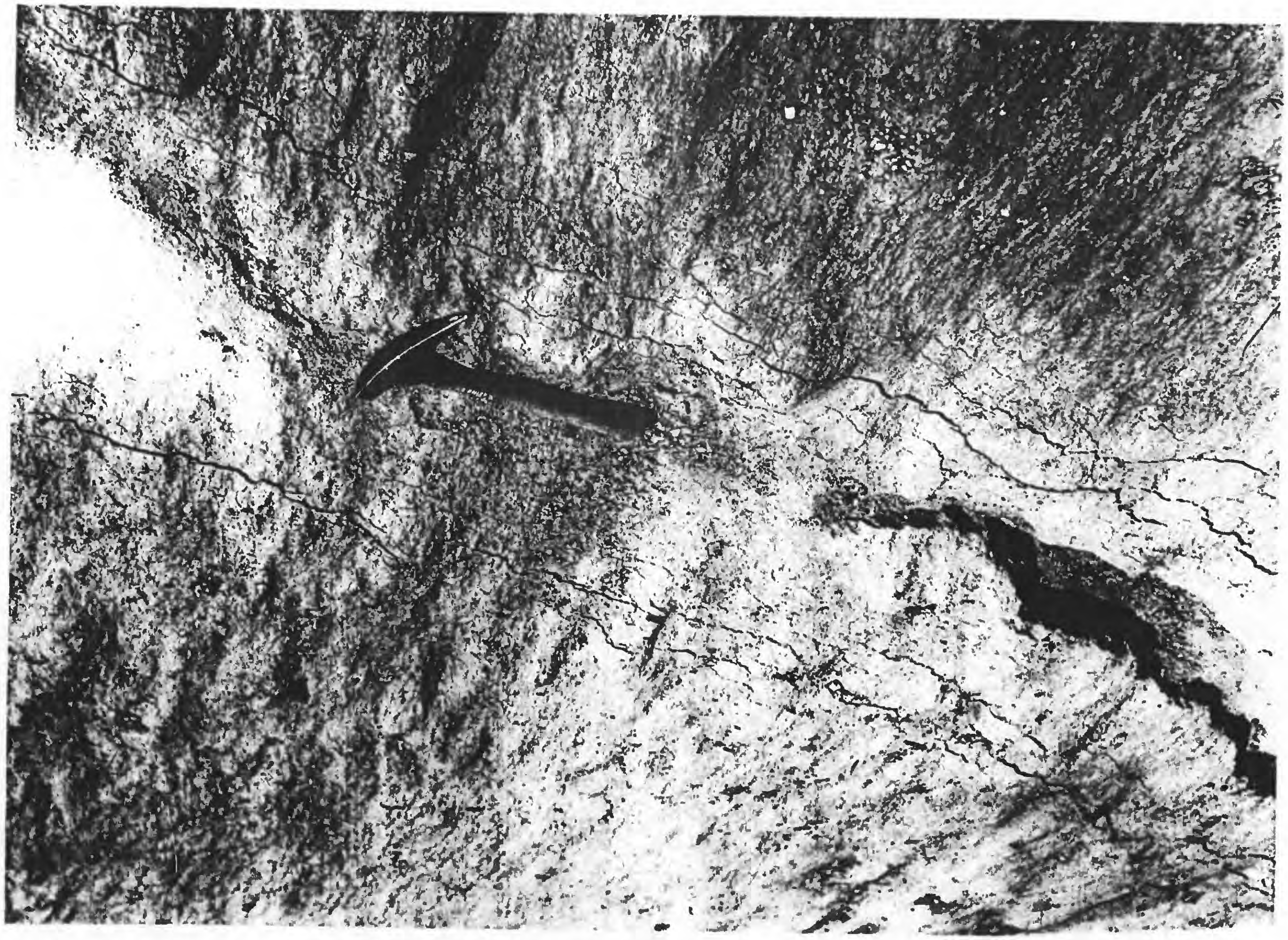


PLATE 2 B.

Zone of multiple fissuring

PLATE 2 C.

Scalloped slump pattern developed adjacent to fissures by September 30, 1949.

(Photos by Coulson and Heindl)

FIGURE I.- GEOLOGIC MAP OF RED ROCK QUADRANGLE, ARIZONA

EXPLANATION

SEDIMENTARY ROCKS

QUATERNARY(?)

Qal

UNCONSOLIDATED AND WEAKLY CONSOLIDATED GRAVEL, SAND, AND SILT FILLING VALLEY BASINS TO DEPTHS OF MORE THAN 600 FEET; PRINCIPAL AQUIFER. IN SUBSURFACE PROBABLY INCLUDES PLEISTOCENE AND POSSIBLY INCLUDES LATE TERTIARY MATERIAL.

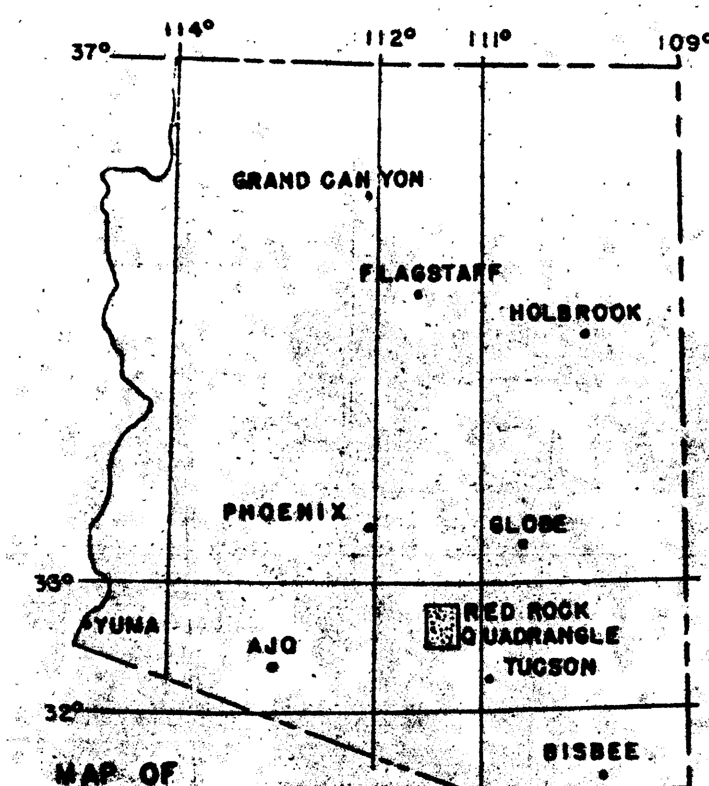
Qs

GRAY, BUFF, AND RED SANDSTONES AND CONGLOMERATES IN SILVERBELL MTS.

TERTIARY(?) AND CRETACEOUS(?)

TKs

CONGLOMERATE INTERBEDDED WITH VOLCANIC ROCKS AT SOUTHEAST TIP OF PICACHO PEAK.



MAP OF ARIZONA

IGNEOUS ROCKS

QUATERNARY(?)

Qb

OLIVINE BASALT OF PICACHO PEAK PLUGS INTRUDED THROUGH OLDER VOLCANICS.

Qa

ANDESITE PORPHYRY DIKE IN SILVERBELL MTS.

Qv

VOLCANIC FLOWS AND TUFFS; PRINCIPALLY BASALT, BUT INCLUDING LESS BASIC ROCKS IN SILVERBELL MTS.

TERTIARY(?) CRETACEOUS(?)

TKv

VOLCANIC FLOWS AND FRAGMENTAL ROCKS.

PRE-CAMBRIAN (?)

gr

GRANITE PEDIMENT IN SILVERBELL MTS.

METAMORPHIC ROCKS

m

GNEISS AND SCHIST IN PICACHO MTS. AND OUTLYING HILLS.

SYMBOLS

KNOWN FAULT

HYPOTHETICAL FAULT

EARTH FISSURE

WATER WELL

20° STRIKE AND DIP OF SEDIMENTARY AND FLOW ROCKS

N

SCALE

1 0 1 2 3 4

MILES

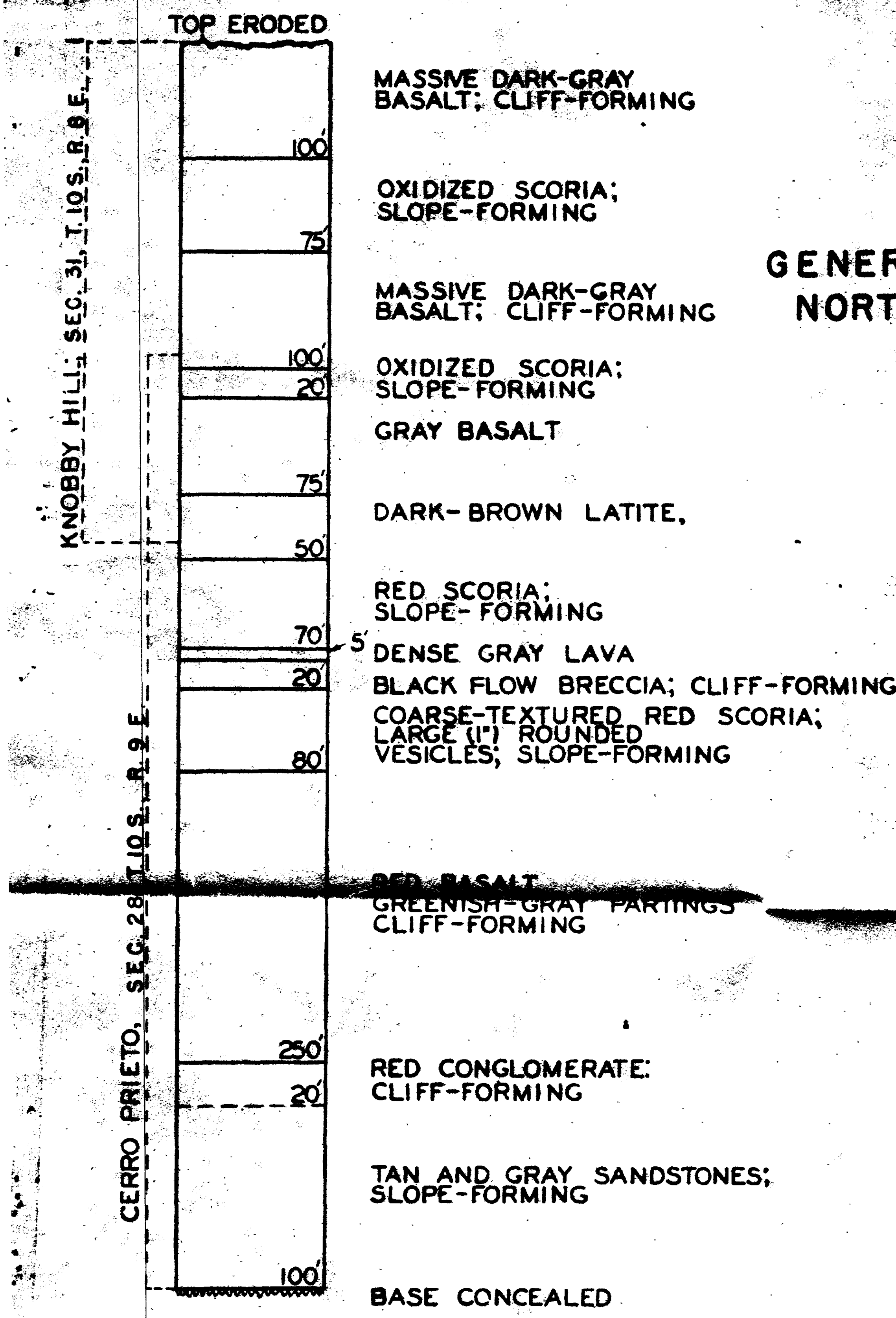


FIGURE 3.
GENERALIZED STRATIGRAPHIC COLUMN
NORTHERN SILVERBELL MOUNTAINS

(THICKNESSES ARE APPROXIMATE)

51-199

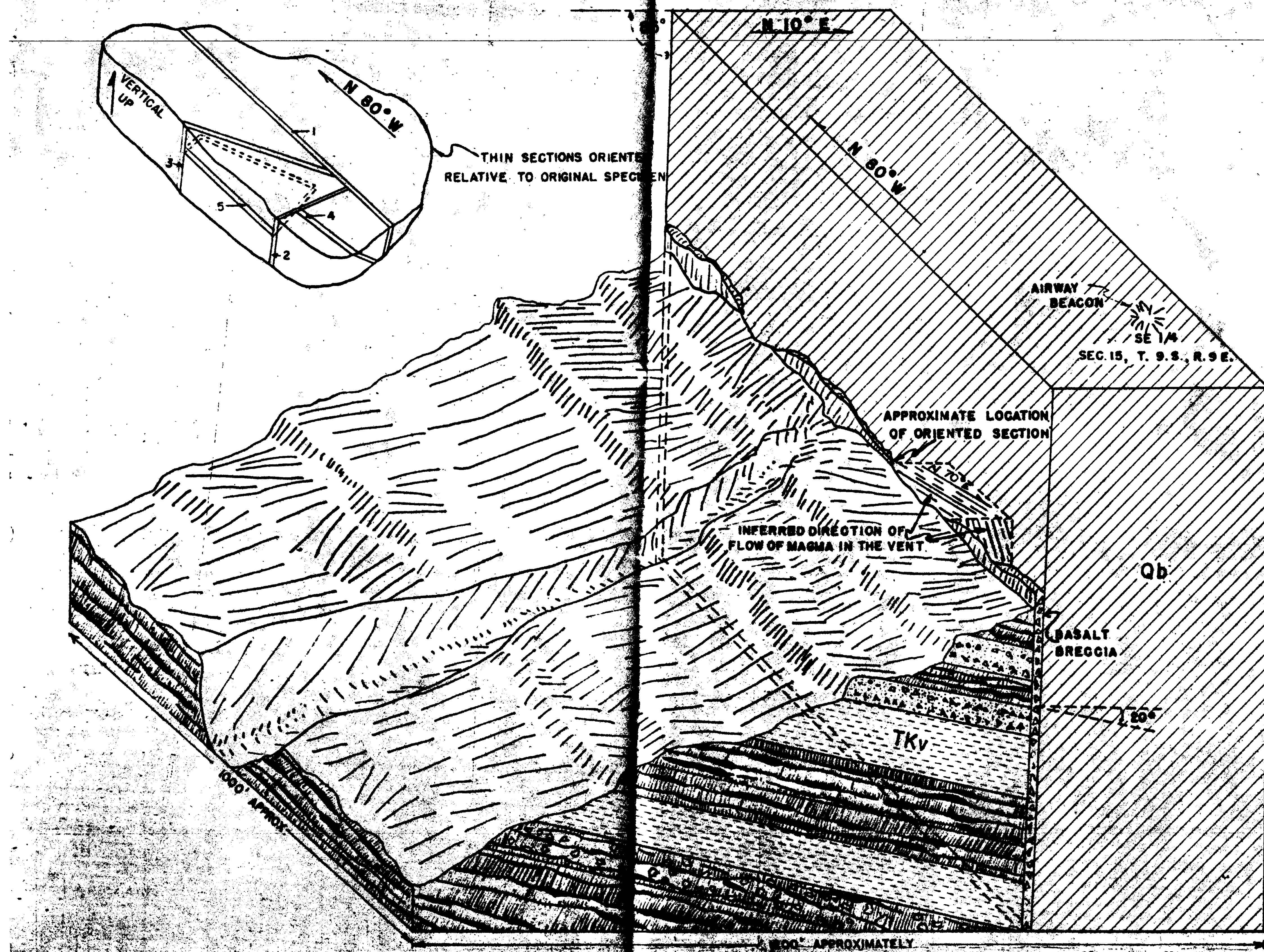


FIGURE 5. BLOCK DIAGRAM OF PICACHO PEAK

SHOWING INFERRED RELATIONSHIPS. SECTION ACROSS FLOWS IS GENERALIZED.

SEE FIGURE 1 FOR EXPLANATION OF SYMBOLS

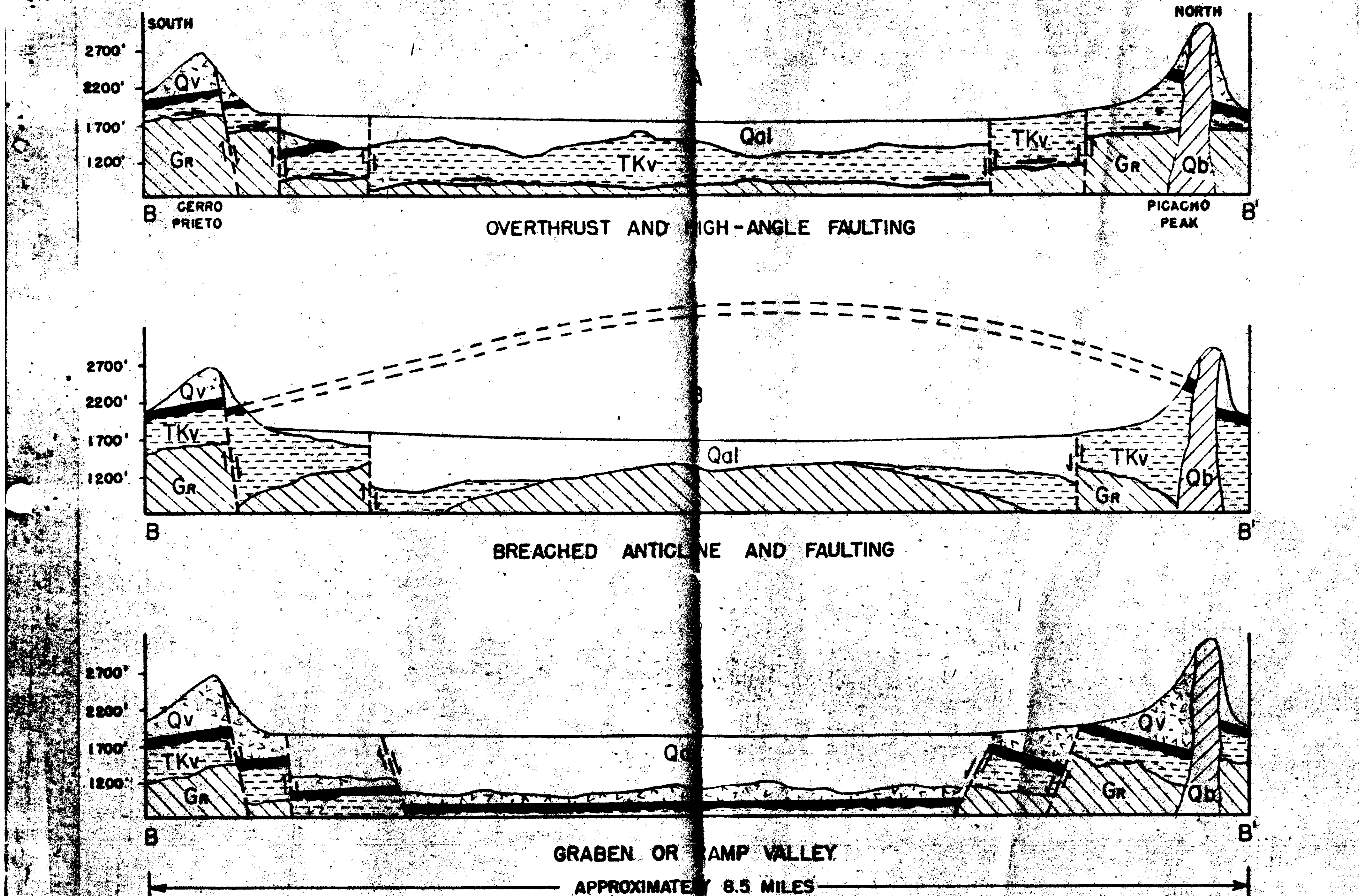


FIGURE 6. HYPOTHETICAL STRUCTURE SECTIONS N-S ACROSS SANTA CRUZ RIVER VALLEY

SEQUENCE AND THICKNESSES OF ROCK UNITS ASSUMED. TERTIARY (?) SEDIMENTS UNDER ALLUVIUM OMITTED.

SEE FIGURE 1 FOR EXPLANATION OF SYMBOLS