GEOLOGY OF THE PAT HILLS, COCHISE COUNTY, ARIZONA

by

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Date

Panoramic view of the Pat Hills. The Chiricahua Mountains are in the background. Looking east.

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ABSTRACT

The Pat Hills are located in a desert region in the extreme southeastern part of Arizona, almost in the center of Cochise County. The hills represent the remnants of an ancient volcano which was active during Cretaceous-Tertiary time. Erosion has stripped off at least 5,000 feet of the upper part of the volcano, exposing its interior portions.

The Pat Hills consist of a volcanic sequence and related plutonic rocks. Two distinct groups of rocks occur, distinguished on the basis of appearance and total potassium content. The first and earlier group consists of porphyritic andesite, laharic breccia, porphyritic hornblende dacite, porphyritic dacite, dacite porphyry, altered acid volcanics, pipes, and plugs of intermediate composition and fine-grained quartz diorite-granodiorite. The second and later group consists of

rhyolite dikes, felsite lenses, quartz veins, and fine-grained quartz monzonite. Interbedded with the earlier group of rocks are small lenses of water-laid tuffs and arkose derived from both the laharic breccia and dacites.

Faulting in the Pat Hills trends in three general directions: (1) northeast in the southern and central part of the area; (2) northwest in the central part of the area; and (3) north in the northern part of the area. Sparse copper mineralization found in the Pat Hills is closely related to faulting in the central and southern parts of the area. Gently inward-dipping volcanics to the north, south, and east suggest the presence of a caldera; however, the exact structure is not clear.

Possibilities for economic mineral deposits in the area appear to be remote.

TABLE OF CONTENTS

LIST OF PLATES

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The Pat Hills are located in T. 16 S. and T. 17 S., R. 27 E., Gila and Salt River base line and meridian, in the eastern portion of the Sulphur Springs Valley, Cochise County, Arizona (see index map, fig. 1).

Rock alteration and scattered copper mineralization in the Pat Hills suggested the possibility of the existence of a hidden mineral deposit. The purpose of this study was to outline the areas of rock alteration, rock types, and structural features to determine possible controls and the most likely location for possible mineral deposits.

Good, ungraded dirt roads which can be traveled by any type of vehicle honeycomb the area. Any point can be reached within half a mile of a road, except during the rainy seasons when the roads become impassable in places.

Several large cattle ranches cover the Pat Hills and surrounding country; however, the area is uninhabited. Windmills adjacent to the hills provide abundant water for livestock.

The Pat Hills cover approximately 4 to 5 square miles, forming an isolated high in the Sulphur Springs Valley. As a result of this condition, both the pediment and drainage systems disperse in all directions away from the hills. In many places, narrow, deep stream channels

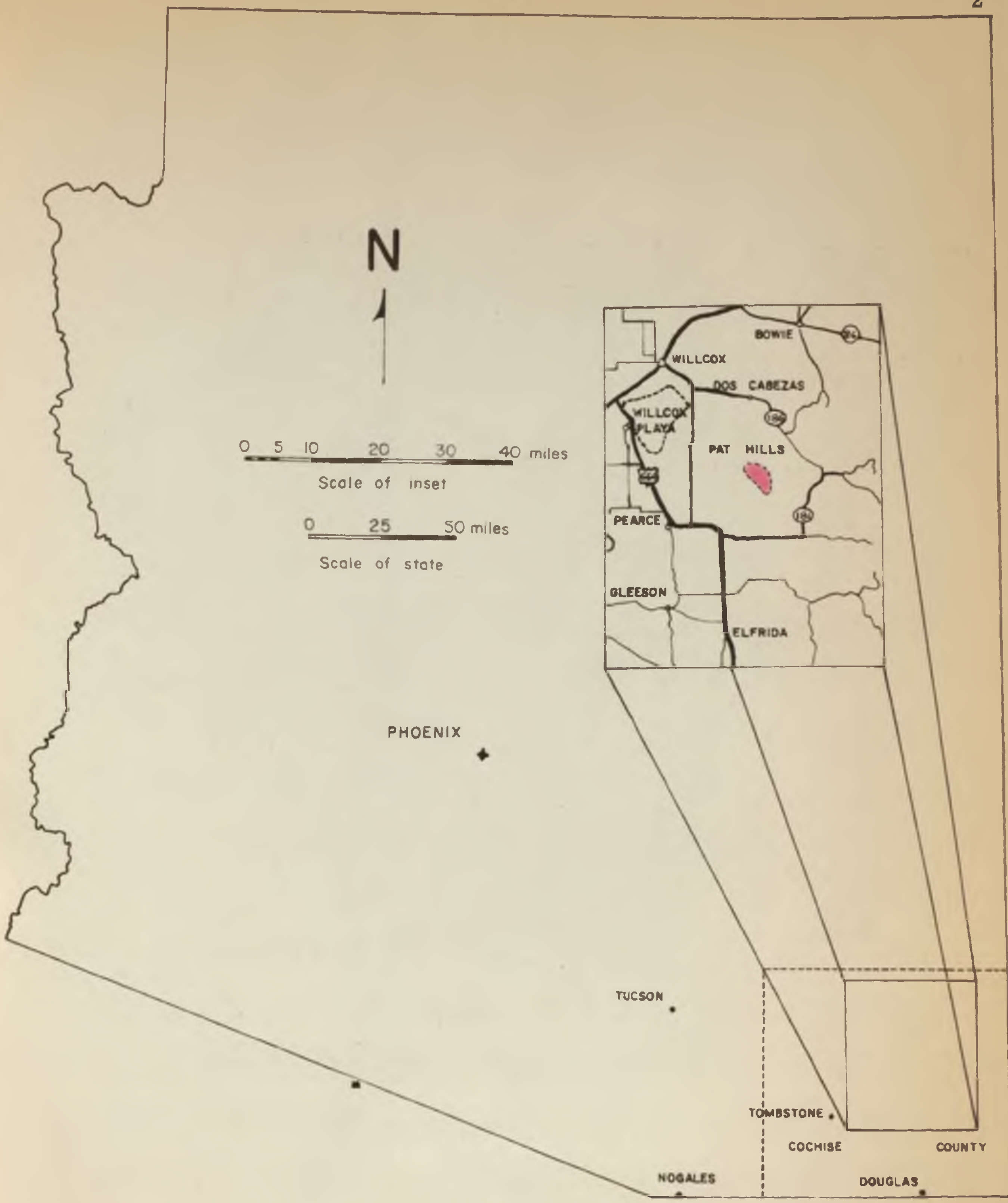

Figure 1. --Index map showing location of the Pat Hills.

occur in the pediment, occasionally exposing volcanics.

The topography consists of ridges and hills, which are generally conical, and are quite rugged and steep in places. The elevation above sea level ranges from 4,400 to 5,087 feet and the maximum relief does not exceed 600 feet, for the most part averaging 200 to 300 feet.

Rainfall usually comes during two seasons—the winter rains and the summer monsoons. Rainfall averages approximately 10 to 15 inches annually.

Typical Southwest desert vegetation predominates. Yucca plants are a guide to quartz diorite-granodiorite and pipes and plugs. California poppies (Eschscholtzia californica) were noted during April growing on alluvial pediment just west of the diamond drill hole in the southwest part of section 28.

No previous detailed report of the Pat Hills has been published. The upper half of the area is shown on a map completed by John Cooper (1960). He spent only 1 or 2 days in the area. Phelps Dodge Corporation completed geophysical and geologic work in the area. Their files are confidential. Carl Lausen (1927, p. 283) wrote an article regarding the mineral piedmontite which is found in the southern part of the area.

The Cyprus Mining Corporation, which at the time of this study held the exploration option on the Pat Hills, kindly made available records of three 500-foot diamond drill holes and a magnetic survey conducted by Heinrichs Geoexploration Company, which included a generalized geologic map of the Pat Hills.

Approximately 25 days were spent in the field completing detailed mapping. Seven days during the first week of May and 14 days in the middle of June made up the majority of the field time. In addition, approximately 12 weeks during July, August, and September were spent completing lab work and writing the report.

The base map was prepared from two U. S. Geological Survey quadrangle sheets, Dos Cabezas and Squaretop Hills. The scale was reduced to one inch equals 1,024 feet. U. S. Geological Survey aerial photographs, GSR 1-07, 1-09; DDR 1-56, 1-57, 1-87, 1-88, and 1-89, were used to aid geologic mapping and interpretation.

PETROGRAPHY

The Pat Hills consist of a volcanic sequence and related plutonic rocks. Two distinct groups of rocks occur, distinguished on the basis of appearance and total potassium content. The first and earlier group consists of porphyritic andesite, laharic breccia, porphyritic hornblende dacite, porphyritic dacite, dacite porphyry, altered acid volcanics, pipes, and plugs of intermediate composition and fine-grained quartz diorite-granodiorite. The second and later group consists of rhyolite dikes, felsite lenses, quartz veins, and fine-grained quartz monzonite. Interbedded with the earlier group of rocks are small lenses of water-laid tuffs and arkose derived from both the laharic breccia and dacites.

Igneous Rocks

Black Porphyritic Andesite

Black porphyritic andesite crops out in patches throughout the area. Outcrops are blocky to irregular, depending upon the degree of fracturing. Related talus accumulations consist of rounded to angular fragments of all sizes. The rock is found capping several hills, along the base of hills and ridges, and is exposed where gentle swells crop out in the pediment.

The weathered surface is reddish brown to brownish gray in color and the fresh surface appears dense and black and generally contains white plagioclase phenocrysts or green epidote which has replaced plagioclase phenocrysts. Locally, plagioclase phenocrysts have been altered to calcite.

The mineralogical composition of the rock varies and was determined from thin sections from several localities. Phenocrysts make up from 10 to 30 percent of the rock and consist of 5 to 10 percent hornblende which forms twinned and zoned euhedral crystals with an average length of 1 mm; 1 to 5 percent quartz crystals which are rounded, embayed, fractured, and contain minute inclusions; 2 percent sanidine; and 2 percent plagioclase (andesine-oligoclase). The remaining portion of the rock consists of matrix and is composed of 60 to 70 percent zoned and twinned plagioclase microliths showing a typical pilotaxitic[1/] texture; 5 to 10 percent sanidine; 2 to 8 percent quartz; and 3 to 5 percent magnetite which occurs throughout the rock as disseminated, subrounded to subangular grains.

All the rocks are altered, some to a greater extent than others.

1/ A textural term proposed by Rosenbusch and applied to the groundmass of holocrystalline, glass-free (volcanic) rocks consisting of a feltlike interweaving of lath-shaped microlites (ordinarily plagioclase), commonly in flow lines.

The main type of alteration is propylitization where plagioclase phenocrysts have been altered to epidote and in places to calcite. Argillization has occurred to a minor degree, the feldspars altering to kaolin. It is probable that minor secondary quartz has formed as a result of the alteration processes.

Porphyritic (Hornblende) Dacite

A porphyritic dacite is the predominant rock type found in the Pat Hills. The rock occurs over wide areas and probably represents several periods of volcanic activity. From place to place physical, chemical, and textural changes occur, resulting in a variety of differently appearing rocks.

Generally, the weathered surfaces are orange brown, maroon, and pale greenish gray in color, and the fresh surface is gray and maroon. In several places plagioclase phenocrysts up to 10 mm in length can be seen and give the rock a speckled appearance. This texture, however, should not be confused with that of the "turkey track" andesites[2/] that are found in the surrounding mountains.

The dacite that crops out along the higher hills is rough to massive. The size and shape of the talus formed depends upon the degree

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2/ A textural term proposed by J. R. Cooper describing a variety of ophitic texture in which plagioclase phenocrysts, in an aphanitic ground mass (andesite), are radiating in nature resembling turkey tracks.

of fracturing and sheeting, which generally is vertical and follows a north to northwest direction. Near the outcrops talus is angular, but tends to become rounded quickly downslope. Toward the base of the hills, exposures are sparse, the dacite being covered by soil and talus. The dacite which is exposed along the very small hills forms low irregular outcrops which break up into small angular pieces.

Thin sections made from rocks throughout the area indicate that the dacite has a fairly constant composition; the main differences are the degree of deuteric and secondary alteration.

The dacite contains approximately 10 to 30 percent phenocrysts which consist of 5 to 25 percent hornblende and 5 to 20 percent plagioclase. The hornblende varies from fresh and unaltered to completely resorbed crystals which have been altered to epidote, sometimes having a red hematite ring along the border. The plagioclase ranges in composition from oligoclase to andesine and varies from unaltered to completely altered, being replaced by epidote and minor calcite. The crystals show albite and carlsbad twinning and are zoned. In places the crystals are broken and fractured. Occasional phenocrysts of rounded and embayed quartz crystals and sanidine occur.

Up to 1 percent magnetite occurs disseminated throughout the rock as irregular grains. The magnetite has partially oxidized to form pure hematite and jarosite. Traces of apatite are also present. The matrix makes up 70 to 90 percent of the rock and has a pilotaxitic texture.

Scattered xenoliths are contained in the dacite and in the west-central part of section 33 many epidote nodules can be found weathered out of the dacite. These nodules are up to a foot in diameter and may represent the epidotized remains of volcanic fragments that were entrapped in the molten host rock during eruption. Reaction rims several centimeters in width between the host rock and the nodules indicate an abrupt chemical difference existed at the time the xenoliths were picked up. One interesting observation is that iron-oxide cores are found only in the nodules which are greater than several inches in diameter. The smaller nodules do not have cores. Sparsely scattered nodules were noted as float over much of the middle one-third of the area.

In the southwest corner of section 27, autoclastic flow breccia (Fisher, 1960, p. 973) dipping gently to the east and of porphyritic (hornblende) dacite composition is exposed at the crest of Beacon Hill.

Porphyritic Dacite

Porphyritic dacite crops out in the north-central and northeastern parts of section 33, the northwest corner of section 34, the southwest corner of section 27, and the south-central part of section 35. The flows of this rock vary in strike from north-northwest to east-northeast and dip up to 45° in a northward direction. The dacite is capped by porphyritic (hornblende) dacite except in section 35 where it is capped by tuff. Porphyritic (hornblende) dacite also underlies the dacite in the volcanic sequence. The relatively limited occurrence of the porphyritic dacite and the fact that it is sandwiched between the porphyritic (hornblende) dacite indicates that it either was extruded as a separate flow or that it occurred as a facies of a porphyritic (hornblende) dacite flow.

The dacite is greenish gray to brownish gray, with a greenish tinge on both the weathered and fresh surfaces. The rock characteristically weathers in such a manner that carlsbad-twinned plagioclase phenocrysts, up to 5 mm in size, stand out on the weathered surfaces. Outcrops are not prominent and talus fragments are small and angular. Usually a break in slope from steep to shallow occurs where the rock is exposed.

Phenocrysts make up approximately 20 percent of the rock, as compared with 40 to 50 percent phenocrysts found in the dacite porphyry which crops out where sections 26, 27, and 34 meet. The phenocrysts consist of approximately 15 percent plagioclase (oligoclase-andesine) which has been partially albitized; 2 percent rounded, fractured, and embayed quartz; 1 percent apatite; and 1 percent altered biotite. The matrix makes up approximately 80 percent of the rock and consists of 30 to 45 percent albitized plagioclase and 35 to 50 percent quartz. At least part of the quartz is secondary, occurring in small veinlets and also around albite which is contained in plagioclase. Secondary minerals include 2 percent epidote, 1 percent calcite, and 1 percent chlorite. Remnants of hornblende and traces of disseminated goethite, pseudomorphic after pyrite, are also present in the rock. Alteration minerals also include sericite and traces of kaolinite.

Biotite Dacite Porphyry

Biotite dacite porphyry crops out where sections 27, 28, and 34 meet. The outcrops in sections 28 and 34 appear to reveal a dike with poorly developed sheeting which cuts both the porphyritic (hornblende) dacite and porphyritic dacite. The outcrops in section 27 may or may not represent an intrusion, for here the dacite porphyry is cut by later felsite and vertical rhyolite dikes.

The dacite porphyry is greenish gray to buff on both the fresh and weathered surfaces, and phenocrysts of plagioclase give the rock a speckled appearance. The rock forms low irregular outcrops which break up into small angular fragments.

Phenocrysts make up 30 to 40 percent of the rock and contain 10 to 20 percent plagioclase (andesine-oligoclase), 1 to 3 percent rounded quartz, 2 to 4 percent altered biotite, and up to 2 percent hornblende. One to 5 percent of epidote also occurs as phenocrysts. The matrix contains 50 percent plagioclase, 5 to 15 percent quartz, 1 percent apatite, and 1 percent disseminated magnetite. The plagioclase is partially altered to epidote, sericite, and minor kaolinite, and the biotite and hornblende are altered to chlorite and minor epidote.

Alteration is intensified near two vertical rhyolite dikes and consists of bleaching, concentrations of iron oxides in stringers, chloritization, and sericitization.

Altered Acid Volcanics

Altered acid volcanics crop out in the north-central part of section 33 and the northeast part of section 32. The rocks in section 33 strike approximately N. 80° W., and dip 25° N. Data from a diamond drill hole near the outcrop indicate a thickness of about 280 feet. Porphyritic (hornblende) dacite both overlies and underlies these volcanics. Rock in the drill core was brecciated throughout the entire thickness of the volcanics; many of the fragments were light gray in color and quite sericitized. The same brecciated rocks were noted in the drill core in the southeast part of section 28 at a depth of from 45 to 285 feet (see pl. 2, section D-D'). This drill hole was started in a breccia pipe. Approximately a dozen prospect pits which show minor chrysocolla in fractures have been dug within the volcanics and overlying porphyritic (hornblende) dacite; however, no copper was found in the drill core.

The outcrop in section 32 exposes the massive volcanics in fault contact with porphyritic (hornblende) dacite. Scattered over the volcanics are banded quartz fragments which were derived from small veins.

The acid volcanics have been highly sericitized and are red, yellow, brown, and various shades of these colors on both the fresh and weathered surfaces. Weathering produces talus which rounds very quickly. The rock contains 20 to 25 percent quartz, 10 to 15 percent plagioclase (oligoclase), 40 to 50 percent sericite, and 20 to 25 percent limonite. Part of the quartz is probably secondary, forming as a result of the intense sericitization.

Pipes and Plugs

Over 100 pipes and plugs of intermediate composition perforate the northern third of the Pat Hills. They crop out as roughly circular bodies averaging from 50 to 100 feet in diameter. Some have radiating dikes, and others occur as small dikes up to 330 feet long. Most of them intrude quartz diorite-granodiorite, and because they are slightly more resistant than the host rock, they appear as small warts on hilltops and hillsides.

The pipes and plugs are colored shades of yellow and brown. The coloring is probably due to alteration and oxidation of the iron-bearing minerals. Many of the rocks have shadows of misty white which were produced as a result of attack by sulfate-bearing solutions. The rocks are well fractured and tend to round rather quickly.

The rocks are intermediate in composition and have a porphyritic, holocrystalline texture. The average composition is 30 to 40 percent quartz, 10 to 25 percent plagioclase, 10 to 35 percent sanidine, 2 to 5 percent biotite, less than 1 percent hornblende, up to 2 percent magnetite, 5 to 15 percent sericite, less than 1 percent chlorite, and up to 10 percent hematite.

Three breccia pipes crop out in the eastern part of section 28 and the southwestern part of section 27. These pipes are deep red in color due to extreme hematitic alteration, and, as a result, are distinct from the other pipes and plugs. The northernmost of the three pipes is composed of both "pancake breccia" and fragmental breccia and the southern two pipes just contain fragmental breccia. A diamond drill hole in the breccia pipe in the southeast part of section 28 revealed that the pipe continued to a depth of 285 feet where quartz diorite-granodiorite was encountered (see pl. 2, section D-D'). The breccia pipes may branch from a single shoot at depth. The drill core also showed abundant pyrite in the pipe in the sulfide zone at a depth below 218 feet.

Quartz Diorite-Granodiorite

The magma chamber from which most of the volcanics originated may have been localized where quartz diorite-granodiorite now crops out in sections 2, 28, and 29. These rocks are massive but well fractured and weather in a manner very similar to granite, which may account for the reason that John Cooper (1960) mapped them as granite.

The rock is not as resistant as the volcanics and its massive nature may account for it forming the highest hill in the area as well as smaller hills.

The rock is buff to gray on the weathered surface and gray on the fresh surface. The texture is fine-grained hypautomorphic granular and the rock is composed of 10 to 15 percent quartz, 50 to 60 percent plagioclase (andesine), 15 to 20 percent sanidine, 1 to 2 percent biotite, up to 2 percent hornblende, up to 4 percent pyroxene, 1 percent disseminated magnetite, and secondary minerals which consist of 1 to 3 percent epidote, 5 to 10 percent chlorite, and traces of sericite, kaolin, calcite, albite, and tremolite.

Porphyritic Rhyolite Dikes

Three rhyolite dikes, each approximately a mile in length, traverse the Pat Hills in a general easterly direction.

A 20- to 50-foot wide dike crops out in the east part of section 34, the west part of section 35, and the northwest part of section 3. The dike strikes from west-northwest to west, and dips from 60° to 80° northward, in sections 34 and 35, to very shallow dip in sections 34 and 3. Porphyritic (hornblende) dacite bounds the dike on the north and laharic breccia bounds the dike on the south, indicating the dike probably intruded along a fault and possibly along a flow contact in sections 34 and 3. Later faults have displaced the dike in several places.

Alteration along contacts ranges from very slight to extreme. Extreme bleaching and sericitization of dacite occurs in the east-central part of section 34. This prompted some prospecting years ago; however, no metal values are present.

The rhyolite is hypohyaline, porphyritic in texture, buff colored on the weathered surface, and light buff to white on the fresh surface. Phenocrysts consist of 10 to 25 percent doubly terminated quartz crystals, 5 to 10 percent plagioclase (oligoclase), and 15 percent sanidine. Matrix minerals consist of 10 percent quartz, 35 percent sanidine, 15 to 20 percent glass, along with minor calcite, sericite, kaolinite, limonite, and hematite. In places disseminated centers of chemical reaction are demonstrated by cores of quartz and sanidine surrounded by shells of limonite and hematite in the matrix.

Two 10 to 12 feet wide, vertical rhyolite dikes crop out in sections 27 and 28. The dikes have an irregular strike which approximates N. 80° E. intruding along faults, and they stick up 1 to 2 feet above the surrounding rocks. Minor faults offset the dikes up to several hundred feet. The dikes cut porphyritic (hornblende) dacites and dacite porphyries, which are altered within a few feet of the contact. The dikes locally show banding of white, gray, and yellow-red colored zones caused by alternating bands of quartz and partially kaolinized sanidine. Weathering produces angular talus fragments. Similar banded rocks have been found within several of the plugs, indicating that the dikes are coincident or post-date the plugs. The pipes and plugs have a total potassium content (see table 3) of approximately 3.96 percent and the banded rhyolite dike rocks of 7.25 percent, suggesting that the rhyolite rocks post-date the pipes and plugs.

The rocks contain 1 to 2 percent doubly terminated, embayed quartz phenocrysts, 25 to 30 percent anhedral quartz, and 50 to 55 percent anhedral sanidine.

Several smaller rhyolite dikes up to 400 feet in length occur in the area.

Felsite

Small lenticular intrusions of felsite are found scattered throughout the area. These bodies are up to a few tens of feet long and usually less than 6 feet wide. The rock is gray on the fresh surface and weathers into small angular pieces which are buff colored. The majority of the rock contains devitrified glass with 4 to 5 percent sanidine and 1 to 2 percent angular quartz phenocrysts which are aligned along a very prominent vertical flow direction. Small vugs are also aligned in the flow direction and appear to be flattened. Many of the vugs are filled with quartz and minor epidote. The felsite contains approximately 6 percent potassium (see table 3) and is probably an aphanitic rhyolite in composition.

The felsite bodies probably originated as small intrusions along faults or fractures. More felsite bodies exist than are shown on the geologic map, for in several instances float noted along slopes could not be traced back to the outcrop. Felsite has been found in several pipes and plugs, indicating post-plug intrusion, based on the same evidence as the rhyolite dikes.

Quartz Veins

Several varieties of quartz veins occur throughout the Pat Hills. Massive iron-stained quartz is associated with copper mineralization in the northeast part of section 10. Clear quartz containing pyrite and limonite crops out in the east part of section 34; however, no copper was seen.

Banded vein quartz is found in the west part of the area (see pl. 3). Two silicified pipelike bodies and a dike crop out in the western and southwest part of section 2. Limonite after pyrite is abundant in these rocks.

A fine-grained quartz lens with an aplitic texture crops out in the north-central part of section 34. It appears as if the quartz grains had crystallized simultaneously from thousands of nucleation points.

Quartz Monzonite

Massive quartz monzonite makes up three conical-shaped hills located in the east part of section 30, southwestern part of section 29, northeastern part of section 31, and northwestern part of section 32. The hills are less than 200 feet high and are surrounded on all sides by alluvium. They consist almost entirely of rough outcrops and very little soil is developed. Talus and the rocks still in place weather round, very similar to granite. Much banded quartz is present in veins up to several inches wide and as float.

The quartz monzonite is brownish pink to pinkish gray on the fresh surface and light buff to pink on the weathered surface. The rock is fine grained with a hypautomorphic granular texture. It consists of 30 percent quartz, 45 percent plagioclase (albite-oligoclase), 15 to 20 percent orthoclase, 1 to 2 percent biotite, 1 to 2 percent epidote, 1 percent disseminated magnetite, minor chlorite, calcite, sericite, and kaolinite, and a trace of apatite, sphene, and allanite.

Sedimentary Rocks

Laharic Breccia

Outcrops of laharic breccia (Fisher, 1960, p. 973) occur in the southern part of the Pat Hills in sections 33, 34, 2, 3, and 10. The breccia fragments range from very coarse, up to 6 inches in diameter, to less than half an inch in diameter. Outcrops at three locations, in sections 2 and 10, expose arkosic sediments which formed as a result of reworking of the breccia. The arkose is bedded and crossbedded.

In general, the breccia strikes N. 70° W. to west and dips northward about 10° to 20°, cropping out along the bases of five hills or ridges in the southern portion of the area. Data from a diamond drill hole in the northeast part of section 10 indicate a minimum thickness of 90 feet. This value, however, probably only has meaning in the immediate vicinity of the drill hole, for in volcanic environments extreme variations in thickness would most likely exist. It is not known what underlies the breccia; however, the drill-hole data suggest porphyritic (hornblende) dacite may underlie a part of the breccia.

The upper part of the breccia grades into a purple dacite. The gradation is rather sharp in places. In section 3 volcanic glass containing feldspar fragments and secondary quartz was noted between the breccia and dacite, and a similar glassy rock was noted in section 2 overlying the breccia.

The breccia is purplish brown in color, very poorly sorted, and is composed essentially of dacite fragments. The rock contains small amounts of disseminated magnetite and very little quartz. The matrix is very fine, probably initially consisting of mud which oxidized.

The breccia exposed in the lower half of section 33 contains 30 to 50 percent dacite fragments and the remaining 50 to 70 percent is made up of plagioclase phenocrysts and fine-grained matrix. Excluding the fragments, the remainder of the rock is dacitic in composition. This rock may well represent a transition between the laharic breccia and the dacite flows which followed.

Of the 50 to 70 percent of the rock which is dacite, 15 to 20 percent is plagioclase (oligoclase-andesine), 5 percent sanidine, and 1 percent disseminated magnetite. The plagioclase is twinned, zoned, fractured, and broken into angular fragments. Alteration minerals include up to 1 percent epidote and minor calcite. The remainder is fine-grained matrix which is slightly kaolinized.

The rock is purple to buff on the weathered surface, and the fresh surface is purple to white with white speckles due to the feldspar phenocrysts. The rock weathers into small pieces which are angular to subrounded in shape.

Arkose

A 2- to 3-foot thick lens of arkose which strikes east-northeast and dips about 20° to the east crops out in the southeast corner of section 28 and the northeast corner of section 33. The arkose is buff colored on both the fresh and weathered surfaces and is fractured into small angular fragments. The rock is fairly well sorted and contains 30 to 40 percent semirounded to angular clear, glassy quartz grains, 45 to 60 percent subangular to subrounded plagioclase grains, 10 percent epidote intergrown between the quartz and plagioclase grains, and scattered 1 to 2 mm-sized dacite fragments. The rock has been slightly oxidized. It was probably derived from surrounding volcanics during a dormant period in the volcanic cycle.

Three lenses of arkose, derived from the laharic breccia, crop out in sections 2 and 10. The rock is reddish brown and contains up to 25 percent quartz and 2 to 3 percent disseminated magnetite. Plagioclase in some of the fragments has partially altered to calcite.

Tuff

Vitric to vitric-crystal tuffs crop out as thin lenses in the upper-central, northeast, and east parts of section 33, and in the southwest part of section 35. The lenses are less than 4 feet thick and, except for the tuff in the southwest part of section 35, are only a few tens of feet long. The limited extent of the outcrops suggests that the tuffs were water deposited. All the lenses are dipping in a general eastward direction at about 20° to 35° which would indicate post-depositional tilting has occurred. In section 33, the tuff lenses are sandwiched between dacite flows and in section 35 the tuff caps a small hill forming a dip slope overlying porphyritic dacite.

The tuffs appear white to buff colored on both the fresh and weathered surfaces. Parallel parting or bedding structure is prominent and talus is tabular or angular shaped as a result. The rock contains 1 percent quartz fragments, up to 2 percent broken plagioclase, and 85 to 95 percent fine-grained matrix which is partially composed of devitrified glass shards. Five to 15 percent secondary calcite is also present.

MINERALIZATION

Vein Minerals and Disseminations

Sparse mineralization occurs in several areas in the Pat Hills. Plate 3 shows the areas of mineralization correlated with faults and areas of alteration.

Copper

Chrysocolla fills fractures and is concentrated in two general areas closely associated with faults. In the northern part of section 33, approximately a dozen prospects were sunk into mineralized rocks, but a diamond drill hole nearby showed no copper minerals at depth. In the northeastern part of section 10 and the central part of section 2, chrysocolla is concentrated along a northeast-striking fault. The chrysocolla is associated with quartz, calcite, siderite, and piedmontite, and is found mainly in the brecciated portions of the fault zone. In the northeast part of section 10, a headframe stands over a 100-foot deep inclined shaft. The shaft follows a stringer of chrysocolla which has been terminated by a vertical fault at a depth of 80 feet (see fig. 2).

The primary source of the copper is not known. It may be hydrothermal in origin or it may have been disseminated in the

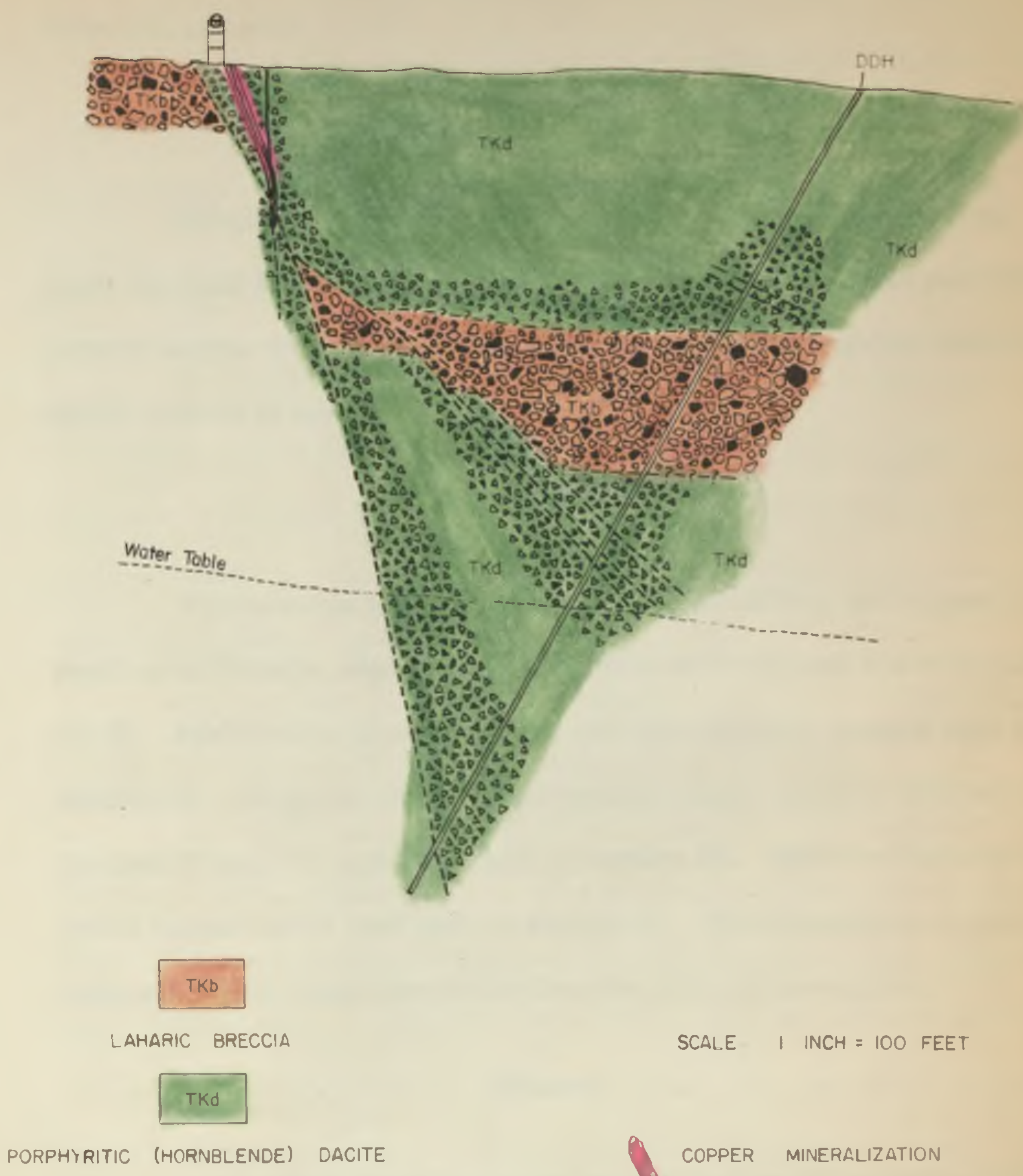

Figure 2.--Structure section between diamond drill hole and inclined shaft, showing chrysocolla mineralization along northeast-trending fault. Located in section 10.

volcanics, being set free during alteration and concentrating along the fault zones as a result of ground-water flow or greater reactivity of the fine rock material.

Calcite

Calcite veinlets, filling fractures, were found in the cores from the drill holes in the northern part of section 33 and the northeast part of section 10. It can be assumed that subsurface calcite veinlets occur in most of the Pat Hills.

Pyrite

Pyrite veins have been found in two localities, and disseminated pyrite and limonite after pyrite are scattered throughout the area (see pl. 3). Pyrite veins are associated with quartz in the eastern part of section 34, and pyrite veins were found at a depth of 218 to 475 feet in the drill hole in the southeast part of section 28. Massive limonite after pyrite occurs in the west part of section 33. The limonite is slightly magnetic and is found downslope from the outcrop as nuggets.

Gypsum

A prospect in the northeast part of section 29 reveals massive gypsum along a north-northeast-striking fault.

Magnetite

One to 2 percent disseminated magnetite is found in almost all of the rocks in the Pat Hills. Black alluvial sands, however, were only observed in the central part of section 29, indicating that the magnetite is oxidized before being set free during weathering.

Alteration

One of the prime objects of this study was the evaluation of alteration, both in the field and in thin sections. Field and thin-section data indicate all alteration was directly related to volcanic activity and post-dated it. The alteration can be broken down into three groups, which can occur as separate phases of or overlap each other.

(1) Deuteric alteration is widespread and occurred as a result of chemical interaction between components of the lavas.

(2) "Hydrothermal" alteration ("hydrothermal" being used in the sense of rising gases and/or hypogene fluids passing through plugs along faults and fractures) bleached and sericitized the rocks along the way. Pyrite veins in the drill core from the drill hole in section 28 indicate that the fluids were in part sulfur rich. Whether or not ground water was present during the "hydrothermal" phase is not known. However, banded quartz veins found in parts of the area may fit in with Harrison Schmitt's ideas (1950, p. 209) that the banding of quartz was

produced by fluctuations of a water table.

(3) Alteration by supergene-oxidizing solutions has probably been active from the time of volcanic activity to the present.

Hypogene Alteration

Deuteric Stage - Sericitization and propylitization occurred to some degree in all of the volcanic rocks. Plagioclase phenocrysts were altered to epidote and minor calcite in some instances and in others to sericite, albite, and quartz.

Hydrothermal Stage - Sericitization occurs to a minor extent in almost all the rocks (deuteric stage) in the Pat Hills; however, certain areas are extremely sericitized, the rocks being bleached buff and yellow. Alteration may have resulted where ascending fluids encountered ground water or reactive wall rocks if ground water was not present. Generally, the areas in which bleaching occurs are related to plugs, faults, contacts, and areas which are highly fractured. In the vicinity of the pipes and plugs bleaching occurs up to 50 yards away, becoming more intense nearer the pipes and plugs. The altered acid volcanics are also highly sericitized.

Moderate silicification occurs in the Pat Hills, mainly concentrated in several localities. Banded vein quartz is localized in five areas (see pl. 3). Vein-type, massive, iron-stained, clear to gray quartz crops out in the east part of section 34, in the south part of section 2, and in the northeast part of section 10. The quartz veins in section 34 are approximately 40 to 50 feet wide and several hundred feet long, and the veins exposed in sections 2 and 10 are up to 10 feet wide and several hundred feet long. A silicified intrusive body crops out in the western part of section 2. This body is dark yellow brown in color and contains minor quartz crystals and limonite pseudomorphic after pyrite. Secondary quartz in the form of small veinlets and disseminated fragments is found in the highly sericitized rocks, forming as a result of the breakdown of the feldspars and ferromagnesian minerals. Thin sections indicate only minor kaolinization throughout the area.

Throughout the Pat Hills epidote forms thin crusts on fracture faces of the dacites, especially in the southern two-thirds of the area. Epidote crusts are more abundant in certain areas; however, these were not mapped due to time limitations. Piedmontite is found in the southern half of the Pat Hills and is closely associated with the epidote crusts. In several hand specimens epidote grades into piedmontite within small radiating crystals.

Supergene Alteration

In scattered areas both magnetite and pyrite have been altered to limonite and hematite. This is usually accompanied by bleaching of the surrounding rocks. Both transported and indigenous limonite occur. The bleached sericitized zones mainly contain the transported limonite, part of the iron probably being set free during sericitization. Scattered areas show limonite pseudomorphic after pyrite.

Hydrothermal Fluids

Field and drill-hole evidence indicates that a scant hydrothermal stage occurred in the Pat Hills. It followed the second stage of activity and was very limited. Rhyolite dikes and felsite lenses consisting almost entirely of quartz and sanidine probably represent the late stage of differentiation of a "dry" magma. Because the magma was "dry" in nature, hydrothermal activity was very limited.

Minerals produced during the hydrothermal stage indicate a medium- to low-temperature depositional environment and consist of quartz, pyrite, piedmontite, epidote, calcite, and traces of copper, gold, and silver.

Lausen (1927, p. 283) states that "piedmontite was deposited by hydrothermal solutions reacting with the silicates in the andesites (dacites), chiefly feldspar and hornblende." Some of the piedmontite, in the form of rosettes, grades outward into epidote. Lausen accounts for this by having the supply of manganese suddenly cease, the crystals then growing as common epidote.

TABLE 1
MINERAL PARAGENESIS IN THE PAT HILLS

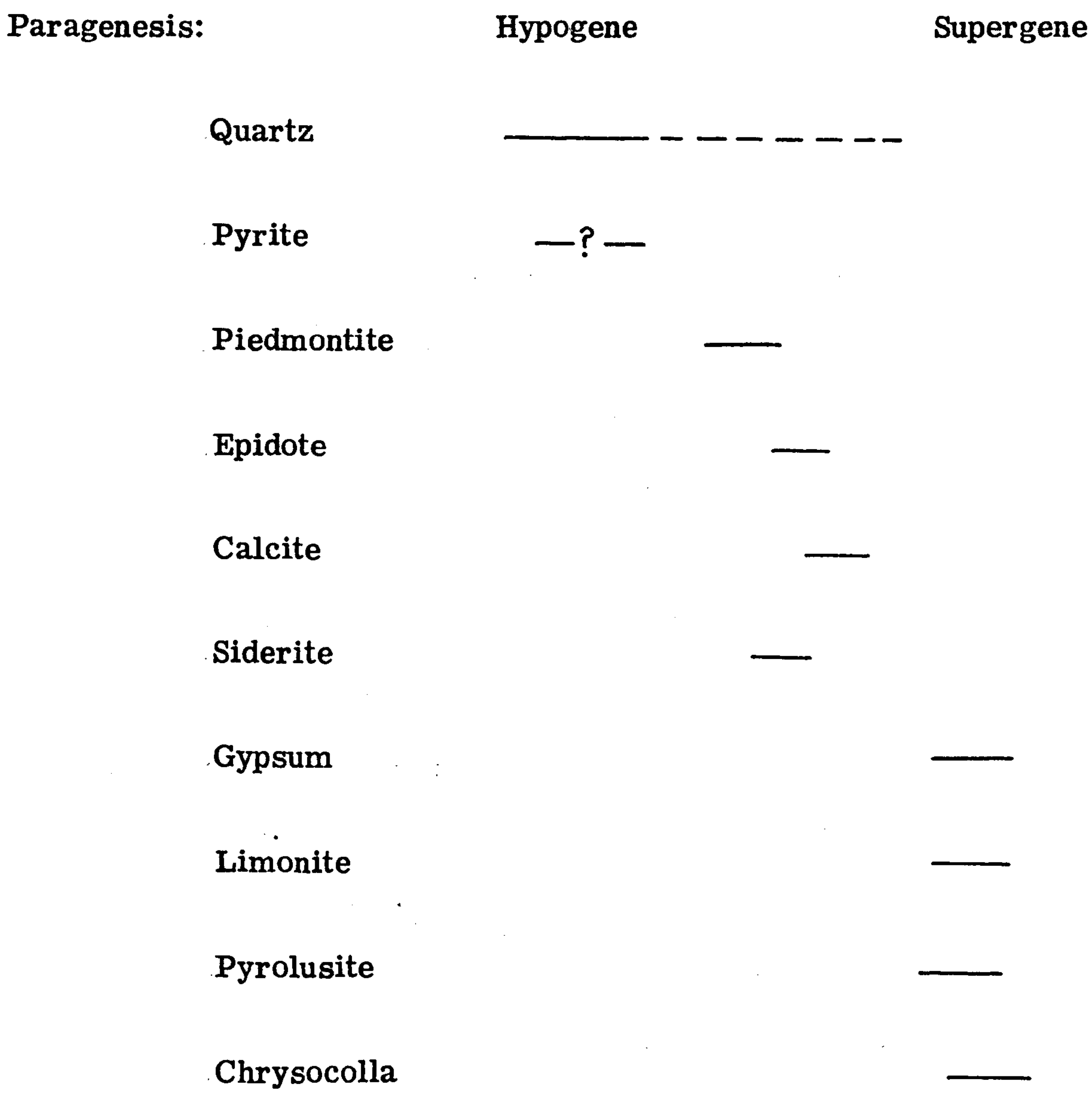

TABLE 2. SUMMARY OF ROCK TEXTURES AND COMPOSITIONS

ROCK NAME	PORPHYRITIC (HORNBLENDE) DACITE	%	BLACK PORPHYRITIC ANDESITE	%	BIOTITE DACITE PORPHYRY	%	PORPYRITIC DACITE	%		
TEXTURE	HOLOCRYSTAL. PORPHYRITIC		HOLOCRYSTAL. PORPHYRITIC		HOLOCRYSTAL. PORPHYRITIC		HOLOCRYSTAL. PORPHYRITIC			
PRIMARY MINERALS	P–PHENOCRYSTS M–MATRIX									
ESSENTIAL										
	QUARTZ	1-10	QUARTZ	2-10	QUARTZ	6-18	QUARTZ	37-50		
	PLAGIOCLASE (OLIGO.-AND.)	P. 5-20 M 60-80	PLAGIOCLASE (OLIGO.-AND.)	P. 2-12 M 60-70	PLAGIOCLASE (OLIGO.-AND.)	P. 10-20 M. 50	PLAGIOCLASE (OLIGO-AND)	P 7 M 20-35		
	SANIDINE	0-3	SANIDINE	2-10						
ACCESSORY										
	HORNBLENDE	5-25	HORNBLENDE	5-10	HORNBLENDE	<1	HORNBLENDE	<1		
	BIOTITE	TRACE			BIOTITE	4-5	BIOTITE	1		
AUXILIARY MINERALS										
	MAGNETITE	1	MAGNETITE	3-5	MAGNETITE	1	MAGNETITE	TRACE		
	APATITE	TRACE			APATITE	1	APATITE	1		
SECONDARY MINERALS										
	EPIDOTE	1-20	EPIDOTE	2-10	EPIDOTE	1-7	EPIDOTE	2		
	CHLORITE		CALCITE	1-2	CHLORITE	6	CHLORITE	1		
	SERICITE		SERICITE		SERICITE		SERICITE			
	KAOLIN	TRACE	KAOLIN	TRACE	KAOLIN	TRACE	KAOLIN	TRACE		
	QUARTZ	0-5	LIMONITE	1-4	LIMONITE	1-5	QUARTZ			
	LIMONITE	0-1					LIMONITE	TRACE		
							CALCITE	1		
							ALBITE	15-25		

ROCK NAME	QUARTZ MONZONITE	%	QTZ. DIORITE — GRANODIORITE	%	PORPHYRITIC RHYOLITE DIKE	%	ALTERED ACID VOLCANIC	%	PIPES AND PLUGS	%
TEXTURE	HYPAUTOMORPHIC GRANULAR		HYPAUTOMORPHIC GRANULAR		HYPOHYALINE PORPHYRITIC		PORPHYRITIC		HOLOCRYSTAL. PORPHYRITIC	
PRIMARY MINERALS										
ESSENTIAL										
	QUARTZ	15-20	QUARTZ	10-15	QUARTZ	10-25	QUARTZ	20-25	QUARTZ	30-40
	PLAGIOCLASE (ALBITE-OLIGO.)	30	PLAGIOCLASE (ANDESINE)	50-60	PLAGIOCLASE (OLIGOCLASE)	5-6	PLAGIOCLASE (OLIGOCLASE)	10-15	PLAGIOCLASE	10-25
	ORTHOCLASE	40-45	ORTHOCLASE	15-20	SANIDINE	40-50			SANIDINE	10-35
ACCESSORY										
	BIOTITE	1-2	BIOTITE	1-2					BIOTITE	2-5
	HORNBLENDE	<1	HORNBLENDE	<2					HORNBLENDE	<1
			PYROXENE ?	<4						
AUXILIARY										
	MAGNETITE	1	MAGNETITE	1					MAGNETITE	0-2
	APATITE	TRACE								
	SPHENE	TRACE								
	ALLANITE	TRACE								
SECONDARY MINERALS										
	EPIDOTE	1-2	EPIDOTE	1-3	SERICITE		SERICITE	40-50	SERICITE	5-15
	CHLORITE		CHLORITE	5-10	KAOLIN		LIMONITE	20-25	CHLORITE	<1
	SERICITE		SERICITE		LIMONITE				HEMATITE	0-10
	KAOLIN		KAOLIN		HEMATITE					
	CALCITE		CALCITE							
			ALBITE							
			TREMOLITE		GLASS	15-20				

TABLE 3
TOTAL K_2O CONTENT OF SOME OF THE ROCKS IN THE PAT HILLS*

Rock	Total percent K_2O
Porphyritic dacite	2.66
Quartz diorite-granodiorite	3.05
Porphyritic andesite	3.07
Porphyritic "hornblende" dacite	3.29
Dacite porphyry	3.48
Pipes and plugs	3.96
Felsite	6.23
Quartz monzonite	6.28
Rhyolite dikes (sections 2, 3, 34, and 35)	7.25
Rhyolite dikes (sections 27 and 28)	8.42

* β counting was done in a lead-shielded low-level anticoincidence counter, using three-quarter inch diameter planchettes. β counts measured were derived primarily from the radioactive decay of potassium 40 to calcium 40. Secondary sources of β counts are the decay series of uranium and thorium and the decay of rubidium 87 (Damon, 1960, p. 75). The β counting analysis for potassium was corrected for uranium and thorium by α counting. For α corrections composite samples were used; however, the results were very close.

STRUCTURE

The planar structural features which exist in the Pat Hills consist of faults, fracturing, and sheeting. Within the volcanic rocks linear alignment of plagioclase and hornblende along flow directions was noted but not mapped due to time limitations. Structure sections (pl. 2) revealed the possible existence of a caldera, tilted blocks shallowly dipping northward, southward, and eastward.

Faults

Faulting in the Pat Hills is oriented in three general directions (see pl. 3): (1) striking northeast in the southern and central part of the area; (2) striking northwest in the central part of the area; and (3) striking north in the northern part of the area. Undoubtedly, more faults exist than were mapped, for faulting dacite against dacite does not juxtapose rocks of different character, and, thus, little surficial evidence of faulting exists. Dikes, lenses, and veins were emplaced along faults contemporaneously with or after faulting. The sparse copper mineralization which is found in the Pat Hills is also closely related in space to faulting (groups 1 and 2 above).

Shallow-dipping fault blocks of volcanics suggest the presence of a caldera; however, the exact structure is not clear (see pl. 2). The laharic breccia would be expected to dip away from the center of volcanic activity which occurred in the northern third of the area. This is not the case however. The breccia, which only crops out in the southern part of the area, shallowly dips in a northward direction toward the center of activity. The breccia also is displaced vertically by blocklike faults.

Fractures and Sheeting

Fracturing of varying intensity occurs throughout the Pat Hills. In the volcanics the fracturing is oriented in places. This is mapped as sheeting which varies in strike from northwest to northeast and dips rather steeply to vertical. Intensified fracturing occurs close to faults, pipes, and plugs.

Faults and fractures acted as channelways for fluids which bleached and sericitized the surrounding rocks.

ECONOMIC GEOLOGY

The possibility that ore bodies exist in the Pat Hills is remote. Copper, gold, and silver would be the only metals worth considering. Copper mineralization in the form of chrysocolla crusts filling fractures is sparse and not continuous. In the northeast part of section 10 chrysocolla within the breccia zone of a northeast-striking fault is cut off at a depth of 80 feet by a vertical fault (see fig. 2). A diamond drill hole in the north part of section 33 was sunk in the center of a small area of chrysocolla. Not a trace of chrysocolla was cut by the hole. The source of the copper values is not known. The mineralization may represent the oxidized remains of minor seepage from depth or may just be local concentrations originating as a result of intense alteration and breakdown of surrounding rocks.

Gold and silver were not seen visually on the surface, but an assay from one of the drill holes recorded a small quantity of both gold and silver. Yet, in an epithermal environment, the possibility always exists that high-grade pockets of gold and silver may have formed.

A magnetic survey (Heinrichs Geoexploration Co.) showed relative highs and lows. It should be remembered that volcanic environments can play magnetic tricks and interpretation of anomalies is very difficult. Three en echelon lows which trend northwest showed up in the southern part of the area in sections 2, 3, 4, 9, 10, and 11. The anomalies occurred over alluvium and paralleled a northwest-southeast-striking fault in sections 3, 10, and 11, and therefore may be related to faulting. This could be explained as limonite altered from magnetite along the more permeable fault zone. A magnetic high was located in the east-central part of section 34 near a zone of bleached alteration. A low would be expected in the bleached area where magnetite has altered to limonite, but the high indicates something out of the ordinary and may be worth looking at in more detail. An irregular northeast-trending high occurred in sections 28, 32, and 33, the majority of which is covered by alluvium. Two small highs were found in section 33, one just east of the drill hole, and the other exactly over the area where the epidote nodules are concentrated.

The possible reasons for these highs and lows involve the magnetite which occurs disseminated throughout the volcanics. The fact that just one area of black sand was seen in the central part of section 29 does not mean that quantities of magnetite could not exist buried within the alluvium. Lows may be accounted for in areas of bleaching and sericitization where magnetite has converted to pyrite.

The three diamond drill holes, in sections 28, 33, and 10, were all approximately 500 feet deep (see pl. 2 and fig. 2), and all showed small amounts of copper, gold, and silver. The only one of interest was in the southeast part of section 28 and encountered disseminated and vein pyrite.

The quartz veins, altered areas, and sparse mineralization, including pyritic veins and gypsum, indicate that a weak hydrothermal phase occurred after volcanic activity and three possibilities concerning metallization exist:

(1) If Paleozoic limestones were penetrated at depth, ore deposits may have formed, the sparse copper mineralization exposed at present representing leakage from depth.

(2) The present erosion surface is in the sericite zone. If a solfateric zone existed above the present surface, ore bodies may have formed and have been eroded, the copper mineralization representing the bottom of metallization.

(3) The hydrothermal solutions lacked metal content to form any type of ore deposit.

GEOLOGIC HISTORY

The geologic history of the exposed part of the Pat Hills is fairly straight forward, but correlation with the surrounding regional geology is marred by alluvium which isolates the hills at least 6 miles in any direction (see pl. 4).

Age

The age of the rocks exposed in the Pat Hills is not certain. John Cooper (1960) indicates a Cretaceous-Tertiary age for the upper half of the Pat Hills. Gilluly (1956, p. 116) has given the volcanics west of the Pat Hills a Tertiary date. They consist of rhyolites and andesites. Sabins' (1957) geologic map, east of the Pat Hills, shows numerous stocks, sills, and dikes consisting of diorites-granodiorites and quartz monzonites of Tertiary age. These rocks may possibly be correlated to the quartz diorites-granodiorites and quartz monzonites found in the Pat Hills.

From this information I have indicated on plates 1 and 2 a Cretaceous-Tertiary age for the rocks of the Pat Hills; however, the rocks probably are Tertiary in age.

Local History

The rocks exposed in the Pat Hills represent the eroded remnants of one volcano. On the basis of evidence from the total potassium content of the different rock types (see table 3), two distinct periods of activity are represented.

The first period of activity consisted of outpouring of black porphyritic andesite flows followed by flows of hornblende dacites, laharic breccia, hornblende dacites interbedded with porphyritic dacites, dacite porphyries, and porphyritic andesites. The porphyritic andesite was not necessarily the beginning of volcanic activity, but only that observed from field and drill-hole evidence. Eruptions were not continuous, but were separated by periods of years as evidenced by lenses of water-laid tuff and arkose within the volcanics and laharic breccia. Eruptions were also non-violent judging from the lack of pyroclastics, excluding the laharic breccia which probably occurred as a mudflow. The magma chamber was probably located near where the quartz diorite-granodiorite is exposed in sections 21, 28, and 29.

Following the flows, over 100 pipes and plugs perforated the quartz diorite-granodiorite and dacites. These pipes and plugs probably represent the center of volcanic activity in the area and fed more lava out of the volcano. Accompanying and following intrusion of the plugs, the host rocks were bleached and sericitized. This alteration is not just restricted to the areas of pipes and plugs, but occurs over isolated parts of much of the area, concentrating along faults and fractures.

The second period of activity consisted of intrusion of rhyolite dikes, felsite lenses, quartz monzonite, and the formation of silica veins. It is not known whether the two periods of activity were a result of separate unrelated intrusions or differentiation of the quartz diorite-granodiorite to quartz monzonite. Most of the faulting and fracturing seen today in the Pat Hills occurred during or after the second period of activity and may be related to the formation of the caldera which formed sometime toward the end of volcanic activity. The volcano may have reached a height of a mile above the present surface judging from the exposed internal features, including the quartz diorite-granodiorite outcrops, which were probably the source of most of the lavas.

Since the end of volcanic activity, the processes of erosion have acted upon the Pat Hills, reshaping the land to its present-day form.

FIGURE 3

BRECCIA AND VOLCANIC PIPES IN THE PAT HILLS

A

Three breccia pipes revealed as reddish areas. Photograph taken from the summit of Beacon Mountain looking north (sections 27 and 28).

B

Three volcanic pipes (plugs). One in the center foreground and two in the background. The large hill is composed of granodiorite-quartz diorite. Looking northwest (sections 28 and 29).

FIGURE 4

BANDED RHYOLITE DIKES

Note the zigzagged strike on the hill in background.

Looking east (section 27).

FIGURE 5

"PANCAKE BRECCIA"

Northernmost breccia pipe (section 28).

FIGURE 6

TYPES OF BRECCIA

A

Autoclastic breccia at summit of Beacon Mountain (section 27).

B

Laharic breccia (section 2).

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1963
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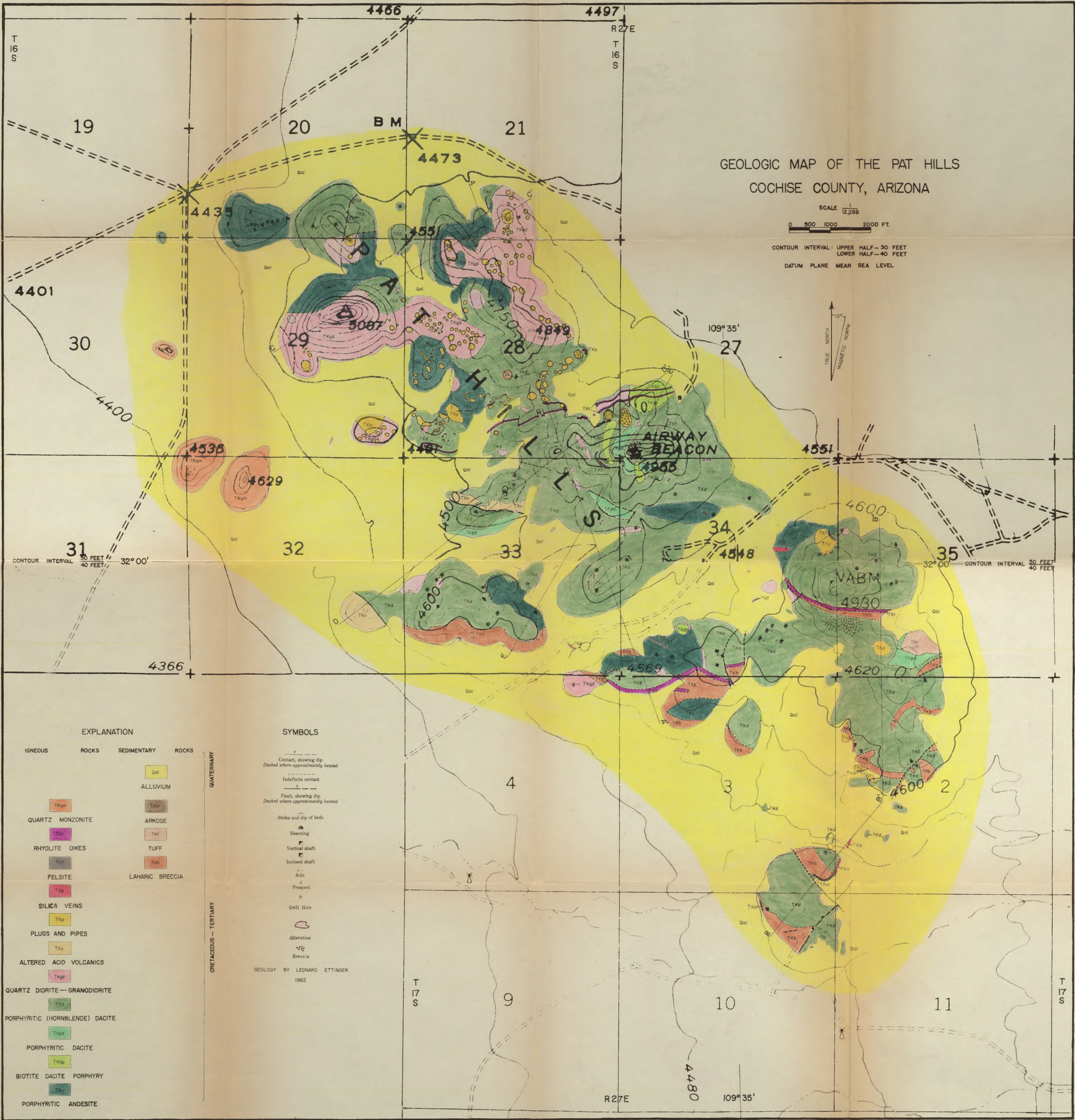
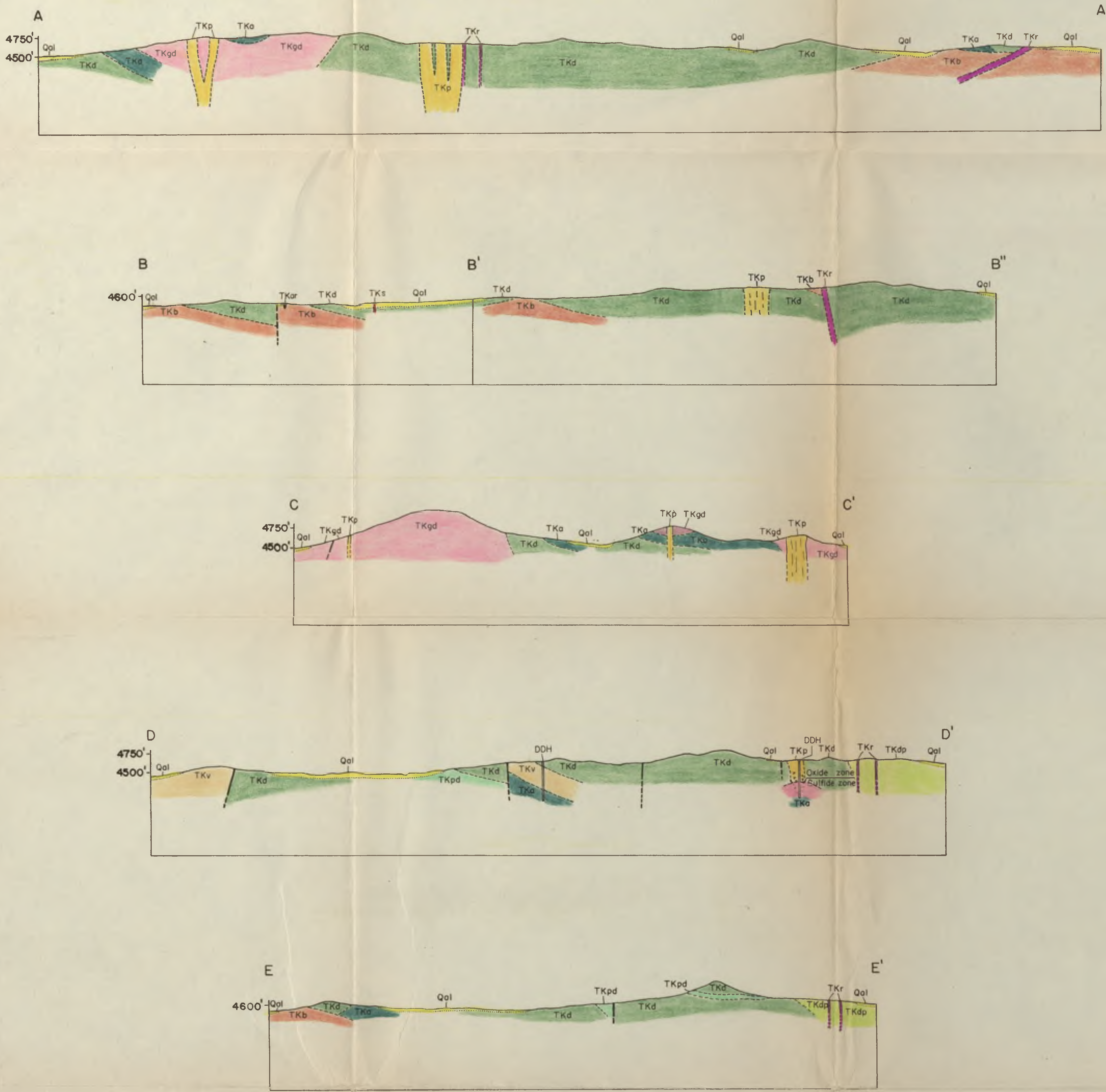
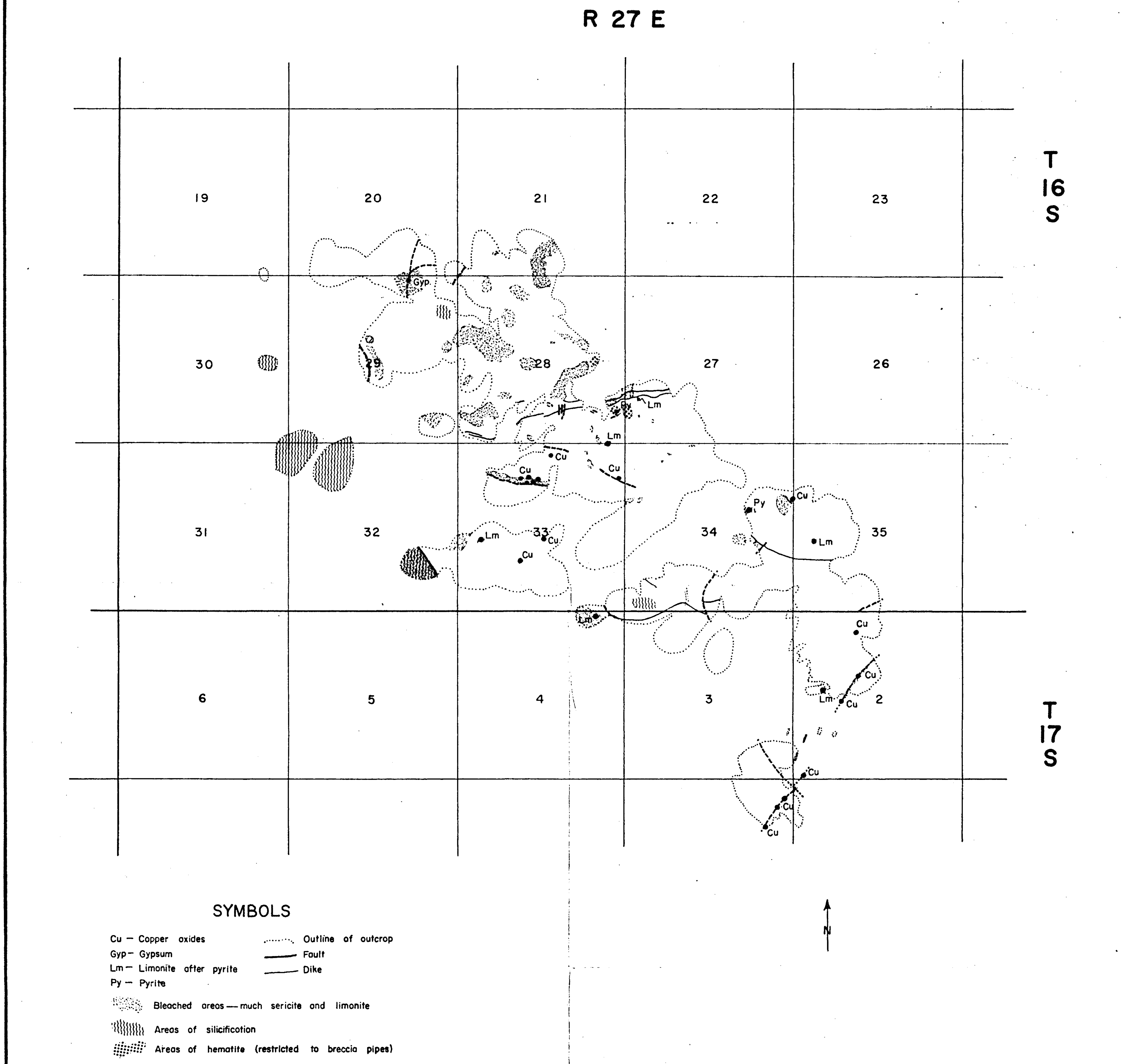
PLATE I





STRUCTURE SECTIONS OF THE PAT HILLS

0 500 1000 2000 FT.



CORRELATION MAP OF FAULTS, ROCK ALTERATION AND METALLIZATION IN THE PAT HILLS

SCALE 2" = 1 MILE

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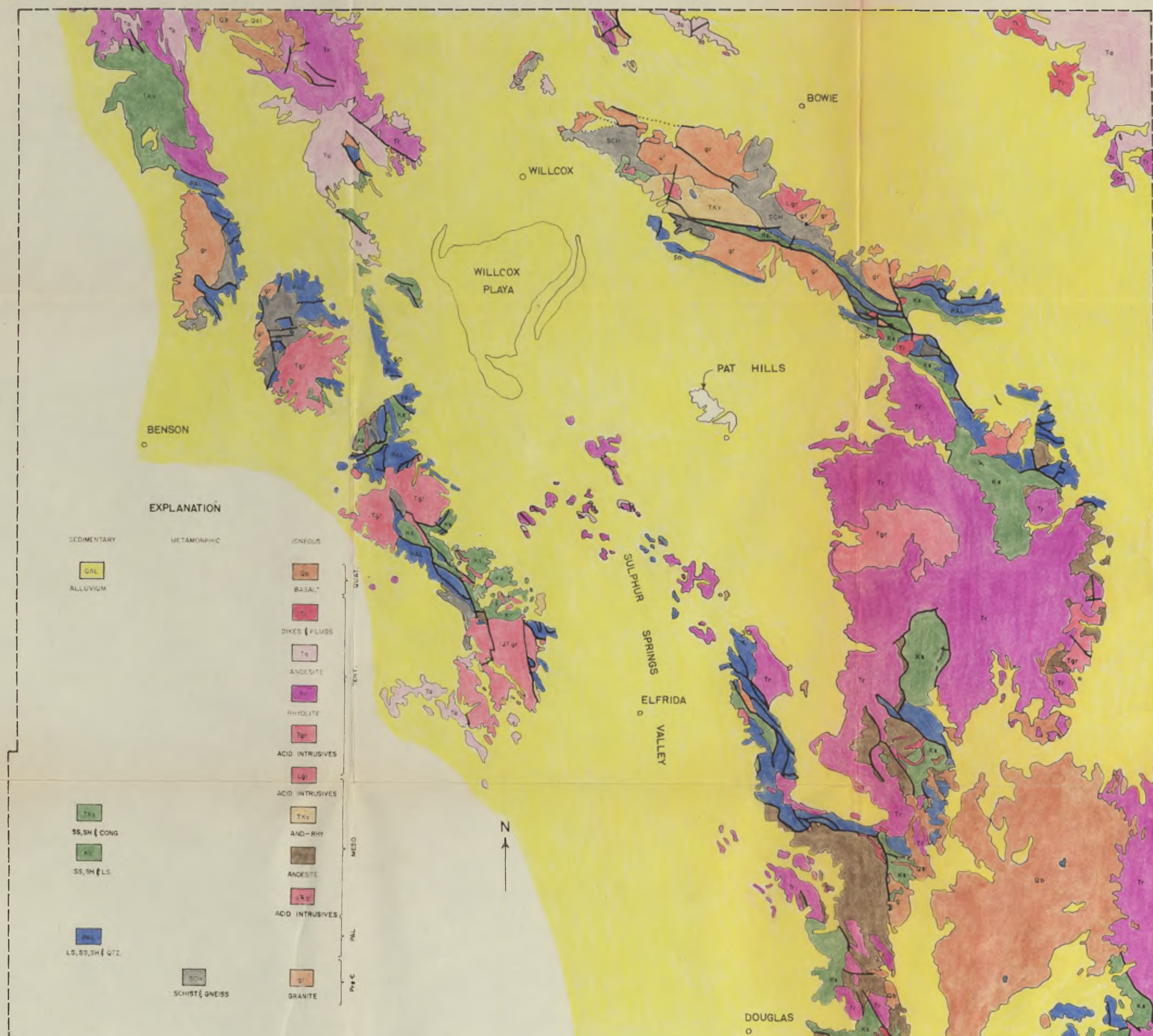
Pl. 3



SOURCE OF GEOLOGIC DATA: GEOLOGIC MAP OF COCHISE COUNTY, ARIZONA BUREAU OF MINES, 1959

GEOLOGIC MAP OF A PART OF COCHISE COUNTY, ARIZONA

SCALE $\frac{1}{375,000}$

10 0 10 20 30 MILES