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GEOLOGY AND ORE DEPOSITS OF APACHE HILLS AND NORTHERN SIERRA RICA, HIDALGO COUNTY, NEW MEXICO

BY

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INTRODUCTION AND ACKNOWLEDGMENTS

The Apache Hills-Sierra Rica district was first proposed as an area for thesis study by Dr. William Holser then of Cornell University. After a visit there in 1949, Dr. Holser suggested that the geology and ore deposits of the two small groups of ranges would constitute a compact unit for a thesis if special emphasis were placed on the contact metamorphic relations expressed in the vicinity of the Apache mine. In view of the intensive consideration that has of late been given to the relation between contact metamorphism and ore deposition, the careful investigation of such relations in this concrete example seemed amply merited. Subsequently through the efforts of Dr. Chas. H. Behre, Jr., funds for the field work were acquired from the Ore Genesis Laboratory of Columbia University and from the New Mexico Bureau of Mines and Mineral Resources under the directorship of Dr. Eugene Callaghan. A total of approximately five months, representing parts of three field seasons, were spent in the field, one month in the summer of 1952, three months in the summer of 1953, and one month in the spring of 1954.

Aerial photographic contact prints from the United States Soil and Conservation Service were used as base maps. These were on the scale of four inches to the mile (1:15,840). The geology was transcribed to a planimetric map of the Hachita and Victorio quadrangles enlarged to a scale of 1:24,000. As the quadrangles were not completely surveyed by the General Land Office at the time of their original publication in 1918, additional section lines were drawn in, using the appropriate county highway maps as a guide.

The area under discussion includes the Apache Hills and the northern part of the Sierra Rica. The remainder of the Sierra Rica was not mapped as it is currently under study by Robert A. Zeller of the New Mexico Bureau of Mines who is investigating the Big Hatchet quadrangle, the northeastern part of which includes a portion of the Sierra Rica.

All the mine maps and diagrams were made by the pace and compass method using measured base lines where possible.

The author wishes to express his sincere appreciation to Dr. Holser, who first suggested the thesis problem, and to Dr. Callaghan who secured the necessary funds, and especially to Dr. Behre without whose generous aid and advice this work would not have been possible. Thanks are also here expressed to the many people whose interest and cooperation greatly aided the field work and writing of this thesis; these include David Miller and Allen Alper of Columbia University, field assistants during the summers of 1952 and 1953; Benito Palomarez, of Hachita, field assistant in the spring of 1954; Fred W. Snyder, of Hachita, who was a constant source of valuable historical and geological information; R.N. Hunt of the United States Smelting Refining and Mining Company, Salt Lake City, who generously provided assays and claim maps of the Apache Mine; Joseph Deckert, of Deming, who supplied assays and reports of the International and Luna Mines; and Robert A. Zeller who aided in interpreting the paleontology. Appreciation is also extended to the people of Hachita who made the stay there a most pleasant one.

PREVIOUS WORK

Little geologic work, other than that of a reconnaissance nature has been carried on in the two districts. Previous reports which provided the principal background information include several papers by Waldemar Lindgren, et al[1] who described briefly the various mines and prospects of the two ranges; that of N. H. Darton[2] on the geology of Luna County, which includes some cursory information on the Apache Hills which he regarded as part of the Sierra Rica but which is really physiographically and geologically part of the Apache Hills; the geologic map of the state by Darton[3] which represents a very generalized geologic study of the region; and the report by S. G. Lasky[4] on the Little Hatchet Mountains - the northward-trending range separated from the Apache Hills and Sierra Rica by the large playa of Hachita Valley - which includes some pertinent comments about the geology of the thesis area. A complete listing of references is given at the end of the paper.

[1]Lindgren, Waldemar, Graton, L.C., Gordon, C.H., et al (1910), The ore deposits of New Mexico, U.S. Geol. Survey Prof. Paper 68.

[2]Darton, N.H. (1916), Geology and underground water of Luna County, New Mexico, U.S. Geol. Survey Bull. 618.

[3]Darton, N.H. (1928), Geologic map of New Mexico, U.S. Geol. Survey.

[4]Lasky, S.G. (1947), Geology and ore deposits of the Little Hatchet Mountains, U.S. Geol. Survey Prof. Paper 208.

GEOGRAPHY

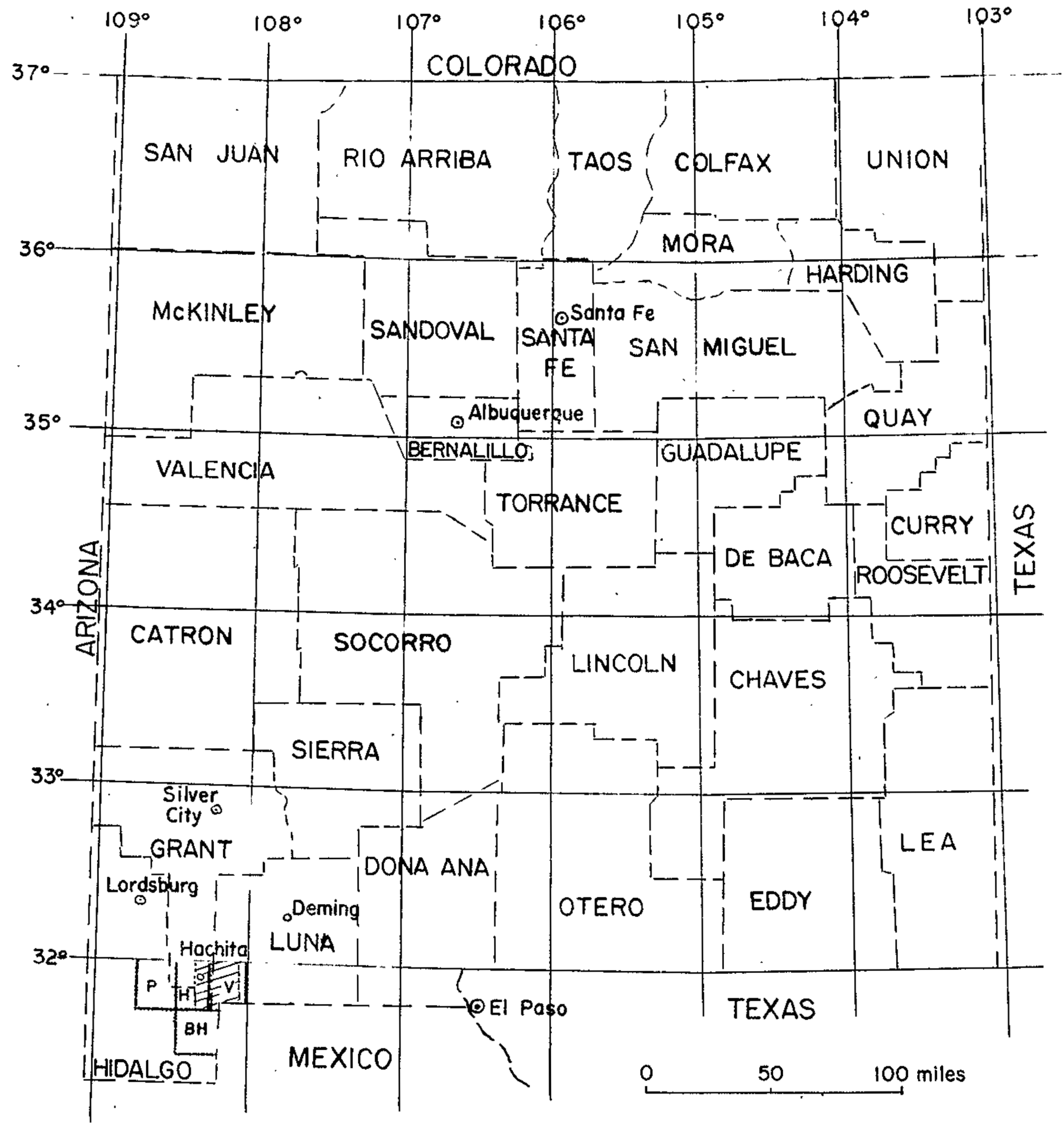
LOCATION AND ACCESSIBILITY

The Apache Hills and Sierra Rica are a low group of mountains in the southwest part of New Mexico, just northwest of the notch in the United States-Mexican boundary (Figure 1). These ranges lie mostly in Hidalgo County, but the northern part of the Apache Hills is in Grant County and their extreme eastern section is in Luna County. Both ranges extend southeastward for some distance into the state of Chihuahua, Mexico. The Apache Hills, the northernmost of the two groups of hills, is five miles south to southeast of Hachita, a station on the Southern Pacific Railroad.

The town of Hachita, which has a population of 250 (1950 census) is at the intersection of two state highways. State Highway 81, a paved secondary road, extends northward for 19 miles to a junction with paved U.S. Highway 80 at a point 25 miles from Lordsburg and 35 miles from Deming. Southward the route extends 45 miles to Antelope Wells on the international border. State Highway 9, a graded gravel road, passes through Hachita following the railroad westward from Columbus to a junction with U.S. Highway 80 near Rodeo, a mile from the Arizona-New Mexico line.

Several ungraded roads branch off from the two state highways and penetrate different parts of the two ranges. These roads, and all recognizable trails are indicated on the areal geologic map. Some roads shown on the Hachita quadrangle, as mapped in 1918, are no longer present, for arroyos have followed the incipient lines of drainage furnished by the old ruts and have completely obliterated them. Both ranges are accessible by automobile, although

Figure I. Index map of New Mexico showing location of Apache Hills and Sierra Rica



Apache Hills and Sierra Rica

P Playas quadrangle

H Hachita quadrangle

V Victorio quadrangle

BH Big Hatchet quadrangle

many of the roads such as that along the international boundary are passable with difficulty.

ECONOMY

The small population of Hachita is principally supported by work on the railroad, but in 1954 the town also possessed a general store, post office, garage, and cafe. The chief activity in the area is cattle raising for which Hachita serves as a shipping point. Within the last few years, farming has gained a foothold, cotton and hay being the main crops.

Mining has been sporadic. Most of the mines have been moderate to small operations. The last mining was at the Hornet mine in the Little Hatchet Mountains; this ended its three year operations in 1953. The last larger mining activity in the Apache Hills was at the Apache mine; this was worked for one year during the last war. Ore from all the mines in the area is shipped to the International Smelter at El Paso.

Hope for an economic resurgence of the area has been generated by the recent intensive interest of both mining and oil interests. Geophysical prospecting has been carried on by at least two petroleum companies and it has been reported that a sizeable acreage has been leased. In 1954, an unsuccessful wildcat well was drilled to a depth of 200 feet on a small Mississippian knoll in Hachita Valley one mile east of the Hatchet Ranch.

Cheap power for both mining and oil operations is readily available in Hachita as the town is connected with the local power lines of the Rural Electrification Administration. A further power source available is natural gas from the line of the El Paso Natural Gas Company twelve miles north of Hachita.

CLIMATE, FLORA, AND FAUNA

The weather is clear and dry and outdoor work can be carried on through most of the year without great discomfort. A Weather Bureau station has been in operation in Hachita since 1909. According to its records[1] the annual precipitation for 1953 was 8.34 inches. The average annual precipitation is about 10 inches. Approximately half of the annual total of rain falls during July and August in the form of thunderstorms of a torrential nature which occur in the late afternoon or evening. April, May, and June are the driest months and the rainy season invariably begins abruptly in July. The average annual temperature is about 60°F. However, temperatures above 100°F are common during the summer afternoons, though the temperature falls rapidly to about 65°F toward evening. The average winter temperature is about 40°F, though short periods of zero temperature are not uncommon.

Storms are remarkably local. The more mountainous sections generally receive far more precipitation than the valley areas. Similarly, the temperature is several degrees cooler in the hilly areas.

The Apache Hills and Sierra Rica are geographically a part of the Sonoran desert, a semi-desert region which embraces northern Mexico, southern Arizona, and New Mexico. Numerous varieties of the common desert plants, such as cactuses, yuccas, mesquite, and the like, are abundant in the valley area surrounding the

[1]U.S. Weather Bureau (1953), Climatological Data, New Mexico, Annual Summary.

ranges as well as on the bare and rocky slopes. There is no timber except for occasional scrub oak, cedar, and juniper trees, and the even rarer cottonwood trees which are found only near a source of water. The country was chiefly used for grazing and up to the recent drought and concurrent decline in beef prices it supported large herds of cattle.

The fauna includes species common to the southwest desert, notably rattlesnakes and other reptiles, rabbits, deer, peccaries, badgers, and coyotes. A herd of about 100 protected Mexican big horn sheep grazes in the Big Hatchet Mountains.

PHYSIOGRAPHY

This area of the state lies within the Mexican Highland section of the Basin and Range Province, a physiographic division characterized by isolated mountain ranges trending approximately north-south and separated by nearly level basins of interior drainage that have been filled with detritus derived from the surrounding hills. The Apache Hills and Sierra Rica, though having a trend considerably more eastward than is usual for the province, nevertheless conform to the general pattern as they are characterized by a straight base along the northeast and southeast flank of the hills and by the presence of a recently dissected pediment between each range and adjacent lowlands. The interior drainage of this physiographic province is confirmed in this area by the alkali crusts found in numerous places in the playas.

Topographically, Apache Valley, located between the Apache Hills and Sierra Rica, can be regarded as a playa. Nevertheless it is not entirely an area of interior drainage, for water from this valley ultimately enters Hachita Valley mostly by way of Doyle Creek which has cut through the divide separating the two. Similarly, the valley between the two ranges has not been developed into a pediment surface although there is a definite general and gradual slope of about 3° toward the center of the valley from both ranges. Numerous low rounded hills occur in the valley for insufficient time has elapsed since the subsequent faulting of the range to permit the leveling of such hills to the general surface of the surrounding pediment. However, the outer margins of the ranges facing Hachita Valley reflect well developed and dissected pediment surfaces not conspicuous at close range; it becomes striking only when the mountains are seen from distances of five or ten miles.

Both the Apache Hills and Sierra Rica consist of low rounded hills of about 1,000 feet in relief. The highest point in the Apache Hills is Apache Peak, with an elevation of 5,740 feet; in that part of the Sierra Rica under discussion the highest point is Doyle Peak (5,470 feet). The lowest elevations, approximately 4,400 feet, are those in the centers of the playas.

As the streams are ephemeral they carry on their erosional and depositional activities immediately after a rain. During such times the arroyos become raging torrents and the amount of transport and erosion then is phenomenal, enormous boulders and cobbles often being moved hundreds of feet into the playa beyond the position of the mouth of the stream. Upon entering the playa, these streams produce the alluvial fans so characteristic of the province. The eventual outlets of all the drainage for the two ranges are two valleys. The western outlet is Hachita Valley located between the Little Hatchet and Big Hatchet Mountains on the west and the Apache Hills and Sierra Rica on the east. The playa to the east between the Cedar Mountains and the Apache Hills, the Mimbres Drainage Basin of Schwennesen[1], receives the eastern past of the discharge.

WATER SUPPLY

All domestic water used in the Apache Hills and Sierra Rica is obtained from wells. Water for livestock is obtained either from wells or from stock ponds made by damming arroyos. The wells include those at the Faulkner, Donaldson, and Hatchet Ranches, as well as the railroad wells in Hachita. The only analyses of the well water that could be obtained are the following:

Analyses of water from two railroad wells at Hachita
(parts per million)

	Analysis 1[2]	Analysis 2[3]
Ca	16	29
Mg	2.6	5.2
Na and K	189	128
CO_3 and HCO_3	146	142
SO_4	145	206
C_1	44	29

[1]Schwennesen, A.T. (1918), Groundwater in the Animas, Playas, Hachita, and San Luis Basins, New Mexico, U.S. Geol. Survey Water Supply Paper 422, p. 10.

[2]Lasky, op cit, p. 11.

[3]Schwennesen, op cit, p. 143.

The railroad well at Hachita serves as domestic water for the town. It is some 800 feet deep and cuts four waterbearing horizons. A test of the well produced 100 gallons per minute during 42 hours of continued pumping. The water is considered fair for domestic use, poor for use in boilers, and good for irrigation.[1] Like virtually every other well in Hachita Valley, it contains 1.8 to 2 parts fluorine per million.[2]

In the few wells, scanty though the data are, the water level appears to be relatively shallow, although extreme variations were noted. The well at the Faulkner Ranch is 100 feet deep, with water at 40 feet. The Robin well goes 80 feet to water. The Chapo well (the former Chapo shaft) is 180 feet deep but found water at 60 feet. The Last Chance well (which uses the shaft of the same name) is 250 feet deep yet found water at 150 feet. The Donaldson well encountered water at a depth of 80 feet, the Doyle well at 170 feet. These figures were obtained from the owners of the ranches on which the wells are located. All utilize windmills for pumping.

The data indicate that on the northern slopes of the Apache Hills the water table is moderately shallow and constant being at depths of 40 to 100 feet. However, on the southern slopes, the water table is more irregular. For instance, both the old Apache shaft, 360 feet deep, and the newer shaft sunk in 1936, 500 feet deep, are dry. This is in sharp contrast with the Chapo well only 2-1/2 miles away which carries water at 60 feet. Another unusual feature is the fact that the Last Chance and Doyle

[1]Ibid, p. 143.

[2]New Mexico Bureau of Mines and Mineral Resources (1954), unpublished data.

wells, both of which are at lower elevation than the other wells, strike water at 150 and 170 feet respectively, much lower then the ground water table in the other wells in which data are available. Perhaps the reason for this anomalous behavior lies in the recent tectonic history of the range. The two wells last named appear to lie in the down-dropped block southwest of the Apache fault in which the movement may well have been of such recent origin that the water level has not had time to rise to its generally prevailing higher level.

LITHIC UNITS

GENERAL FEATURES

The rocks of the area consist in part of sediments, chiefly late Paleozoic and late Mesozoic, and extrusive flows and tuffs of Cenozoic age. The pre-Tertiary rocks are largely composed of clastics and limestones. Their sequence is difficult to decipher because of the large normal and thrust faulting they have suffered. Moreover, it is not clear whether various rock types represent one sequence or several different lithologic facies of two equivalent sequences. Since most of the Tertiary igneous rocks are essentially stratiform flows or tuffs, the following description presents all formations in chronologic sequence as nearly as this can be determined.

The oldest known rock in the area here described are Paleozoic sediments which occur in the Sierra Rica as klippen overlying the Lower Cretaceous sediments. These klippen, derived originally from Mexico, contain both Pennsylvanian limestones and Permian red beds. As in southeastern Arizona, no autochthonous

? What an extraordinary statement!

Pennsylvanian or Permian beds are found here though Pennsylvanian rocks are widespread throughout central New Mexico.

The major sedimentary rocks of the two ranges are Lower Cretaceous limestone and clastics, some 7,000 feet thick. The best exposures occur in the central and eastern sections of the Apache Hills. Isolated outcrops of Upper Cretaceous clastics were observed in both ranges.

Extensive exposures of intrusive and extrusive igneous rocks are common in the Apache Hills but are scarce in the Sierra Rica. With the exception of a few scattered trachyte and felsite sills and dikes, the only intrusive of any note in the Sierra Rica is a thick rhyolite sill, trending southeast, that bisects the range. The sill terminates just south of the mapped area, at the point where felsites are indicated (Plate 1).

Sedimentary rocks are overlain and intruded by andesitic and basaltic volcanics and by diorite and quartz diorite intrusives. The main mass of the Apache Hills is composed of a composite stock of monzonite and quartz monzonite which forms the backbone of the range and accounts for the highest peaks. The quartz monzonite of the stock is bordered on its southern flank by a contact metamorphic aureole which has developed in the Lower Cretaceous sediments. The major ore deposits of the region are closely related to the intrusion of the stock.

Intimately associated with the stock are porphyritic rhyolite dikes and flows. These are exposed on the southern slopes of the Apache Hills and partly adjoin and in the case of the dikes partly intrude the quartz monzonite and surrounding sediments.

The intrusive and extrusive rocks mentioned are generally referred to the early Tertiary whereas overlying igneous rocks are assigned to the middle or late Tertiary. Strictly, no more definite age can be established for these two groups of igneous rocks than that they are all later than the Lower Cretaceous; some of them may be Upper Cretaceous. For these igneous rocks, a system of grouping is used which places them in their general geologic order rather than to classify and assign each rock type to a specific subdivision of the Tertiary epoch. This grouping is preferred because evidence as to the exact age for each type is lacking. A broad natural time and rock division is available, though too general to afford a detailed classification, in that almost all the sediments are pre-Tertiary and all the igneous rocks are presumably Tertiary in age.

On the northern flanks of the Apache Hills, the surface rocks are flows of latitic composition which were extruded upon the beveled and eroded slopes of earlier intrusives. These in turn are succeeded by pyroclastic rocks, tuffs, breccias, and flows, which form the northwestern fringe of the Apache Hills. They can be traced northwestward across Hachita Valley to the Coyote Hills. These lavas and pyroclastic rocks are believed to be part of the lava fields of Mexico, Arizona, and New Mexico, the earliest representatives of which have been classified as Miocene (?) and the latest as Pliocene.[1] Still later, extrusions of local quartz latite and basalt flows, so fresh as still to show

[1]Callaghan, Eugene (1953), Volcanic rocks of southwest New Mexico, Guidebook, 4th Field Conference, New Mexico Geol. Soc., p. 143.

characteristic surface features, attest to the continuity of the igneous activity through the Pleistocene.

Numerous dikes and plugs of rhyolite porphyry and accompanying felsites are younger than all the other igneous rocks with the exception of the pyroclastics and latest flows. Weak mineralization is genetically associated with these late acidic intrusives.

Table 1 summarizes the general stratigraphy and lithology of the region.

PENNSYLVANIAN

Magdalena Formation

The formation as exposed in the Sierra Rica is composed entirely of massive blue-gray limestone, coarsely crystalline and abundantly fossiliferous, especially rich in crinoid stems. Interbedded are thin lenses of breccia containing angular limestone fragments half an inch or less in diameter, set in a matrix of gouge. The lens-like forms are probably secondary and due to thrusting. Chert lenses are also prevalent and no doubt for a similar reason. These beds can be correlated definitely with the Magdalena formation of southern New Mexico, a name applied to all of the Pennsylvanian in this part of the state. It may include some clastic beds, in addition to the predominating limestones.[1] ?

The Magdalena formation occurs as thrust sheets or klippen in the western part of the Sierra Rica overlying the Permian redbeds, the Corbett formation, and the unexposed Howells Ridge

[1]Flower, R.H. (1953), Paleozoic sedimentary rocks of southwest New Mexico, Guidebook, 4th Field Conference, New Mexico Geol. Soc., p. 111.

Table I.

Summary of lithologic sequence in the Apache Hills and Sierra Rica

AGE		FORMATION		THICKNESS	DESCRIPTION
Quaternary	Pleistocene to Recent	High alluvium	Mapped as one unit	0-25'	unconsolidated gravel, sand, and clay of ephemeral streams and arroyos; covers pediment surfaces
Quaternary	Pleistocene to Recent	Valley alluvium	Mapped as one unit	0-800'	unconsolidated gravel, sand, and clay underlying the pediment surfaces
		Disconformity			
Quaternary	Pleistocene	Basalt		100'+	several flows forming a prominent mesa east of Hachita
		Disconformity			
Middle and Upper Tertiary		Quartz latite		0-10'	one or several flows; occurs as isolated outcrops near Donaldson Ranch
		Disconformity			
Middle and Upper Tertiary		Pyroclastic rocks		0-500'	rhyolite breccia, tuff, flow, welded tuff, and rare interbedded thin latite
		Disconformity			
Middle and Upper Tertiary		Latite		250-500'	separable unit of latitic flows; includes some thin beds of welded tuff
		Disconformity			
Lower Tertiary		Last Chance volcanics		500'+	flows of andesite and basalt
		Disconformity			
Upper Cretaceous or Lower Tertiary		Skunk Ranch fanglomerate		50'	boulders, cobbles, and pebbles of Pennsylvanian and Cretaceous limestones
		Disconformity			
Lower Cretaceous		Corbett formation		2500'	interbedded massive orthoquartzite and red and green shale
Lower Cretaceous	Howells Ridge formation	Limestone-Sandstone member		815'	interbedded limestone, sandstone, shale, and minor conglomerate; metamorphosed
Lower Cretaceous	Howells Ridge formation	Rudistid Limestone member		40-350'	massive limestone; forms prominent cliffs
Lower Cretaceous	Howells Ridge formation	Orbitolina Limestone member		900'+	thin beds of dense blue limestone
Lower Cretaceous	Howells Ridge formation	Oyster Limestone member		900'+	thin-bedded limestone; contains coquina strata
Lower Cretaceous	Howells Ridge formation	Red Beds member		1000'+	red sandstones and shales
Permian		Abo formation		200'+	red beds with dolomite and gypsum lenses
Pennsylvanian		Magdalena formation		200'+	massive limestone

Upper Tertiary intrusives
- Felsite
- Rhyolite porphyry

Lower Tertiary intrusives
- Porphyritic rhyolite
- Quartz monzonite
- Monzonite
- Quartz diorite
- Diorite
- Dike rocks (trachyte, lamprophyre)

Abo formation and Magdalena formation: occur as thrust sheets formation. Topographically, it may either form high resistant ridges as in the western Sierra Rica, or it may occur as low rounded knolls, as in Hachita Valley and Apache Valley. In the southeastern part of the Sierra Rica in Mexico, outside the area here described, resistant ridges typical of the Pennsylvanian klippen were likewise seen from the air.

The maximum thickness of the Magdalena formation is at Doyle Peak where approximately 200 feet was measured. Comparable figures are not available from the Little Hatchet Mountains, but it is believed that since the Magdalena formation only occurs as klippen within this part of the state, the thickness varies greatly depending upon the amount of the rock involved in the thrust block.

Correlation with other Pennsylvanian formations to the west and north is based on fauna. Fossils noted include the coral *Chaetetes*, the bryozoan *Fenestella*, a Productid brachiopod, a Spiriferoid, and the fusulinds *Triticites*, *Fusulina*, and *Wedekindelina*. Lasky identifies the earliest fusulinds as *Triticites beedei* and *Triticites secalicus*.

PERMIAN

Abo (?) Formation

The small section of Permian rocks that occurs in the Sierra Rica can be tentatively correlated with the Abo formation (Wolfcampian) of central New Mexico on lithologic grounds. Whether this correlation is valid remains to be seen since recent work by Zeller in the Big Hatchet Mountains, where a more complete section occurs, indicates that the Permian there is more closely related to that of southeastern Arizona.[1] Further intensive investigation is needed before the complexities of the lateral gradations of the Permian from northern to southern New Mexico can be completely solved.

The one exposure of Permian red beds in this area is at the base of Doyle Peak where the facies occurs as a klippe overlying the Howells Ridge formation, here covered by alluvium, and the exposed Corbett formation. The red beds are in turn overlain by older Pennsylvanian limestones which represent a second stage of thrusting. The section measured at Doyle Peak is only a small part of the much thicker Permian section measured in the Big Hatchet Mountains where a thickness of some 4,000 feet has been reported.[2] The section below can be correlated with the middle part of the Big Hatchet Section.

Magdalena formation of block above thrust block

Thrust fault

<u>Top of Permian redbeds exposed on the north slope of Doyle Peak</u>

	Thickness of unit	Cumulative thickness
Dolomite	6 feet	6
Red sandstone, partially recrystallized, ? and shales, thin bedded; sandstone beds are one foot thick at maximum; shale beds average 6 inches in thickness; occasional gypsiferous lenses	140	146
Dolomite	2	148
Red sandstone and shale	20	168
Dolomite	1	169

[1]Flower, op cit, p. 111.

[2]Zeller, R.A. (1954), Personal Communication.

Limestone	1	170
Red sandstone and shale with limestone interbeds 6 inches thick	9	179
Interbedded red shale and beds of limestone and dolomite one foot thick; gypsiferous lenses	15	194
Red and green shale	5	199
Dolomite, fine grained, dense, dark blue; weathering grayish-green	2	201
Blue-gray limestone, fine grained, dense	9	210
Alluvium		
Total	210 feet	

In other areas in the state, the boundary between the Pennsylvanian and Permian is difficulty recognized because of similar lithologies and faunas at the contact; for the most part, the rocks of the two systems can only be distinguished on the basis of rare fusulinid genera. In the area here described, however, thrusting has avoided that problem for Pennsylvanian and Permian rocks are nowhere in contact in chronologic order. Fossils are rare in the section described above, only an occasional brachiopod being noted in the limestone, together with numerous worm trails and borings. But even lithologically, the Permian age of the section can be definitely established by comparison with more fossiliferous exposures elsewhere.

LOWER CRETACEOUS

Howells Ridge Formation

General Description

The Howells Ridge formation is named from the type locality described by Lasky in the Little Hatchet Mountains. That section and the one from the Apache Hills, as well as an analogous one from the Big Hatchet Mountains, are all similar in lithology and thickness, with only minor variations.

The Howells Ridge formation occurs in both the Sierra Rica and Apache Hills. In the latter, the exposure is just east and west of the International mine. Here, all of the formation, except the youngest member can be seen. Parts of the formation, particularly the upper limestone units, also crop out as fault blocks between the Chapo mine and the International mine. Similarly, a fairly complete section is exposed at and southwest of the Occidental mines. In both ranges, one of the uppermost members, a massive, fina grained blue limestone, is commonly a cliff builder and tends to form a dip slope on the back side of the ridge (Figure 2). Topographically, the higher hills are underlain by limestone while the lower areas are underlain by the less resistant red sandstone and shale.

This formation is the oldest Cretaceous formation in the area. It is believed to overlie Permian red beds though no such contact has been seen in the Apache Hills or the surrounding areas. The Howells Ridge formation is probably not underlain by Triassic or Jurassic rocks since no trace of Triassic or Jurassic sediments is known in this area or within this corner of the state or in adjacent parts of northern Mexico. The sharp demarcation between the predominant limestone below and the first thick quartzitic bed of the overlying Corbett formation was chosen as the upper limit of the Howells Ridge formation.

Subdivisions

For purposes of structural emphasis, the formation has been subdivided into five different units or members, each of varying thickness. The lowest member, dominantly clastic, consists primarily of red and green shale, siltstone and sandstone with occasional limestone conglomerate lenses and red limestone. A striking feature of this member is the abrupt intertonguing of beds through a short lateral distance (Plate 11). This unit is here termed the Red Beds member. The next oldest unit, the Oyster Limestone member, is composed of dense fine to medium grained crystalline blue-gray limestone, including some coquina-like beds consisting almost entirely of oysters. The middle member includes thick to thin beds of dense blue limestone characterized by numerous <u>Orbitolinas</u> and less prevalent echinoids. This bed is termed the Orbitolina Limestone member. The next youngest unit, here called the Rudistid Limestone member, is the massive cliff-building limestone referred to above, which contains abundant rudistid fossils. The youngest member consists chiefly of interbedded limestone and sandstone with less common interbeds of shale and conglomerate. It is here designated the Limestone-Sandstone member to stress its chief characteristic.

This member has been thermally metamosphosed in a striking manner along the southern slopes of the Apache Hills west of the Chapo mine area.

Generally sills and dikes of various igneous rocks cut this formation, but in the section measured they happen to be rare. Trachyte, lamprophyre, and felsite are common in all members, whereas diorite is confined to the base of the Rudistid Limestone and quartz diorite to the youngest member of the Howell Ridge formation.

Detailed Succession

Section from Border Post No. 38 northwest*

Alluvium

Top of Section of Limestone-Sandstone member

	Thickness of unit	Cumulative thickness
Limestone conglomerate	2 feet	2
Interbedded variegated orthoquartzite and green shale. Thickness includes two trachyte sills totalling approximately 10 feet	139	141
Trachyte sill	5	146
Gray and red orthoquartzite with trachyte sills	45	191
Variegated orthoquartzite	146	337
Andesite sill	18	355
Medium grained variegated sandstone	47	402

*Base of section started at Border Post No. 39 and continued northwest to a point 250 feet west of the Ford Prospect. Measurement of the Orbitolina and Rudistid Limestone members commenced at the stream bed north of Border Post No. 39 and continued north-northeast to the top of the massive limestone. The measurement of the youngest unit started at SW.1/4, SE.1/4, SE.1/4, section 1, T.29S., R.14W. and continued in a general S.60°E. direction until concealed by alluvium.

Red and brown orthoquartzite with interbedded thin blue limestone lenses	37	439
Coarse grained reddish-gray arenaceous and fossiliferous limestone	2	441
Reddish-brown sandstone, coarse and gritty	8	449
Blue limestone	48	497
Interbedded limestone and sandstone	16	513
Red, gritty, coarse grained sandstone	28	541
Gray argillaceous sandstone	19	560
Red to brown coarse grained sandstone	12	572
Gray argillaceous sandstone and pure sandstones fine to medium grained, thin bedded	25	597
Blue limestone	24	621
Andesite sill	32	653
Interbedded limestones and argillaceous sandstone	35	688
Blue limestone, thin bedded	19	707
Red to brown medium grained sandstone	35	742
Blue limestone, thin bedded	41	783
Greenish-gray siltstone	13	796
Interbedded blue limestone and green shale in beds 6 inches thick	12	808
Blue limestone, fine grained and dense, thin bedded with average thickness of 1 to 2 feet	29	837
Total Limestone-Sandstone member	837	
	− 65	
Basic sill	772	

<u>Rudistid Limestone member</u>

Blue massive limestone, fine grained or dense, about 45 feet thick, a prominent cliff-building unit, extremely fossiliferous, with abundant <u>Toucasia</u> and <u>Orbitolina</u>. (Other measurements of this member at NW.1/4, SE.1/4, section 35 T.28S., R.14W. and at NE.1/4, NE.1/4, section 2, T.29S., R.14W., reveal a thickness of approximately 250 and 350 feet respectively)	45

Orbitolina Limestone member

Blue-gray limestone, dense and fine grained; individual beds vary in thickness from one to five feet, becoming thicker toward the top, rich in *Orbitolina*.	873	

Oyster Limestone member

	Thickness of unit	Cumulative thickness
Alluvium above bed rock, introducing uncertainties as to maximum thickness		
Interbedded shale and siltstone	20	20
Oyster-rich limestone, each bed 4 feet thick	16	36
Blue, fine grained limestone, fossiliferous	14	50
Oyster-rich limestone with *Exogyra* up to 6 inches in length; beds vary from 2 feet to 8 feet thick	59	109
Oyster-rich limestone with green shale interbeds	20	129
Blue limestone, fine grained	36	165
Oyster-rich limestone with *Pecten*	8	173
Blue, dense argillaceous limestone	10	183
Blue limestone, fine grained	17	200
Interbedded gray shale and fine grained limestone	33	233
Interbedded finely and coarsely granular limestone	43	276
Calcareous gray sandstone	7	283
Red, coarse grained limestone	5	288
Blue, coarse grained arenaceous limestone	5	293
Gray orthoquartzite	100	393
Oyster-rich limestone	5	398
Blue limestone, medium to fine grained, arenaceous in part, fossiliferous	47	445
Arenaceous limestone	10	455

Interbedded coarse and fine grained limestone	45	500
Interbedded fine grained blue limestone, and green shale and calcareous shale	35	535
Coarse grained blue limestone in occasional outcrops	500	1,035
Coarsely granular calcareous sandstone	2	1,037
Interbedded coarse and fine grained blue limestone	77	1,114
Blue, coarse grained limestone with arenaceous lenses	10	1,124
Oyster-rich limestone	6	1,130
Blue, coarse grained limestone	10	1,140
Gray, coarse grained arenaceous limestone	8	1,148
Interbedded fine and coarse grained thin bedded blue limestone 3 to 5 feet thick with arenaceous layers and thin trachyte sills	70	1,218
Red, fine grained arenaceous limestone	2	1,220
Blue, thin bedded, coarse grained limestone with sandy layers 2 to 3 feet thick	27	1,247
International fault		

Total Oyster Limestone member 1,247 feet

Red Beds member

	Thickness of unit	Cumulative thickness
Alluvium		
Red argillaceous sandstone	15	15
Conglomerate composed of limestone pebbles in a sandy matrix	3	18
Red and gray, thin bedded, shale and siltstone	117	135
Red siltstone	6	141

Red, fine grained limestone	3	144
Red shale, thin bedded	14	158
Red orthoquartzite	38	196
Interbedded red shale, sandstone, and limestone conglomerate lenses	25	221
Concealed	23	244
Red and buff sandstone and shale	77	321
Red and gray sandstone, in part quartzitic	19	340
Red and gray variegated shale and siltstone	125	465
Interbedded red shale and thin dolomites	39	504
Concealed	47	551
Limestone conglomerate consisting of limestone pebbles and cobbles in a fine grained sandy matrix	31	582
Red shale	10	592
Reddish-brown medium grained sandstone	44	636
Interbedded blue cherty limestone and brown medium grained sandstone	36	672
Buff to gray, thin bedded, coarse grained sandstone, in part quartzitic	40	712
Interbedded thin bedded, blue, fine grained limestone and brown fine grained sandstone	89	801
Concealed	245	1,046
Buff to gray shale	57 +	1,103
Gray sandy limestone, cherty and thin bedded	40 +	1,143
International boundary		
Total Red Beds member	1,143 +	

Paleontology

The fossils found and identified by the author include the gastropods Tylostoma and Nerinea and the ammonite Douvilleiceras, all three of which were noted in the oldest limestone bed of the Red Beds member. The same bed also contains an unidentified belemnoid. The lower member is for the most part singularly devoid of fossils in the clastic beds; however, the limestone beds do contain occasional examples of Pecten, Turritella, and oysters. The Oyster Limestone member, on the other hand, is conspicuously rich in fossils, the most striking being entire beds of oysters which form coquina-like strata varying in thickness from 2 to 10 feet. The "oysters" are mostly Exogyra and less commonly Ostrea. The other limestone beds of this member are also fossiliferous but they contain a more varied fauna which includes, besides oysters, the gastropods Turritella and Tylostoma and the pelecypods Arctica, Trigonia, and Pecten. The fauna of the middle member is strikingly different from the other two in that it contains abundant specimens of Orbitolina throughout; numerous echinoids identified as Hemiaster are confined to the upper part of the member. An unidentified bryozoan was also noted in that part of the section, as well as the pelecypod Arca. The cliff-forming member is characterized by large specimens of the pelecypod Toucasia, a rudistid; associated with it are subordinate numbers of Orbitolina. The overlying youngest member contains toward its base numerous Orbitolinas which occur in marked clusters scattered throughout the limestone beds.

Other specimens from the same formation in the Little Hatchet Mountains[1] include Beudanticeras hatchetense Scott, Trinitoceras reesidei Scott as well as Tylostoma c.f. mutabilis Gabb. The dominant fossils of the oyster beds have been identified as Exogyra quitmanensis Cragin.

Corbett Formation

General Description

The Corbett formation is named from the type locality described by Lasky in the Little Hatchet Mountains, with which the occurrences in the area here discussed can be directly correlated. It is analogous to the Sarten sandstone, a term used by Darton on his geologic map of the state and in his report on Luna County.

In the Sierra Rica, the Corbett formation, occurring as a wide band in the western part of the range, conformably overlies the Limestone-Sandstone member of the Howells Ridge formation. In the Apache Hills, the Corbett formation is apparently missing either through non-deposition or subsequent erosion. In the Sierra Rica, the contact between the Howells Ridge formation and the Corbett formation is obscured to the southwest by the intrusion of a porphyritic rhyolite sill 1,000 feet thick along the contact. The contact between this sill and the Corbett formation is beyond the limits of the area covered by this report. From Doyle Peak southwest, the formation is overlain by Pennsylvanian limestone and Permian red beds which have been overthrust from the south or southwest.

[1]Lasky, op cit, p. 18.

Topographically, individual beds of the formation produce prominent parallel ridges or hogbacks whereas the less resistant beds are marked by troughs. Lithologically, the unit consists of thick, massive, well cemented orthoquartzite, with interbedded red and green shale. The orthoquartzite contains subangular to well rounded quartz grains. Quartz composes more than 95% of the rock; other constituents include rare feldspar and mica. The colors of the rock range from gray through red to brown. In many places, manganese staining imparts a black color to the rock. Cross bedding and ripple marks are occasionally noted. Banding is very common. Petrified wood, commonly stained black, is another characteristic feature.

The contact between the Howells Ridge and Corbett formations is here drawn at the top of the youngest limestone bed in the upper Howells Ridge member. The top of the Corbett is not exposed in the area here described since it is either covered by alluvium or overlain by Pennsylvanian klippen.

A section giving a reliable maximum thickness was measured from points known to be at its base and at the highest exposed bed, as plotted on an enlargement of the topographic map. This indicated an approximate thickness of 2,500 feet, which is in fair agreement with the thickness of 3,000 feet measured in both the Little and Big Hatchet Mountains. The beds are dominantly quartzitic sandstones (probably orthoquartzites) and range from ten to 40 feet in thickness, as contrasted with the thickness of beds in the interbedded shale and siltstone, about a foot at most.

Paleontology

No fossils were found in the orthoquartzite but some poor unidentifiable specimens were noted in the shaly interbeds. In the Little Hatchet Mountains, however, in a thin limestone bed at the base of the formation, the following fossils were identified: Trigonia sp., Protocardia sp., Arctica sp., A.medialis (Conrad), and Neithea occidentalis.[1]

CORRELATION OF THE LOWER CRETACEOUS SEDIMENTS

All the lower Cretaceous sediments of the Apache Hills and Sierra Rica can be correlated with rocks of similar lithology either in the Little Hatchet Mountains or the Big Hatchet Mountains or both. The main bulk of the sediments appears to be Trinity (Lower Cretaceous or Comanchean) in age, as established by Lasky on the basis of fauna in the Little Hatchet Mountains. In that range some 15,000 to 20,000 feet of Lower Cretaceous rocks are exposed. This contrasts with the 7,000 to 8,000 feet of Lower Cretaceous found in both the Apache Hills and Big Hatchet Mountains.[2] These two sections are similar to the Lower Cretaceous section of southeastern Arizona.[3] An exception to this consistent pattern of Lower Cretaceous deposition is the thick section in the Little Hatchet Mountains.[4]

[1]Lasky, op cit, p. 24.

[2]Zeller, R.A. (1953), Lower Cretaceous stratigraphy of southwest New Mexico, Guidebook, 4th Field Conference, New Mexico Geol. Soc., p. 143.

[3]Stoyanow, A.A. (1949) Lower Cretaceous stratigraphy in southeastern Arizona, Geol. Soc. Amer. Mem. 38, pp. 4-12.

[4]Lasky, op cit, pp. 16-26.

However, it is believed that the section there may involve some duplication by faulting. Further work being conducted in that area by Robert A. Zeller of the New Mexico Bureau of Mines will test this belief.

In general the succession of beds in the Lower Cretaceous consists of a lower clastic unit followed by massive limestone beds which in turn are overlain by an upper clastic unit. This sequence was first observed in the Bisbee, Arizona area,[1] where a composite thickness of about 5,000 feet was measured. The section there consists of a lower clastic unit, the Morita formation, largely red beds, comparable to the Red Beds member of the Howells Ridge formation; overlying it is the Mural limestone which can be considered equivalent to the four limestone members of the Howells Ridge formation; the youngest unit, clastic in nature, the Cintura formation, can be tentatively correlated with the Corbett formation.

UPPER CRETACEOUS (OR LOWER TERTIARY)

Skunk Ranch Fanglomerate

The Skunk Ranch fanglomerate derives its name from the type locality in the Little Hatchet Mountains. The rocks there exposed as constituents of the formation can be directly correlated with the thinner section of the same formation cropping out in the Apache Hills and Sierra Rica. In the present description fanglomerate is used in place of conglomerate, as applied in the Little Hatchet Mountains, for reasons to be shortly explained.

[1]Ransome, F.L. (1904), The geology and ore deposits of the Bisbee quadrangle, Arizona, U.S. Geol. Survey Prof. Paper 21, pp. 56-73.

The Skunk Ranch fanglomerate lies disconformably upon Paleozoic and Cretaceous sediments. West of the Daisy mine and in the immediate vicinity of the mine, the fanglomerate occurs as thin beds uncomformably overlying the Rudistid Limestone member of the Howells Ridge formation (section C-C' on Plate 1, Plate 10). In the same general area scattered remnants of the formation occur locally overlying the Rudistid Limestone member as well as the younger Limestone - Sandstone member. Another area of exposure is east of Doyle Peak where the fanglomerate rests uncomformably upon older Pennsylvanian limestone and was apparently involved and carried along with the thrusting.

In the Apache Hills, the formation consists largely of conglomerate-boulders, cobbles, and pebbles of limestone cemented by iron oxide, in a matrix of coarse red sandstone. Igneous rocks are conspicuously lacking among the boulders. Laterally there may be a gradation to sandstone conglomerate boulders and to a fine grained sandstone matrix. Interbeds of green shale were noted locally. Chert lenses, probably of secondary origin, are very common. The average diameter of the cobbles is about 4 inches, but some range up to 1-1/2 feet in diameter. The limestone boulders and cobbles contain Paleozoic and Cretaceous fossils, crinoid stems characteristic of the Magdalena formation, and <u>Orbitolinas</u> from the Howells Ridge formation. The reason for the term fanglomerate is thus obvious.

In the Apache Hills, the thickness of the fanglomerate varies from 10 feet to about 50 feet at its best exposure, whereas in the Little Hatchet Mountains the thickness, as determined by Lasky, is 3,300 feet. A similar thickness holds for the Big Hatchet Mountains. The discrepancy may be accounted for by assuming that the Apache Hills and Sierra Rica represent the outer limits of Skunk Ranch deposition, or by assuming that a more intense erosion was localized to the Apache Hills. Considering the local nature of such a non-marine fanglomeratic unit of this type, the first explanation seems more probable. The fact that many of the large boulders and cobbles are of rocks now found in the Little and Big Hatchet Mountains supports the same concept.

The only fossils found in this formation were in the boulders and cobbles, not in the matrix; thus paleontologic evidence as to the age of the formation is lacking. However, lithology, unconformable base, and relationship to tectonic features all point to a late Cretaceous (post-Corbett or later) or early Tertiary age. Yet, if of Tertiary age, it was certainly deposited prior to any of the igneous activity of that time. Its relationship with the Last Chance volcanics is not entirely clear but there is at least no evidence that points to the fanglomerate as being younger than the volcanic unit.

SUMMARY OF THE IGNEOUS ROCKS

The igneous rocks of the area include some fifteen distinguishable units. The petrographic features and relative ages are discussed under each unit. Their relation to mineralization is graphically indicated in Table 2.

Although an attempt is made to relate each rock unit to a chronologic sequence, adequate field evidence for some of the assigned ages is lacking. For example, the age relations of certain dike rocks transecting only Lower Cretaceous sediments cannot be determined with confidence. Similarly, the exact ages of many of the later flows and tuffs is not determinable because of the lack of interbedded Tertiary sediments and associated fossils. In such cases, ages were tentatively assigned by comparison of lithologies with those of other local areas where age determinations were more soundly based and have received general acceptance. A good example of this procedure is the correlation of the diorite and quartz diorite intrusives of this area with those at Silver City; the latter have been classified as early Tertiary, prior to the emplacement of the major stocks.[1]

Despite the general acceptability of such lithologic correlation, certain problems arise in assigning a specific age to some igneous rock units. For example, rhyolite porphyry dikes that cut the earliest mafic flows exposed in Apache Valley, though lithologically similar, may be earlier in time than those exposed on the northwestern flanks of the Apache Hills. Likewise, the mafic flows of Apache Valley may not be of the same period as those in the vicinity of the Queens Taste mine. Nor can the Apache Valley mafic rocks be correlated with the mafic sill exposed southeast of the Daisy Mine, though alike litholo-

[1]Hernon, R.N., Jones, W.R., and Moore, S.L. (1953), Some geologic features of the Santa Rita quadrangle, Guidebook, 4th Field Conference, New Mexico Geol. Soc., p. 123.

gically and possessing generally analogous primary structural features. Variations are to be expected in any group broadly classified on the basis of composition, and the many uncertainties make any such correlations tentative at best.

Broadly, early Tertiary igneous rocks differ from later Tertiary rocks by containing deuteric or hydrothermal epidote. The early Tertiary intrusives - whether diorite, monzonite, or trachyte - are characterized by abundant pistacite which has imparted to some rocks a dark green color. The only exception is the Last Chance group (mainly mafic flows and intrusions) which, although containing epidote, has less of it than the other but more nearly intermediate rocks of the same age. In many mafic rocks, chlorite is an accompanying alteration mineral, though usually of minor occurrence in the intermediate rocks. In contrast, the later Tertiary rocks are characterized by the absence of epidote but are generally chloritized. The ore deposits of these periods are distinguishable in like manner. At the Apache and Chapo mines, epidote is a prevalent and persistent gangue mineral whereas all the other ore deposits in the Apache Hills and Sierra Rica known to be later in age contain much chlorite and only rare epidote. This alteration association is not merely distinctive of the Apache Hills, but is apparently common to the surrounding ranges.

UPPER CRETACEOUS OR LOWER TERTIARY IGNEOUS ROCKS

Last Chance Volcanics

General Description

The Last Chance volcanics derive their name from their most prominent occurrence near the site of the Last Chance mine. The formation crops out as two major bands extending across the playa between the Apache Hills and Sierra Rica. Both bands are composed of porphyritic andesite and basalt flows and plugs with occasional flow breccias, breccia plugs, and more rarely silicic tuffs. Southeast of the Daisy mine, the same rock type, primarily of basaltic composition, presumably occurs as a sill between the Rudistid and Limestone - Sandstone members of the Howells Ridge formation; north of the Daisy mine, the volcanics occur as andesite and basalt flows and dikes. In all three localities the rocks form low rounded hills separated from each other by shallow arroyos and alluvium. The flows rest unconformably upon the eroded surface of the Howells Ridge formation (section C-C' and D-D' of Plate 1).

The exact thickness of the formation cannot be adequately determined because neither top nor bottom are exposed. Moreover, the scarcity and difficult interpretation of flow structures or other guides to the bedding make the plotting of thicknesses very difficult. However, inferences based on cross-sections seem to support a thickness of 500 feet for the sill and probably a similar thickness for the flows. The figures are questionable as the thickness should vary locally depending on the erosional surface upon which the flows were extruded. An inconclusive attempt to measure a section south of the Apache fault resulted in similar figures. The measurement was complicated by the intrusion of mafic plugs, felsites, and rhyolite porphyry dikes, as well as by the Apache fault which has drag-folded some of the flows. The few places where true bedding could be measured in the flows show a north dip near the Last Chance mine and a south dip near the Quartz prospect.

Age and Correlation

The age of this formation is in doubt because the lack of sharp contacts prevents accurate determination of the upper and lower limits of the unit. The uncertainty is also caused by the lack of interbedded sediments and accordingly of fossils. In his description of the Little Hatchet Mountains, Lasky assigns the Last Chance formation to the Lower Cretaceous, regarding it as underlying and hence older than the Howells Ridge formation. In the Little Hatchet Mountains, the unit is called the Hidalgo volcanics by Lasky who concludes after a short visit to the Apache Hills that he was able to correlate the Hidalgo volcanics with the volcanics here described from the Last Chance area. The same unit is cited as occurring in the Lordsburg mining district and in the Florida Mountains southeast of Deming. These and other areas are cited by Lasky to prove the Lower Cretaceous age of the Hidalgo volcanics and its equivalents. Yet all the evidence in the area here described points to a post-Cretaceous age.

In the Apache Hills, the relative age, at least, of the Last Chance volcanics can be readily determined. The volcanics are older than the rhyolite porphyry dikes which intrude them since the latter contain andesite fragments in many places; the Last Chance volcanics are overlain by latites and rhyolite flows and tuffs near and southeast of the Luna mine; they are themselves intrusive into Howells Ridge sediments southeast of the Daisy mine. No direct evidence is available regarding their age relative to the Corbett formation since the two formations are nowhere contiguous. It is hardly to be expected that so resistant a formation as the Corbett, once deposited, would be completely eroded leaving no remnant whatever; it seems more probable that the lack of the Corbett formation in the Apache Hills stems entirely from lack of deposition rather than complete erosion. In view of this probability it appears justifiable to assume that the sediments assigned to the Howells Ridge formation were once deposited in the Apache Hills; subsequently, leveling of this surface occurred and then the Last Chance flows were poured out over it. Three other kinds of evidence point to an age later than the Howells Ridge formation and most probably either late Cretaceous (i.e., later than the Skunk Ranch formation) or early Tertiary. First, dikes of andesite of the same composition (and therefore probably of similar age) occur sporadically in the Limestone-Sandstone unit of the Howells Ridge formation southwest of the Daisy mine. Second, similar intrusions occur in the Orbitolina Limestone member of the Howells Ridge formation along the crest of the anticline just north of Border Post No. 39, though too small to be indicated on the map. Third, conditions at the Apache fault strongly suggest again that the Last Chance volcanics are younger than the Howells Ridge formation; these conditions are explained in the section on Structure.

The relation between the Skunk Ranch fanglomerate and the Last Chance formation could not be definitely ascertained. This is because, though both overlie unconformably the Howells Ridge formation in the Apache Hills, they are not in contact with each other. However, two isolated outcrops of fanglomerate occur in the basalt sill, both of which may well represent xenoliths or blocks picked up and incorporated during the sill's intrusion.

In review, the Last Chance volcanics are younger older than the Lower Cretaceous and may be as young as Upper Cretaceous and possibly even Lower Tertiary. Volcanics similar in age to those discussed have been recently mapped in the Lake Valley[1] and Dwyer[2] quadrangles near Deming, about 50 miles away from the region here described. ? WEE

I have no idea what the age of the Dwyer quad andesite volcanics might be, other than that they are post-Colorado pre-Pliocene. In the Steeple Rock area the oldest volcanics are post-Colorado and pre-Hell Creek or Lance WEE

Petrography

The formation consists almost wholly of basalt and andesite. It is made up of flows, dikes, and plugs with subsidiary tuffs and breccias. The flows compose about 75% of the unit. Their lineation is seen with difficulty, partly because they are

[1] Jicha, H.L. (1955), Geology of the Lake Valley quadrangle, New Mexico, New Mexico Bur. Mines and Min. Res., Bull. 37.

[2] Elston, ~~Wolfgang (1954)~~ W.E. 1957, Geology and mineral deposits of ~~the~~ Dwyer quadrangle, Grant, Luna and Sierra counties, New Mexico, New Mexico Bur. Mines and Min. Res., ~~unpublished manuscript~~ Bull. 38.

generally poorly exposed on the low rounded outcrops; prospect pits usually show these igneous features to a moderate degree. In outcrop, the rocks range from occasional green through greenish gray to black and deep violet. Generally, the flows, dikes, and plugs contain numerous large phenocrysts; feldspar phenocrysts up to an eighth of an inch in diameter are not uncommon. Sill rocks, whether andesite or basalt, on the contrary, are equigranular and contain few phenocrysts.

Microscopically, the formation is characterized by euhedral phenocrysts of plagioclase, mostly andesine though labradorite is also widespread. Zoned plagioclase is also abundant and ranges from labradorite in the core to andesine and, less commonly, oligoclase in the rims. Polygonal outlines of olivine phenocrysts, for the most part converted to antigorite and iddingsite with brown pleochroism, are prominent in some of the more basaltic members. Certain andesite dikes are characterized by phenocrysts of dull black augite or hornblende, up to half an inch in length. One dike of this kind was observed at the Cochise vein; others are at the Big Shiner mine. In these, zoned plagioclase is conspicuously absent.

Ferromagnesian minerals other than olivine, include hornblende, usually in phenocrysts with green to brown pleochroism; brown pleochroism is characteristic of oxyhornblende. Augite is present as phenocrysts, commonly badly chloritized, and as part of the groundmass interlocked with labradorite laths; together these two minerals produce the ophitic texture so usual in basalt. Biotite, though only rarely observed, appears in large phenocrysts as much as 4 mm. long, with brown pleochroism.

Magnetite is a primary constituent within the groundmass and an alteration product of the ferromagnesian minerals. Apatite and zircon are accessory minerals which in some cases are the cause of pleochroic haloes in biotite.

Quartz occasionally occurs as phenocrysts and as part of the matrix within the volcanics. In some specimens there is about 15% quartz which would warrant terming the rock a dacite (quartz andesite) or perhaps even a quartz basalt.

Amygdules of chlorite, calcite, quartz, chalcedony, and rarely analcite are fairly common, the first three being most prevalent. The amygdules are generally concentrically banded; quartz forms the outer band, calcite appears next, and chlorite fills the central portion of the amygdule. Individual amygdules composed solely of these minerals are also present.

The matrix of the rock varies, depending on whether it is a flow, a tuff, or an intrusive. In the flows, the texture is generally glassy and flow lines, if not noted in outcrop, are commonly observed in thin sections as swirls. In tuffs, a glassy devitrified matrix with thin delicate streaks or laminae is noted. In intrusives, the texture of the groundmass ranges from partly glassy to entirely crystalline, the latter consisting of a matte of plagioclase laths and microliths. The grain size of some intrusive varieties is almost coarse enough to make the rock diabase.

Some pyroclastic beds of the formation were noted in the hills south of Border Post No. 40 where breccia pipes are exposed. Here the breccia fragments are cemented by hematite, each fragment consisting of devitrified glass containing aligned plagioclase laths and occasional augite phenocrysts. Near the Last Chance mine, a light green amygdaloidal flow breccia with well developed lineation contains closely spaced clusters, each cluster consisting of angular crystals of albite, sanidine, and quartz within a partially devitrified groundmass. In the same general area, thin tuffs, of silicic composition occur interbedded with more numerous basaltic flows. These tuffs are generally light violet, possess a delicate lamination upon close observation, and contain in many places numerous unoriented inclusions an inch or less in diameter. Some of the tuffs are welded.

Another variation in the formation is the occurrence of the dacite previously mentioned, exposed in the eastern part of Apache Valley adjacent to the international border. It is marked by a topographic contrast in that the dacites and associated hornblende and biotite andesites form high hills rather than low rounded knolls. Each rock mass of such high hills apparently represents a thick short flow or a steep sided volcanic neck or both. Though not studied in detail these high hills appear to be more siliceous and alkaline than other parts of the Last Chance volcanics and could thus grade into the dacites exposed along the flanks of the hills. There are no surface lithologic or structural features to indicate that the dacite and andesite are two separate flows. For the most part, the dacites and the hornblende andesites are similar in appearance and contain needles of oxyhornblende half an inch long and trachytic in arrangement, as well as zoned plagioclase phenocrysts and andesine and oligoclase laths. The groundmass is subtrachytic and contains varying amounts of interstitial quartz. Zircon and pyrite are common accessories. Sericitization of the plagioclase, especially the zoned ones, is notable.

Alteration of all members of the formation is particularly pronounced. The alteration minerals consist of abundant chlorite, calcite, sericite, and rare epidote. This is in sharp contrast to the more silicic intrusions and surrounding sediments, in which epidote is the dominant alteration mineral.

Variations in mineralogy particularly in regard to quartz, tend to produce members that may be classified as dacites while variations in grain size result in rocks that may be termed diabase. Since these variations are difficult if not impossible to discern on the outcrop, the grouping of all these rocks under one formation seems the most feasible treatment. Certainly andesite and basalt of similar texture, color, and mode of outcrop could not be distinguished from each other in the field. For purposes of identification, the two types were distinguished on the basis of plagioclase composition, i.e., rocks with labradorite were considered basalts regardless of the nature and content of the associated ferromagnesian minerals.

LOWER TERTIARY IGNEOUS ROCKS

Diorite Porphyry

Diorite sills represent one of the earliest periods of igneous activity in the Apache Hills and have been tentatively correlated with the diorite rocks of late Cretaceous age in the Little Hatchet Mountains and at Silver City. In the Apache Hills, diorite occurs as thin sills 20 to 25 feet thick and 150 to 300 feet long, intrusive into the Orbitolina Limestone member of the Howells Ridge formation, just below the Rudistid Limestone member (Figure 3). Such a diorite sill can be traced easily in the field as it may form a topographically resistant ridge. There are only two occurrences of diorite in the Apache Hills - one on the hill just northeast of the Mairland mine, and the other, much smaller in extent, northwest of Border Post No. 39.

The rock from the outcrop near the Mairland mine has a dull brown color on weathering, and consists of prominent phenocrysts of gray feldspar and altered hornblende in a fine grained crystalline groundmass. Microscopically it is composed of euhedral to subhedral phenocrysts of andesine averaging 2 mm. in diameter, and zoned plagioclase, with labradorite or andesine in the center and oligoclase or albite on the borders. Green pleochroic hornblende, partially chloritized, occurs in subhedral prismatic grains. The groundmass is holocrystalline and medium grained; it is composed of orthoclase with occasional hornblende and some interstitial quartz. Orthoclase constitutes up to 15% of the total composition.

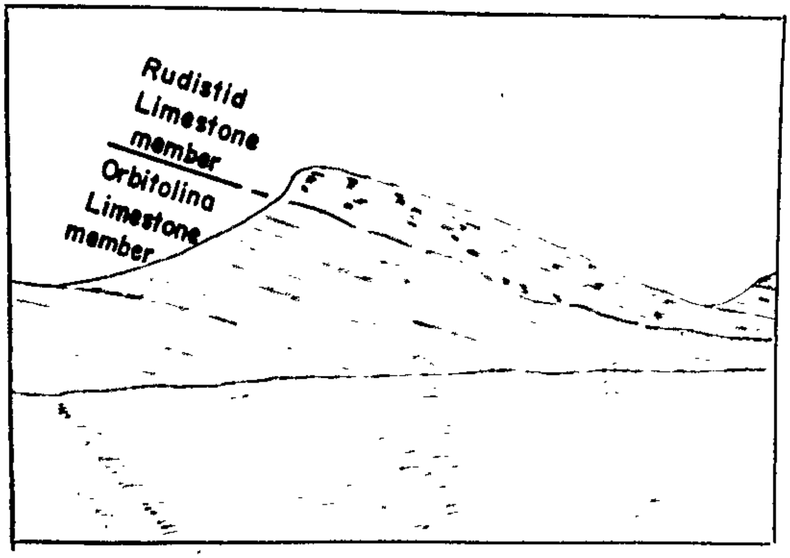


Figure 2

Dip slope on the Rudistid Limestone member. View looking west from the International mine.

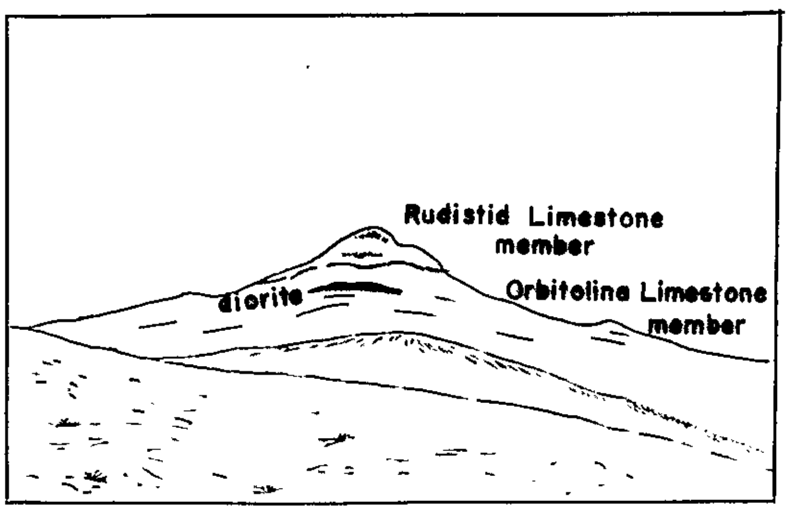


Figure 3

Looking east from the Chapo mine toward the cliff-forming Rudistid and Orbitolina Limestone members. A diorite sill crops out near the base of the Rudistid Limestone member.

Accessory minerals include magnetite, rare sphene, and apatite. The latter exhibits well developed hexagonal cross sections and elongated prisms 0.5 mm. in length. Deuteric alteration is pronounced, the hornblende having been changed to either anomalously birefringent chlorite or epidote together with rarer hematite and calcite. The feldspars are altered to sericite, chlorite, and calcite, the calcite almost entirely replacing the feldspar crystals. Some of this calcite may well have been derived from the surrounding rocks. There is differential alteration as the unzoned plagioclases have been more widely converted to chlorite and calcite than the zoned plagioclases. This is the converse of what occurred in the other intrusions in the range.

An approximation of the composition indicates that the volume ratios of calci-feldspar to alkali feldspar is greater than 5:3, which presumably places the rock within the diorite group.

No alteration of sediments adjacent to the sill was noted. It is believed that these sills have no genetic connection with any of the ore deposits of the area. By contrast, the associated quartz diorite plugs and dikes have been contact metasomatized and contain fissures that bear ore.

Quartz Diorite Porphyry

Quartz diorite porphyry intrusives, in conjunction with diorite porphyry sills, represent the eqrliest sequence of intrusion of intermediate composition. By analogy with the Santa

Rita area, they are believed to be of late Cretaceous age, certainly prior to the intrusion of the major stock that composes the western part of the Apache Hills. Quartz diorite occurs as sills, plugs, and dikes in the metamorphosed member of the Howells Ridge formation west of the McKinley fault and in the vicinity of the Chapo mine. In the former locality the intrusives occur close together and suggest a larger coalesced parent magma at depth. The age relationships are evidenced by the Indian fault which continues westward from the McKinley fault and bisects one of the quartz diorite plugs. The presence of tactite mineralization along this fault, as well as tactite-type minerals within the plug itself, indicates that the quartz diorite rocks were intruded prior to the major stock since metasomatic silication is shown to be associated with the latter intrusion.

The quartz diorite has no characteristic topographic expression; all the intrusive rocks weather to a gravelly talus in the low hills west of the McKinely fault. Their weathered sp surfaces greatly resemble the enclosing metamorphosed sediments in the hand specimen; the two kinds of rock can only be distinguished on fresh surfaces. The fresh surface of the quartz diorite is characterized by a dull green or tan color with prominent large white feldspar phenocrysts and occasional quartz phenocrysts in a generally microcrystalline groundmass. Microscopically, the rock contains euhedral to subhedral phenocrysts of andesine and oligoclase up to 5 mm. in diameter. Zoned plagioclase crystals with andesine cores and albite rims comparable in size to the plagioclase phenocrysts, are common in some specimens but completely lacking in others. Orthoclase and albite are minor constituents usually in the form of antiperthite. Quartz occurs as occasional corroded phenocrysts. However, both quartz and orthoclase are more typical of the groundmass where they occur intergrown; there the orthoclase appears to have a nearly parallel alignment.

Minor minerals include pleochroic biotite, augite, (altered to chlorite and secondary magnetite), hornblende, and apatite. Hornblende has been incompletely converted to what is believed to be pargasite. The alteration which produced minerals believed to be deuteric (such as sericite, chlorite, epidote, and calcite) has markedly affected the feldspar. Introduced minerals include quartz, calcite, epidote, and magnetite which are generally confined to thin veinlets. Apatite is particularly prominent in some specimens and composes approximately 3-5% of the quartz diorite plugs exposed at the Chapo mine. Although apatite is not restricted to observable fissures, it is believed to be associated with the contact metasomatism affecting this area.

Differential deuteric alteration of the more calcic plagioclase, in preference to the albite and orthoclase, is very marked. This is exemplified by zoned plagioclase phenocrysts where andesine cores are wholly sericitized and are surrounded by fresh albite rims.

The mineralogical composition of the rock is approximately as follows; 35-50% plagioclase feldspar, 15-25% alkali feldspar, 10-15% quartz, 5-10% minor biotite and augite, and 5% accessory minerals.

The Apache Hills Composite Stock

The intrusive body that forms the major mass of the Apache Hills is a composite stock composed of an earlier stock of monzonite porphyry and a later stock of quartz monzonite porphyry. Similar composite stocks of intermediate composition have long been recognized near Santa Rita, New Mexico and more recently in the Little Hatchet Mountains. The stock occupies an area of approximately seven square miles on the western flank of the range and forms the highest peak in that area. To the southwest, it displaces part of the Howells Ridge formation, the upper member of which has been subjected to thermal metamorphism and metasomation. The beds south of the stock generally have a gentle northward dip toward the stock but are dragged upward close to the contact. To the northeast, the stock is overlain by bordering latite and andesite flows and by intervening and intrusive rhyolite porphyry which has been intruded along the contact between the monzonite and overlying flows. The latter condition also holds true on the southwest flanks; there numerous porphyritic rhyolite dikes have been introduced along the contact between the quartz monzonite and the Howells Ridge formation. To the northwest, the stock is abruptly terminated by the McKinley fault which brings the rock of the intrusion into sharp contact with a thick sequence of the contact metamorphosed Limestone-Sandstone member. Here the McKinley fault marks the western, outer limit of the contact metasomatism affecting this upper member.

The monzonite and quartz monzonite that compose the stock are moderately resistant rocks and tend to form the highest peaks of the range. Adjacent to Apache Valley, the quartz monzonite has been largely eroded to very gentle slopes which decline evenly into the level of the valley alluvium.

In general the outline of the stock is elongated parallel to the west-northwest trend of the range and to the major folds and the Indian and Apache faults, as further discussed below. This is particularly noted in the quartz monzonite facies whose contact with the sediments is singularly concordant. However, alluvial cover, not penetrated by shafts in this locality, conceals the pitch of the stock. The angle of pitch or dip of the main axis of the plug is obviously highly irregular since isolated plug-like cupolas of quartz monzonite and monzonite are exposed in the Limestone-Sandstone member of the Howells Ridge formation (Plate 2). These offshoots suggest that the stock widened downward. The apparent concordance between stock elongation and structure then, is only a matter of two dimensions and the stock is obviously discordant at depth.

Outcrops of monzonite or quartz monzonite are completely absent west of the McKinley fault and it is therefore believed that the stock was emplaced along this fault; here subsequent ore solutions were probably also channeled.

Monzonite Facies

Monzonite constitutes about three-fifths of the exposed part of the stock. Megascopically it has characteristic greenish gray or bluish gray colors. Phenocrysts of feldspar up to 1/8 inch long are embedded in a microcrystalline groundmass. The border zones of the monzonite are very finely granular and closely resemble the latites which overlie the stock. In fact, the chief distinction between this latite border zone and the latite flows lies in the fact that the stock has undergone considerable epidotization, prominent even in hand specimens, whereas the flows, though otherwise highly altered, are only very slightly epidotized.

Microscopic study reveals a characteristic granitic or "monzonite" texture, i.e., euhedral to subhedral plagioclase grains interlock with subhedral to anhedral orthoclase grains. An estimation of mineral content from three slides indicated an almost equal percentage of potash feldspars and calcic feldspar with varying amounts of hornblende or augite or both and rare biotite.

The calcic feldspar is andesine, which commonly occurs as the core of zoned plagioclase phenocrysts surrounded by oligoclase and rarely albite rims. In addition, unzoned crystals of oligoclase were also common. The dominant potash feldspar is orthoclase which occurs as separate microliths associated with andesine. Perthite-type intergrowths of orthoclase were noted while albite and pericline twinning were observed in some plagioclase crystals. The major ferromagnesian minerals are augite and hornblende, which constitute about 15% of the rock. Hornblende occurs in euhedral crystals with polysynthetic twinning and light green pleochroism. The groundmass is fairly fine grained and consists of a matte of feldspar microliths (orthoclase and albite) and quartz, the latter comprising less than 6% of the rock. Accessory minerals are magnetite, sphene, zircon, apatite, and pyrite.

The most abundant and widely pervasive alteration mineral is epidote (pistacite). This replaces the groundmass and phenocrysts and is mainly responsible for the green color of the rock. It is generally restricted to veinlets and microveins. The epidotization in the major monzonite facies may be contrasted with the isolated monzonite dikes and plugs south of the Indian fault. In the latter the epidote occurs in larger crystals and clusters and has almost completely obliterated the primary minerals. Other alteration processes include sericitization of the feldspar. In addition there is slight chloritization of the ferromagnesian minerals; the chlorite possesses anomalous blue colors. Uralitization is also typical. Some secondary calcite and quartz are present.

The border zones of the monzonite facies are all finer grained and to some degree less porphyritic than the more central areas. These differences in texture could not be easily observed in the field, and it is only in thin section that they become readily apparent. The mineralogy is fairly regular throughout the monzonite except for the more abundant development of zoned plagioclase and biotite in the border zone. The first development suggests that there was an inequilibrium between the growing plagioclase crystal and the cooling magma. This inequilibrium was caused by rapid cooling, naturally most prominent in the margins of an intrusion, thus preventing the crystal core first formed, calcic in composition, from reacting with the residual magma. As crystallization proceeded successive shells will be increasingly sodic in composition, the result being a zoned feldspar. A greater concentration of biotite is to be expected in the border zone since its formation is promoted by the presence of mineralizers, which are to be expected at the outer margins of a crystallizing magma. The border zone is characterized by both linear and platy flow structures, especially swirls, as evidenced by the alignment of phenocrysts and the noticeable orientation within the microcrystalline matrix. Epidotization is here more pronounced which is to be expected in view of the fact that the outer rim of the intrusives should naturally be more severely fractured and thus serve to localize channels for epidotizing solutions.

Quartz Monzonite Facies

The quartz monzonite facies forms the southern extension of the composite stock. In the field the two facies can be distinguished easily by alteration intensity, by color, by degree of weathering, and by the presence of quartz phenocrysts. The later age of the quartz monzonite in comparison with the monzonite is attested by the transgressive quartz monzonite dikes; in

Plate 1, two such dikes are shown cutting the older intrusion. Shorter, transgressive dikes, 10 feet or less in length, were also noted in the field but were omitted from the map for reason of scale. The relation of the quartz monzonite to the porphyritic rhyolite which forms its southern boundary is similarly evident in that the latter contains large angular breccia fragments of quartz monzonite along the sharp contact separating the two rocks. To the east and southeast, the younger facies is intruded and cut by rhyolite porphyry dikes and plugs. Isolated plugs occur in the area between the Indian and Apache faults.

The intrusion of quartz monzonite is believed directly responsible for the recrystallization and indirectly the cause of the metasomation of the surrounding sediments. Furthermore, the beds adjacent to the major mass of quartz monzonite are greatly recrystallized and altered whereas those immediately surrounding the isolated plugs just north of the Apache fault show no change in mineralogy or size of grain.

I question this. The maps show that contact metamorphism is confined to contacts of Cret. sediments & porphyritic rhyolite (Tpr) not qtz monzonite (Tqm). I found good field evidence that Tpr is younger than Tqm & older than the metasomatism. VEE

Topographically, the quartz monzonite presents a somewhat anomalous picture. North of the Indian fault, its eroded surface forms the highest peaks of the range while south of the fault the plugs have been largely reduced to low rounded hills of little relief which merge smoothly with the gently sloping flanks of the range leading to the Apache Valley. This description applies equally to the monzonite facies. Both rock types tend to erode to a gravel-like talus along their steeper slopes.

The quartz monzonite porphyry is grayish-pink to greenish-gray in color. It has a crystalline texture except at its outer margin where the texture is felsitic to microcrystalline. Phenocrysts of gray feldspar and bipyramidal quartz are visible in hand specimens. In thin section, the rock contains euhedral to subhedral phenocrysts of alkalic and calcic feldspars in almost equal amounts and lesser amounts of quartz grains. The plagio- in zones or in separate xls clase is primarily andesine with lesser amounts of oligoclase and albite. Plagioclase is characterized by typical albite and pericline twinning. Other primary structures involve antiperthite, and Carlsbad twinning in orthoclase. Hornblende with green pleochroism occurs in euhedral and bent tabular prisms up to 2 mm. in length. Brown pleochroic biotite is a rarer constituent. The groundmass consists of a mesh of euhedral and subhedral orthoclase, albite, quartz, and occasional hornblende.

Accessory minerals include both indigenous and veined magnetite and pyrite, the latter being especially preponderant along the southern margin of the stock. Others include sphene and rare zircon.

Alteration of the deuteric type is pronounced. The secondary minerals are muscovite derived from biotite alteration, and chlorite and calcite from orthoclase and plagioclase. Epidote is the most common alteration mineral. Some of it is obviously introduced. It is most prevalent along the border zone; there it is replaced by magnetite. Other introduced minerals are calcite, vein quartz, and chalcedony.

The average mineralogical composition of the quartz monzonite as determined from an approximation of three slides indicates 40% orthoclase, 30% soda-lime feldspar, 20% quartz, and 10% ferromagnesian minerals.

Porphyritic Rhyolite

Porphyritic rhyolite, the earliest of the intrusions of rhyolitic composition, occurs primarily as a series of thin dikes and sills on both sides of the Indian fault. It is later than the quartz monzonite stock to the north as it contains numerous fragments of the stock, it was also presumably intruded after contact metamorphism had affected the area as it contains metasomatized limestone fragments.

The average thickness of the composite rhyolite dikes between the Indian fault and the quartz monzonite is approximately 500 feet. Variations from that average are due to faulting more or less perpendicular to the rhyolite trend. The series of porphyritic rhyolite dikes forms a continuous, somewhat sinuous outcrop from a point east of the Chapo mine, where it is intruded by a rhyolite porphyry plug, to a point some three miles westward, where it is abruptly terminated by the McKinley fault. Along its entire length it forms the southern boundary of the quartz monzonite except at the extreme eastern end of the stock. The dip of the dikes ranges from vertical to 70° S. Another area of dike occurrence in the Apache Hills is south of the Apache fault in the vicinity of the Apache mine. Here, the rock, though otherwise similar in megascopic and microscopic features to that north of the Indian fault is characterized by pronounced swirling flow structures. The flows probably rose along fissures now occupied by the thick series of dikes.

Between the Apache fault and the Indian fault numerous porphyritic sills and occasional dikes are exposed (See Plate 2 and 3). Many of these dikes are responsible for the upward drag of adjacent sediments. In addition, they contain sedimentary inclusions and fragments of quartz monzonite composition.

For the most part the porphyritic rhyolite forms prominent ridges which usually can be identified even from a distance. They generally have an orange-red surface where weathered and are light greenish-tan where fresh. Their texture is very finely granular to cryptocrystalline, and where not contaminated by breccia fragments they contain only a few quartz phenocrysts, usually bipyramidal. In thin section the texture may be considered hyalopilitic, in that the rock contains identifiable mircroliths of feldspar and quartz in an almost glassy matrix. The phenocrysts average 1 mm. in diameter. They constitute less than a quarter of the rock and consist of euhedral to subhedral sanidine, albite, and resorbed quartz. The accessory minerals include magnetite, zircon, and apatite. Sericitization is pronounced and the mineral is common in veinlets. One such occurrence shows sericite along the sides of a veinlet with colorless crystals of fluorite toward the interior, the latter in turn cut by magnetite and epidote. The occurrence of these contact metamorphic minerals suggests that contact metamorphic action continued during and after the intrusion of the porphyritic rhyolite dikes, but the dikes are apparently not responsible for the thermal metamorphism. More probably this phenomenon points toward a source for the metasomatizing solutions independent of either the porphyritic rhyolite or the quartz monzonite.

Why not? (see p. 54)

Felsites associated with porphyritic rhyolite are noted northwest of the Sierra Rica sill. They are believed to be of the same period of intrusion. Their petrography is analogous to that of later felsites discussed below.

MIDDLE AND UPPER TERTIARY IGNEOUS ROCKS

Latite Porphyry

Latite porphyry flows, together with rarer welded tuffs, form the fringe of the northwestern part of the Apache Hills. The unit presumably overlies the unexposed erosion surface developed on the monzonite porphyry facies of the composite stock as well as that developed on the Last Chance volcanics. The latite porphyry flows can be separated from the fine grained monzonite border by the lack of epidote and consequent absence of green coloration. The latite flows are overlain and intruded by rocks of rhyolite composition.

The latite flows form low rounded hills and knolls, which in appearance greatly resemble the earlier Last Chance volcanics both on the fresh and weathered surfaces. Only subtle color differences distinguish the two megascopically; the latite is usually gray to light gray or light brown and is only faintly porphyritic, whereas the andesite is dark violet or dark brown or black and is conspicuously abundant in phenocrysts. The contiguous latite flows, half a mile east of the Robins Camp on the trail to the Faulkner Ranch, show striking variations - a change in color from grayish-green to dark gray with a concomitant change in texture between the two flows from a vesicular, felsitic, and virtually non-porphyritic rock to a non-vesicular, felsitic rock with feldspar phenocrysts.

The problem of estimating thickness, either of individual flows or of the unit as a whole, is analogous to that of the Last Chance volcanics: poor outcrops, scarcity of flow structures, and lack of clearly exposed top and bottom contacts preclude accurate measurement. A probable minimum figure for the whole unit is 250 feet, and 500 feet represents the maximum thickness. Some individual beds were established to be about 25 feet thick. The interbedded welded tuff at the Luna mine was accurately measured to be 4 feet thick.

Five thin sections of the latite flows were examined. All contained almost equal parts of alkali feldspar (sanidine and or? ? albite) and calc-alkali feldspar (oligoclase or andesine). Sanidine, a dominant phenocryst mineral, occurs with Carlsbad twinning and a peculiar wavy extinction. It can be distinguished from orthoclase which it so closely resembles by its much smaller axial angle. It is usually euhedral and ranges up to 2 mm. in length. Albitization of the borders of the sanidine phenocrysts is notable. In the two flow rocks mentioned above, variations in composition keep pace with variations in physical appearance.

In one flow, the mineralogy is characterized by numerous phenocrysts which comprise more than half of the rock and consist of andesine and oligoclase with subordinate sanidine and albite. Pleochroic green and prismatic hornblende is a minor mineral. Accessory minerals are apatite, magnetite, and pyrite. Amygdules of chlorite, quartz, and calcite, in many cases concentrically banded, are prominent. Alteration is pronounced and sericitization of the feldspars makes identification difficult. The hornblende is altered to chlorite and magnetite. Introduced vein minerals include quartz and calcite. The other flow consists of dominant phenocrysts of sanidine and albite with minor oligoclase. These phenocrysts comprise less than a third of the rock. Hornblende is conspicuously missing from the second flow. Accessory and introduced minerals are alike in both flows, but the alteration, though similar, is less marked than in the first flow. Both flows are characterized by a felsitic matrix of sanidine and albite microliths and laths.

A summary of variations from the earlier flow to the later flow indicates the following: change in color and texture, decrease of amygdules, decrease in number of phenocrysts, slight increase of plagioclase feldspar, and less intense alteration.

Other slides of the latite flows also reveal slight but discernible differences. These variations are mineralogic and textural in nature. The latite in the vicinity of the Luna mine is abundantly porphyritic and most closely resembles the andesite and basalt flows to the east. Texturally, the rock has a pilotaxitic matrix in which are embedded phenocrysts of orthoclase, oligoclase, and andesine. Other differences are noted in the latite exposed in other areas. For example, the flows examined in the area between the Robins Camp and the Donaldson Ranch were found to be somewhat richer in quartz than elsewhere and in them biotite is an important minor constituent. Some flows are markedly porphyritic, more than 50% of the rock being composed of phenocrysts; other flows contain less than 10% phenocrysts.

In general, the quartz-free latites have a more or less consistent composition with some variations. None is megascopically flow banded; however, in all the thin sections examined, subparallel alignment of the feldspar microliths was noticeable.

Incompletely welded tuffs are scarce within the general sequence of latite flows. The best exposures occur at the Luna mine where prospect pits reveal thin tuffs exceptional in being strikingly banded (Figure 4). The blue-gray rock is partly porous, moderately friable, and dotted with angular quartz phenocrysts. Petrographically, it contains glass, quartz, orthoclase, and oligoclase in a partially devitrified flow-banded matrix of glass and quartz. Alteration was particularly intense and produced chlorite, limonite, and calcite. This rock is apparently more silicic than other latite rocks in the area. Thus immediately south of the Donaldson Ranch there are flows which have the more usual latite mineralogy but contain microphenocrysts of quartz composing 10-15% of the rock.

Rhyolite Group

General Summary

The assorted rhyolites of the Apache Hills and Sierra Rica are by far the most abundant and certainly the most varied of any of the igneous rocks of the whole district. The varieties range from an early sequence of porphyritic rhyolite dikes and sills to a later sequence of rhyolite porphyry dikes, flows, pyroclastics, and felsites. The second group of rhyolites was preceded by latite flows, extruded upon the erosional surface developed on the monzonite stock. Each rhyolite sequence or facies is given separate treatment, the oldest porphyritic rhyolite having been previously discussed. Apparently, the facies of each such sequence represents at once a time and a textural unit. The varying rock facies of the second group are discussed below in chronologic order, the oldest first.

Rhyolite Porphyry

Rhyolite porphyry intrusives usher in the last volcanic cycle (aside from the Pleistocene basalts) that affected the Apache Hills. In general, they occur as a series of closely spaced dikes or plugs traversing the older volcanics and intrusives. In Apache Valley a series of dikes comprising two wide bands cuts the preexisting Last Chance volcanics. In the vicinity of the Queens Taste and Luna mines, isolated dikes and plugs traverse earlier monzonite, quartz monzonite, latite, and andesite flows. Although contacts are rarely seen, the later age of the rhyolite is evidenced by the inclusions of the other igneous rocks that it locally contains. The intrusive rhyolites are in turn cut or overlain by later rhyolite and felsites as intrusive bodies, flows, tuffs, and breccias.

Topographically, rhyolite porphyry dikes form low, rounded and elongated ridges which, though of low relief, are more pronounced than those formed by the surrounding volcanics. Dome-shaped plugs occur northeast of the Mairland Mine while an isolated plug of explosive nature is situated near the international border at SW.1/4, NE.1/4, section 24, R.14W., T.29S. Thin isolated sills and dikes, analogous to these exposed at the Daisy mine (Plate 10) occur south and southeast from that mine, but they are too small to justify showing on the areal map.

In outcrop, rhyolite porphyry presents a great diversity in color and texture, and to some extent mineralogy. In color the rock ranges from black through violet to pink, variants of the latter two being its most common shades. The weathered surface is dark and often similar to that developed on the intruded volcanics. Texturally, the rock grades from a dense or very fine grained variety, relatively free from megascopic phenocrysts, to one which is fine grained and extremely porphyritic. The phenocrysts invariably include bipyramidal quartz and gray feldspar. Minute copper-colored biotite books and black hornblende prisms may or may not be present.

Occasionally rhyolite that was bleached white occurs in close proximity to the more normal violet variety. This rock owes its bleaching to extreme seriticization and kaolinization of the feldspar, particularly plagioclase. At the Queens Taste mine, the altered rhyolites have served as localizers for ore solutions, although in other areas where they are present ore deposits are lacking.

In thin section, the rhyolite porphyry consists of phenocrysts of quartz, feldspar, hornblende, and biotite in a fine grained felsitic groundmass. Phenocrysts averaging 1 to 2 mm. in diameter account for approximately 50% or more of the rock. The most abundant phenocryst is quartz, in many cases corroded. The feldspar includes euhedral to subhedral sanidine and plagioclase in almost equal amounts. The plagioclase is albite for the most part, though oligoclase rarely occurs. The feldspar, like quartz, also exhibits marked resorption. Biotite occurs in amounts ranging up to 5% of the rock but may be entirely lacking in some specimens; this holds also for hornblende, which has the characteristic brown pleochroism of oxyhornblende. Accessory minerals include magnetite, apatite, and zircon, the latter two commonly causing pleochroic haloes in biotite. The matrix is often composed of an almost unrecognizable matte of sanidine microliths and intersertal quartz. Within a single thin section the texture of the matrix varies from completely glassy to holocrystalline. In the matrix of the latter type minerals can be readily identified. Deuteric alteration is fairly intense and clearly differential for plagioclase phenocrysts are markedly affected in preference to sanidine. The alteration minerals include calcite, chlorite, sericite, and kaolin. Secondarily introduced minerals are quartz, siderite, and calcite.

Felsite

Felsitic rhyolite of singular field appearance and mineral composition crops out in different places throughout the Apache Hills and Sierra Rica and with only one exception can be assigned to an age earlier than the rhyolite flows and pyroclastics. Numerous felsitic dikes and plugs, many too small to be indicated on the areal map, occur intruding all the preexisting sedimentary, volcanic, and intrusive rocks. In the northern part of the Apache Hills, they commonly occur as thin dikes intrusive into larger rhyolite porphyry dikes. They have no topographic expression but are marked by conspicuous white sinuous streaks traversing the enclosing rock.

The felsite is generally white to light tan and usually porcelain-like. It is very fine grained and generally nonporphyritic; but some is porphyritic and contains rare quartz phenocrysts. In many places, the borders of the intrusives show poorly developed fine and delicate sheeting, further emphasized by parallel to supbarallel limonite streaks or bands. Some of the dikes have peculiar minute red spots which, in part at least, represent limonite pseudomorphs after pyrite.

In thin section, the matrix texture is partly micrographic, in part spherulitic. It consists of quartz and sanidine microliths, together with sericite shreds. Phenocrysts up to 1 mm.

in maximum diameter are present but extremely rare, the only ones noted being quartz, sanidine, albite, and biotite. Zircon is an occasional accessory mineral. Usually those specimens containing quartz phenocrysts lack phenocrysts of other minerals. Sericitization of feldspar phenocrysts and microliths is notable; biotite is similarly affected. Some of the red spots mentioned above can be attributed to the limonite staining of sericite that surrounds feathery spherulites.

Some felsite bodies were the routes for ore solutions and have in part become mineralized. This is illustrated at the Christmas mine (Plage 16), where veins in the felsite dikes have been worked for their ore content. Some of the prospects near the Last Chance mine (Plage 14) have minor ore deposits in the andesite flows presumably genetically related to the nearby felsite dikes.

Rhyolite Flow

A low gravelly ridge just north of the Donaldson Ranch and extending southeast toward the Faulkner Ranch is almost wholly composed of a thin series of rhyolite flows and two interbedded latite flows, each three feet thick. This sequence of flows directly overlies the older unit of latite and minor tuffs previously described. Overlying the rhyolite flows are occasional isolated exposures of a subsequently extruded quartz latite flow. The rhyolite flows also occur as a single exposure covering the Last Chance andesites southwest of the Queens Taste mine. The thickness of the rhyolite flows is estimated to be 150 to 200 feet.

The fresh rock is light blue-gray in color and very fine grained. It is marked by delicate, only slightly contorted flow lines, so fine and so closely spaced that the distance between each band is about 1 mm. or less. The bands are remarkably persistent along the entire length of exposure and commonly surround and embay minute fragments. The upper few feet of the flow has more widely spaced flow lines and here the orientation of quartz and feldspar crystals is more prominent than below. Quartz stringers occur parallel to the flow lines.

Microscopically, the texture is generally glassy and partially devitrified to quartz and feldspar. Elongate clusters of spherulites 0.1 to 0.2 mm. in diameter follow the general lineation. The rock is ordinarily non-porphyritic with the exception of the upper few feet. Phenocrysts averaging 1 mm. in diameter include partially resorbed quartz, sanidine, albite, and a few oligoclase individuals. Muscovite is rare as a phenocryst. Pyrite is a common accessory mineral. Deuteric minerals include chlorite, sericite, kaolin, and epidote in specks. Minerals in the veinlets are chalcedony, quartz, and calcite; these usually follow the incipient lines of fracture offered by the flow lines.

The interbedded latite flows occur in isolated beds, two or three feet thick. In outcrop, they are black to dark purple in color, fine grained, but crystalline, and contain few phenocrysts. They differ from earlier latite flows in their comparative lack of phenocrysts, somewhat larger grain size, darker color, and less altered appearance. Microscopically, phenocrysts comprise less than a quarter of the rock. They are embedded in a hypocrystalline groundmass, and are generally 1 mm. or less in diameter. They include sanidine together with albite and subordinate oligoclase and rare zoned plagioclase. Sanidine and plagioclase constitute almost equal amounts of the total rock. Biotite flakes, greatly altered, are less common phenocrysts. Magnetite is the only accessory mineral. The matrix is largely glassy except for numerous sanidine microliths and minute quartz crystals. On the whole the rock is comparatively unaltered and the feldspars are only slightly and incipiently sericitized. Secondary minerals include calcite and quartz.

Rhyolite Tuff

Rhyolite tuff is exposed as an isolated band, half a mile wide at its maximum, east and southeast of the Queens Taste mine. It is definitely younger than the andesite flows to the west and older than the rhyolite breccia with which it is in direct contact. No direct evidence of the relative age of the tuff is available but it presumably covers the rhyolite flows to the northwest.

The tuff has a varied physical appearance. At its top, directly under the breccia, it is a partly porous, fragmental, and friable rock which forms a gravelly exposure rather than a sharp, well delineated outcrop. The rock is light colored and appears altered. Angular pumice and quartz fragments are abundant. The western borders of the unit are violet in color, compact, dense, and unaltered. Fragments are scarce and are usually chips derived from rhyolite porphyry dikes. This section of the unit may be considered a wholly "welded" tuff, while that to the east is incompletely "welded". In consequence the western edge has a somewhat higher relief due to its more thorough welding and hence greater resistance to erosion.

Aside from the above, in thin section, the two varieties are similar. They contain varying amounts of assorted fragments (as much as 4 to 5 mm. in diameter) of pumice, quartz, muscovite, biotite, albite, sanidine, and zoned plagioclase in a glassy matrix that is partially devitrified and spherulitic. The matrix consist of glass shards, dust, and pumice fragments more or less compressed, fused, and devitrified. The shards are easily identified and are usually narrow, attenuated, and imperfectly aligned. Some specimens show buckling of shreds around fragments. Spherulites of 0.1 mm. in diameter are common.

Devitrification in the tuffs is evidenced by fine cristobalite fibers growing inward from attenuated shards and by the presence of feldspar microliths and specks in the matrix.

Rhyolite Breccia

Two topographically prominent red domes of rhyolite breccia form the northern border of the western part of the Apache Hills. The domes probably represent the orifices through which the breccia was exploded and extruded. A line drawn between them can be theoretically extended across Hachita Valley to the Coyote Hills, the northern group of hills composing the Little Hatchet Mountains. Along this line westward is a more or less continuous zone of weakness.

The rhyolite breccia has a deep iron-red color, and contains abundant inclusions and fragments of glass, chert, quartz, feldspar, and occasional pyrite. Rare spherulites as much as half an inch in diameter are also noted. The domes are devoid of flow structures except at the outer margins, which possess incipient swirling flow lines indicating that the breccia was somewhat more fluid along its thinner outer borders.

Microscopically examined, the rock is composed of more than 60% phenocrysts and fragments in a glassy groundmass that is incompletely devitrified to quarts. Spherulites occur sporadically. Among the inclusions are angular and fractured glass, quartz, sanidine, albite, and considerable pumice. Such fragments range in size from 0.5 to 1 mm. Smaller crystals of biotite, plagioclase, and sanidine are also common. Magnetite, pyrite, and zircon are accessory minerals. Iron oxide staining is particularly prevalent and has deeply colored the glassy groundmass. The phenocrysts are generally unaffected. The only significant alteration noted was the slight sericitization of the feldspar phenocrysts.

Quartz Latite

This unit, only locally developed, represents the last epoch of Tertiary vulcanism in the Apache Hills. Isolated exposures of one or several quartz latite flows occur in the alluvium overlying the gravelly ridge of rhyolite flows in the northwestern part of the range. Actually, only three outcrops of quartz latite were noted, each less than 50 feet in diameter, so that their appearance is somewhat exaggerated on the areal map. In the hand specimen the rock is dark violet to black and finely crystalline and contains numerous feldspar phenocrysts. Microscopically it is composed of phenocrysts which make up about 30 to 40% of the rock, enclosed in a felsitic groundmass of parallel to subparallel feldspar laths and intersertal quartz. The dominant phenocrysts, ranging in size from 1 to

2 mm., are partly resorbed quartz and euhedral sanidine, albite, and rare oligoclase. Zoned plagioclase phenocrysts, consisting of andesine cores and albite rims, are fairly common. Brown biotite is a rare constituent. Alteration is pronounced: the feldspars, particularly the plagioclase, are greatly altered to sericite and calcite. The biotite has been severely limonitized. Quartz and calcite have been introduced since solidification.

Aside from a larger quartz content, the quartz latite both megascopically and microscopically closely resembles the latites interbedded with the underlying rhyolite flow. Although the quartz latite has been classified as a separate unit, it could be justifiably placed within the earlier rhyolite group.

Dike Rocks

Numerous dikes are scattered throughout the Apache Hills and Sierra Rica. They include rocks that are felsites, trachytes, and lamprophyres. Felsites were discussed in the section devoted to the rhyolites since their relationship with that group can be definitely established. The other intrusives present a more difficult problem for they occur within the Cretaceous sediments and cannot be assigned to any specific igneous sequence.

Many of the dikes are too short to permit their indication on the areal map. All dikes longer than 50 feet, regardless of width, were mapped, even though this involved some width exaggeration. Some dikes mapped are only 10 feet wide or less. Continuity in trend, despite concealment under cover was also deemed an important feature. Thus, some of the felsite dikes half a mile west of the Queens Taste mine were mapped because of their generally continuous trend, even though many individual exposures are less than 50 feet in length.

Lamprophyres

Only two lamprophyre intrusions are exposed in the Apache Hills. One is a sinuous sill only 5 feet thick near the Ford prospect. The other is a dike cutting the Red Bed member of the Howells Ridge formation near Border Post No. 38. This dike trends southward into Mexico.

The rocks of the two lamprophyric intrusions resemble each other physically. They are dark greenish-gray, fine grained and speckled with hornblende needles. Microscopically, the sill is composed of black hornblende prisms with marked brown pleochroism and feldspar crystals in a felsitic matte of slender needles of hornblende and feldspar microliths. The feldspar phenocrysts consist of zoned plagioclase with andesine cores and albite or oligoclase rims. Accessory minerals include magnetite and apatite. The feldspars are altered to sericite, chlorite, and calcite. From the point of view of mineral composition the rock can be considered a spessartite.[1]

The dike rock has a similar matrix of feldspar and hornblende but with less calcic feldspar than in the sill. The euhedral phenocrysts are primarily albite and orthoclase with rare oligoclase. Hornblende prisms with brown pleochroism are likewise prominent. Accessories include magnetite, hematite, and chlorite; feldspars are converted to chlorite, calcite, and sericite. Because of its more felsic composition this rock can be classified as a vogesite.

Trachyte Porphyry

Trachyte porphyry, presumably early Tertiary in age, occurs as thin dikes and sills intruding members of the Howells Ridge formation, particularly the upper Limestone-Sandstone member. Southeast of the Daisy mine and immediately west of the Luna-Hidalgo county line, isolated dikes and some sills with a maximum thickness of 15 feet and an average length of about 50 feet occur in the above member. The ridge west of the McKinley fault contains talus fragments of hornblende trachyte but no definite dikes were noted. Other areas of exposure include section 7, R.14W., T.29S., where trachyte sills have intruded Pennsylvanian limestones of the exposed klippe. No absolute proof exists as to whether the intrusion was earlier or later than the thrusting. In the monzonite facies of the stock, isolated, somewhat rounded xenoliths were observed. Some measured over 100 feet in diameter but others

[1]Williams, H.L., Turner, F.I., and Gilbert, C.M. (1954), Petrography, W.H. Freeman and Co., San Francisco, p. 88.

were only of boulder size. They were usually very fine grained and nonporphyritic in outcrop, although in this section altered phenocrysts are abundant. They could only be distinguished from the monzonite in the field on the basis of their nonporphyritic character. Other outcrops of trachyte are indicated on the areal map, although several lesser dikes have not been plotted because many are too short to be shown on a map of that scale.

In outcrop two types of trachyte could be distinguished. One occurs in the vicinity of the Apache mine, where the trachytic talus remnants are light to dark green, and very fine grained, and contain hornblende needles with long dimensions parallel or nearly so. The other type is characteristically dark green and contains epidotized feldspar phenocrysts embedded in a felsitic groundmass. Hornblende is less common in the second type. The two types of rock are mineralogically similar except for the relative quantity of hornblende.

Microscopically, the rock contains a finely granular mass of euhedral to subhedral phenocrysts of albite with subordinate amounts of orthoclase. The matrix contains higher proportions of potash feldspar and consists of much orthoclase with rare albite; it has a distinctive trachytic texture with elongated laths of feldspar parallel or obliquely crossed. Hornblende in varying amounts occurs in crystals up to 3 mm. in length with typical amphibole cleavage, polysynthetic twinning,and green to greenish-brown pleochroism. The accessory minerals include apatite and much magnetite.

Alteration is very marked and especially noticeable in the phenocrysts, partly, perhaps, because their quantity is larger than that of the matrix. Indeed, the albite and orthoclase phenocrysts are in places so completely changed as to be almost beyond recognition. The common feldspar alteration products include sericite, chlorite, calcite, and epidote (pistacite), the latter two most prevalent. Hornblende is also commonly converted to chlorite, hematite,and epidote. The dominant dark green color of the rock is undoubtedly due to the pronounced and intense deuteric epidotization.

Keratophyre (Albitized Trachyte)

A variation of the normal trachyte described above appears at the International mine where three sills, each about 5 to 15 feet in width and 50 feet or less in length, occur in the Red Beds member of the Howells Ridge formation in the immediate vicinity of the International fault (map of International mine, Plate 11).

The keratophyre exposed there is dull green, dense, and felsitic and contains prominent phenocrysts of white altered feldsapr and occasional quartz. As seen in thin section the texture of the matrix is subtrachytic and consists of identifiable subparallel feldspar laths of albite and orthoclase 0.1 to 0.2 mm. in length. The ferromagnesian matrix minerals could not be identified. The phenocrysts range from 1 to 2 mm.; they compose about half of the rock and consist of albite and oligoclase with subordinate orthoclase. Apparently some of the oligoclase crystals have been altered and converted to albite. Grains of a ferromagnesian mineral possibly augite or hornblende, are totally chloritized and defy recognition. Quartz occurs as partially resorbed phenocrysts but constitutes no more than 2% of the rock in any sample. Accessory minerals include much magnetite and rare apatite.

Deuteric and hydrothermal alteration is striking and chlorite and calcite have replaced any mafic mineral that may have been originally present. Chlorite in turn has been oxidized to hematite and limonite. Other alteration processes include sericitization and kaolinization of the feldspar, mainly plagioclase.

The alteration pattern in the keratophyre is peculiar in that epidote is completely lacking whereas in the trachyte it is very plentiful. This is the sole exception to the generalization previously made, that early Tertiary rocks alone are characterized by epidotization. The keratophyre, doubtless closely allied to the trachyte in composition and time of intrusion, would be expected to reflect analogous alteration conditions. The cause for the complete lack of apidote in this instance, evidently involving a change in the alteration fluids emanating from the magma, is not apparent.

PLEISTOCENE IGNEOUS ROCKS

Basalt

The youngest igneous rock in the Apache Hills and northern Sierra Rica is the basalt flow which caps a flat-topped mesa near the Southern Pacific Railroad two miles east of Hachita (Figure 5). Isolated exposures of basalt also crop out in the alluvium just north of the Donaldson Ranch. The flow lies in the alluvial gravels mantling the drainage area between the Apache Hills and the Cedar Mountains. It represents the last event in the igneous history of the region and is comparable in age and lithology to the "malpais" basalt so widespread throughout New Mexico.

In outcrop, the basalt is dark red or brown to black, crystalline, fine grained, nonporphyritic and particularly vesicular at the top. Some of the vesicles are filled with chalcedony; others are empty. Microscopically, the rock consists of well developed andesine and labradorite laths, usually averaging 0.3 mm. in length, scattered throughout a matrix of anhedral to subhedral augite, the whole giving the basalt a characteristic poikilitic texture. Generally the augite occurs in large grains up to 1 mm. in diameter, many of which enclose several labradorite crystals. Zoned plagioclase crystals also appear as rare phenocrysts. Abundant olivine crystals, generally euhedral but partly corroded, form phenocrysts within the plagioclase-augite mesh. Accessory minerals include magnetite and sphene.

The fresh character of the basalt is indicated by the fact that the plagioclase laths are completely intact and that some olivine crystals are only slightly altered along the edges to iddingsite, pleochroic in brown. For the most part, the olivine has sharp borders and clearly hexagonal outlines in section.

QUATERNARY SEDIMENTS

The Apache Hills and Sierra Rica contain many thick deposits of sand, gravel, and clay. For the most part these are confined to the wide playas between adjacent ranges, notably Hachita Valley and the Mimbres Basin. The deposits in the centers of the playas consist of shifting sand and silt which may form small dunes against the clumps of mesquite and other plants. For a more detailed discussion of the character of the bolson deposits, the reader is referred to A.T. Schennesen, U.S. Geological Survey Water Supply Paper 422, 1918.

The thickness of the sediments in Hachita Valley is unknown but is at least more than 800 feet. This figure was obtained from the railroad well in Hachita, in the center of the valley, one mile west of the town. The well is confined entirely to unconsolidated sediments. The thickness of such sediments is variable, because, although the top of the alluvium is a well developed pediment surface, the bottom surface is highly irregular insofar as isolated knolls of Pennsylvanian and Mississippian limestone occur in Hachita Valley.

The sediments in the bolsons cannot be easily distinguished from the younger alluvium which mantles the playa between the Apache Hills and Sierra Rica. The areal map (Plate 1) makes no attempt to distinguish these two kinds of alluvium. As boundaries are largely gradational and definite ages cannot be established, the valley fill of the playas, the younger alluvium of the streams and pediment mantle, and the talus deposits are all

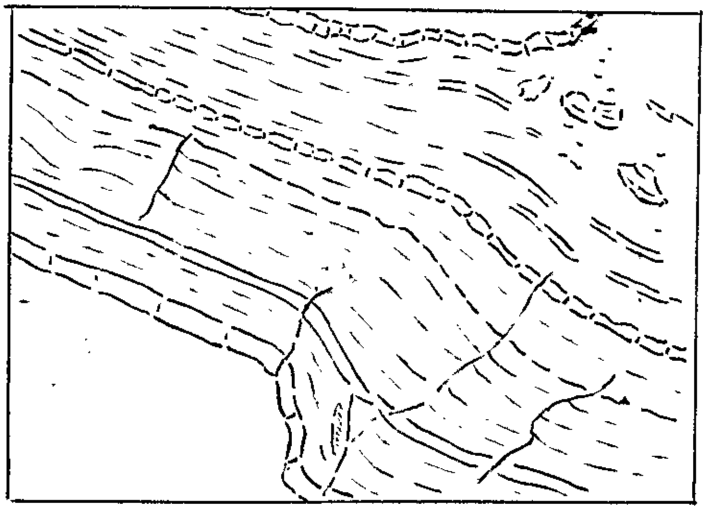


Figure 4

Flow structure in a welded tuff at a prospect pit of the Luna mine. The thickness of the bed here is four feet.

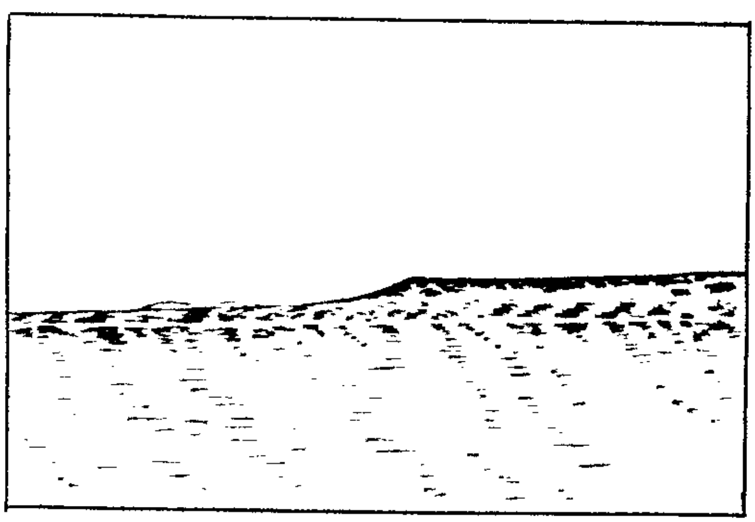


Figure 5

Basalt mesa east of Hachita

classified here as Quaternary alluvium. The younger alluvium consists of boulders and cobbles of varying sizes and degrees of sphericity, intermixed with coarse grained sands and gravels. Such is the situation in the steeper portions of the stream valleys, but a progressive reduction in gradient toward the valley signals a corresponding increase of finer material such as sand and silt.

An approximate measurement of alluvial thickness is given in Table 1.

LOCAL AND REGIONAL COMPARISONS OF IGNEOUS ROCKS AND ASSOCIATED MINERALIZATION

It should be noted here that the igneous sequence in the Apache Hills and Sierra Rica conforms to the generalization expressed by Butler[1] and others in regard to associated mineralization for the western part of the North American continent. The generalization holds that the Tertiary igneous rocks follow a tripartite succession; the early Tertiary igneous rocks, predominantly mafic in character, are succeeded by middle and late Tertiary intermediate to silicic intrusives including monzonite and quartz monzonite stocks, rhyolite and subordinate latite. These in turn are followed by the mafic rocks of the Quaternary. Important commercial mineralization is associated with the intrusion of mid-Tertiary quartz monzonite and monzonite stocks in the Apache Hills, which is likewise the case not only in other districts of southwestern New Mexico, but

[1] Butler, B.S. (1933), Ore deposits of the United States in their relation to geologic cycles, Econ. Geol., vol. 28, pp. 301-308.

also throughout the Rocky Mountains and Basin and Range province of the United States and Mexico. The Apache Hills area differs somewhat from other nearby localities in that it lacks such early pre-stock mineralization as that at the Santa Rita district, but it has weak post-stock mineralization genetically related to rhyolite porphyry intrusives. Such later mineralization is of an age comparable to that in other local mining districts (Table 2).

GEOLOGIC STRUCTURE

INTRODUCTION

The Apache Hills and Sierra Rica, though physiographically two well separated ranges, are geologically closely similar in stratigraphy and structure. The major difference between the two is one of vulcanism and the amount of regional thrusting. In general, the Sierra Rica represents the southern limb of a major anticline, the axis of which trends northwest along the foot of Doyle Peak and then west toward the Occidental mines where the axis is exposed on the surface immediately north of Border Post No. 41. The Apache Hills represent the northward limb of this anticline with the distinct possibility that further gentle folds occur in the valley between the two ranges. This probability is furthered by the anticline and syncline exposed just north of the Apache fault.

This is a compact area with a large succession of structural events, some of which on a minor scale reflect broad regional influences whereas others are of strictly local significance. In addition to the folds mentioned above, other

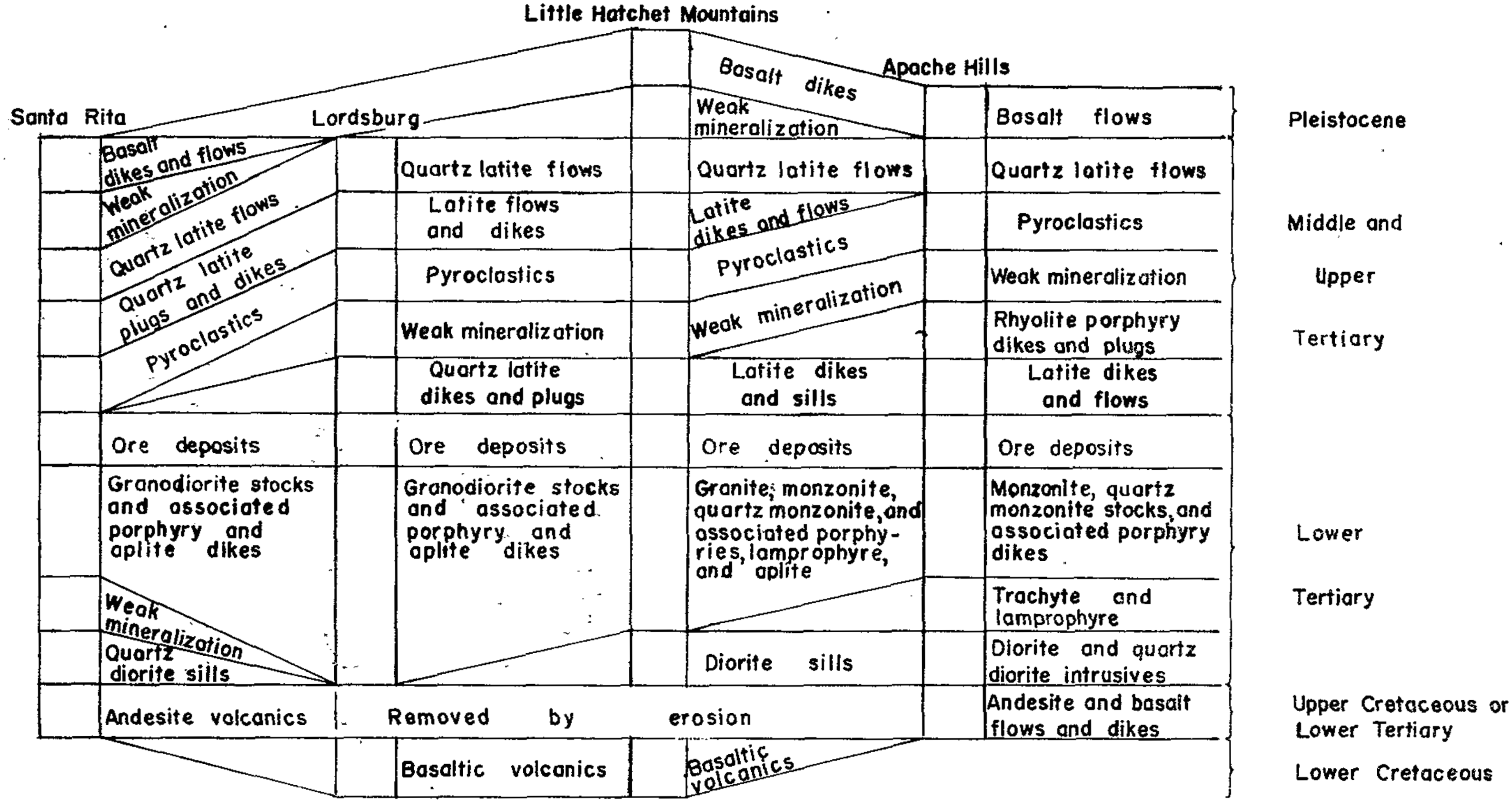


Table 2. Regional comparison of igneous sequence and mineralization
(Modified after Lasky, 1947, p.38; Apache Hills column by the author)

structural features include high angle normal and reverse faults, thrusts, tear faults, fissure faults related to the emplacement of the composite stock, and normal vein fissures. The geologic map shows that all the structural features are characterized by one of two directions - west-northwest and north-northeast. The longer direction of the stock as well as the strikes of the smaller ore bearing fissures illustrate this grouping. As a corollary, all the available evidence in regard to the major structures apparently indicates that, with the exception of the Apache and Indian faults, the west-northwest ones appear to be earlier.

FOLDING

Deformation of the rocks of the Apache Hills and Sierra Rica has produced three major long-trending folds - the Occidental anticline at the base of the Sierra Ricas, and the Mairland syncline and the Daisy anticline north of the Apache fault. The last two are definitely asymmetric and the Occidental anticline is apparently similar although its asymmetry is only exposed at the western portion. In addition there is minor drag folding. All the available evidence points to the fact that the folding in this area marks the earliest local expression of the Laramide orogeny, probably postdating the intrusion of diorite and quartz diorite, as evidenced by the diorite sill northeast of Mairland mine, which was folded along with the enclosing sediments. Thus the folding may be said to have occurred in the interim between the intrusion of dioritic

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rocks and the intrusion of the composite stock. Accordingly these folds represent the earliest tangential Laramian pressures affecting the Apache Hills.

The axis of the Daisy anticline, the northernmost of the three folds, has a sinuous trend from a shallow draw immediately north of Border Post No. 39, curving westward toward the Luna-Hidalgo county line, where it is abruptly cut off by the County fault. The westward continuation of the fold axis occurs south of the Daisy mine where erosion has followed the axis in a shallow alluvial-covered draw. To the west, the axis is terminated by rhyolite dikes intruded along the crest and what is also probably the nose of the anticline.

The anticline is fairly regular with no minor folds superimposed on the limbs. The plunge of the fold appears to be to the west as indicated by the convergence of the Oyster Limestone member east of Border Post No. 39 and the local convergence of individual *Orbitolina*-rich limestone beds north of that post. The fold shown in the Daisy mine section suggests a convergence of the Skunk Ranch fanglomerate, again indicative of a westward plunge.

The Mairland syncline, of small amplitude and length, is abruptly terminated on its eastern end by faulting and on the west by an intrusive rhyolite dome. No clear plunge direction is indicated but it should be the converse of that of the associated anticlines. An eastward plunge is also suggested by the fact that the thick section of the Limestone-Sandstone member east of the terminating fault is not synclinally folded but has a fairly constant southward dip expressive of the southern limb of the Daisy anticline which would indicate termination of the syncline prior to faulting. The syncline probably extended westward along the range as the sediments have a northern dip characteristic of the southern limb.

The Occidental anticline which accounts for the geologic continuity of the two ranges is only exposed just north of Border Post No. 41. It seems probable that its axis is parallel to the foot of the Sierra Rica. This would account for the geologic continuity of the formations across Apache Valley. The rocks south of the anticlinal axis represent the southern limb (Sierra Rica) while the rocks south of the Mairland syncline represent its northern limb. Other minor folds probably occur between these two major folds. For example, the volcanics have a northward dip near the Big Shiner mine, but a southward dip at the Quartz prospect. An anticlinal axis probably passes between these two areas. Accordingly, Apache Valley would represent an area of structural weakness with numerous fissures able to provide access to rising rhyolite intrusives. The plunge of the Occidental anticline is inferred to be westward as chiefly evidenced by the outcrop pattern of the Corbett formation. In the Sierra Rica, it strikes approximately N60°W whereas northward the strike gradually turns toward the north. This change evidently signifies a shift toward the nose of the anticline and apparently confirms the direction of plunge determined for the Daisy anticline.

No! ... B.P.

Sediments domed by either igneous intrusions or faults are prevalent throughout the region, particularly in the vicinity of the Apache-Chapo mining area (Plates 2 and 3). Numerous porphyritic rhyolite dikes caused drag folds in the sediments immediately adjacent to them. At the Indian fault, sediments with a general dip of 15-20° N. have been up-ended by intrusions resulting in a dip of 25-35° S. Favorable loci of ore deposition were created at the crests and troughs of these folds.

Drag folding of beds by faulting is noted in some of the minor faults near the Chapo mine. In many places these faults have closely associated ore or tactite zones. Many of the major faults in the two ranges have produced upfolded sediments. Two examples include the McKinley and International faults, both of which are mineralized; in both the association between ore deposition and upwarped sediments is clear. A more striking illustration of drag folding is seen in the western Sierra Rica where Paleozoic thrust sheets have warped the underlying Corbett beds, as well shown on the southwest slopes of Doyle Peak.

FAULTING

General Discussion

The Apache Hills contain two major normal faults parallel with the general west-northwest extent of the range. They include the Apache fault and the Indian fault. Other normal faults like the McKinley, Chapo, Mairland, County, International, and others, trend more or less perpendicular or at a high angle to the major faults. Faults trending similarly occur in the northeastern section of the Sierra Rica. The western hills of the Sierra Rica are composed of two major thrust sheets, now partially eroded, which seemingly reflect a horizontal displacement of many miles. Minor thrusting occurs in the Apache Hills east of the Apache mine (Plate 2) and just northeast of Border Post No. 39. Numerous tear faults of small horizontal displacement like those at the International mine (Plate 11) are common throughout the two ranges. Usually each of these faults has a strike slip of only a few feet and the fault or the displacement is too small to be indicated on the areal map.

At least five separate phases of faulting are recognized, starting from those that took place after the folding but before the stock-like intrusions to those of the late Tertiary (late Pliocene ?). Thrusts that brought the Paleozoic sediments atop the folded Lower Cretaceous orthoquartzites and limestones represent the first stage. These resulted from the same Laramian tangential pressures that were responsible for folding. Following the faults of this stage, virtually all other faulting is of the normal or high angle reverse type, suggesting a change from tangential to tensional stresses. The second stage is also manifested by the Indian fault along which the quartz monzonite and later porphyritic rhyolite dikes were intruded. The Doyle fault in the eastern Sierra Rica also possibly belongs to this stage. The third stage is represented by faults trending north to northeast, some of which were originally tensional fractures associated with the intrusion of the stock. The ore deposits of the Apache-Chapo Mining District and probably those of the Occidental and International mines were formed in fissures of this stage. Short transverse faults cutting the mineralized faults reflect a recurrence of faulting toward the close of this vein-forming stage. The fourth major episode is the upheaval of the Apache Hills along the Apache fault, a displacement similar to the Basin and Range type. Concomitant with this stage are the parallel normal faults of small throw and step-like pattern in the eastern block of the Apache Hills (section E-E' of Plate 1). Small tear faults and the reverse fault in the same area probably indicate stresses associated with this period of faulting. The youngest stage is represented by the fault northwest of the Luna mine which occurred after the rhyolite flows and breccias had been deposited. It is definitely local in extent and may well be due to slumping rather than to tectonic stresses.

Thrusting

Low angle thrust sheets of klippen exposed in the western edge of the Sierra Rica overlie the Corbett orthoquartzites (Figure 6). Doyle Peak represents a double thrust, for a Permian klippe is overlain by a Pennsylvanian klippe (Figure 7). Both have a southwestward dipping sole (section C-C' of Plate 1). The age of the thrust cannot be definitely assigned. At best, it postdated the folding and antedated the rhyolite porphyry intrusion, as indicated by the folded condition of the underlying Corbett formation and by the isolated klippe in section 7, R.14W., T.29S. which is cut by rhyolite dikes.

Normal Faulting

The Indian fault can be traced from a point west of the Apache mine where it is abruptly cut by the Marathon fault to a point east of the Chapo mine where it is again abruptly terminated, this time by the Mairland fault. Along its entire length the fault is well marked by a prominent breccia zone which contains various rock fragments depending upon the surrounding rocks. For the most part it contains silica-cemented tactite fragments (garnet, epidote, and diopside) together with assorted chips of sediments and intrusives. The limestone side of the fault is usually silicated and bears ore.

The Indian fault is evidently the fissure along which the stock had risen and which subsequently provided egress for the rhyolite dikes. The displacement along the fault cannot be determined as the thickness of sediments overlying the stock upon its intrusion is not known.

The McKinley fault, Chapo fault, and others representative of the third stage of faulting are in part related to the stock. Such fissures were probably channels for silicate and ore solutions and sites of ore deposition. Following ore deposition, further adjustment produced small displacements. The figures for these displacements can be accurately determined in some places. For example, the Chapo fault has a throw of 150 feet;

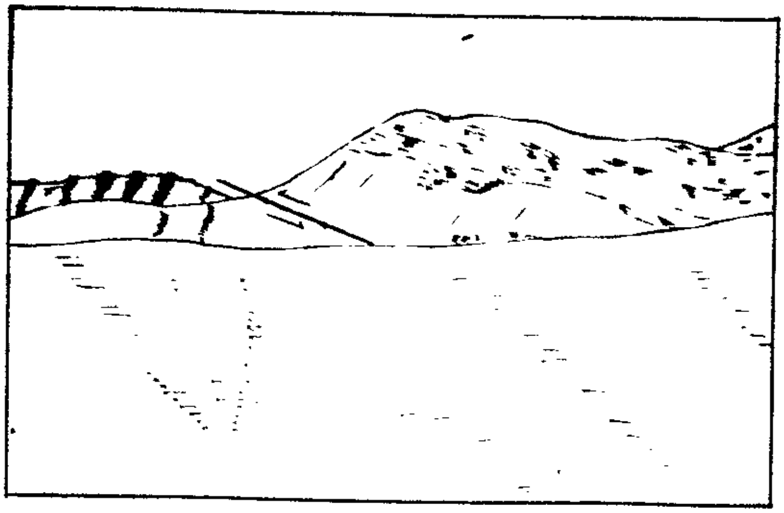


Figure 6

View looking southwest from Doyle Peak, demonstrating the thrust of Pennsylvanian limestones (right) over the Corbett formation (left) in the northwest part of the Sierra Rica.

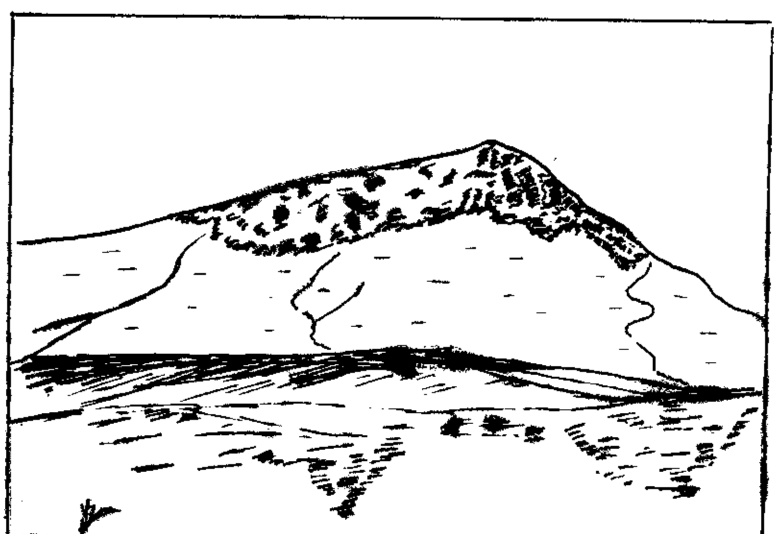


Figure 7

Thrusting at Doyle Peak: View looking toward the west side of Doyle Peak showing massive Pennsylvanian limestone overlying Permian red beds.

this is illustrated by the fact that just west of the fault, the same Rudistid Limestone member that is exposed on the surface to the east, occurs near the bottom of the Chapo shaft, 180 feet below the surface. The presence of the fault here is also indicated by the absence of tremolitized limestone east of the fault and its striking continuity to the west. The Mairland fault has a vertical displacement of about 400 feet; this figure is derived from the fact that to the west of the fault the contact of the Rudistid Limestone member and Limestone-Sandstone member is exposed at an elevation of approximately 5,000 feet, whereas to the east the same unit forms a prominent cliff at about 5,400 feet.

In the northeastern Sierra Rica, conditions are analogous but on a smaller scale than those in the Apache Hills. The Doyle fault trending west-northwest and the similarly trending tactite veins of the Occidental Mines (Plate 9) are offset by northeast faults. The Doyle fault involves a stratigraphic separation of about 900 to 1,000 feet which is the thickness of the missing Orbitolina Limestone member. The vertical displacement in the younger faults cannot be determined. The horizontal separation on the Occidental fault is approximately 1,500 feet.

The International fault is partially mineralized both in the United States and along its continuation into Mexico. As is obvious from the map, Plate 1, neither horizontal nor vertical displacement can be determined.

The Oyster fault is indicated by a slight horizontal displacement at its southern extension; to the north, the only indication of this fault is the noticeable change in strike across the alluvium separating the two blocks.

The County fault, covered entirely by alluvium, has been inferred from the contrasting lithology on either side. To the west are exposed the Limestone-Sandstone beds and to the east the Orbitolina and Rudistid Limestone members. The horizontal separation is about 7,500 feet, of which the vertical component is estimated to be a masimum of about 1,200 feet, in view of the thickness exposed east of the fault. Sp

The McKinley fault is important structurally and also from the point of view of ore deposition. It is a fault of small horizontal separation, to judge by its cross-cutting relationship with the Indian fault. Like the Indian fault, it has acted as a guiding fissure along which the composite stock and other intrusives have been introduced; it has also been mineralized. One striking feature of the fault is that it has acted as a barrier to silicating and ore solutions, for west of the fault, with the exception of the Indian fault continuation, tactite and ore veins are conspicuously scarce or lacking. The McKinley and related faults were apparently responsible for the uplift and subsequent present exposure of the quartz diorite plugs in the immediate vicinity of the fault. This is particularly probable in the northern section of the fault.

East of the McKinley fault, along the southern fromt of the Apache Hills between the Apache and Chapo mines, numerous faults of small displacement are fairly abundant. The displacement of each has a greater horizontal than vertical component, for the beds on either side of the faults are similar and topographic elevations are about the same. These fissures are radial to the stock and tensional in origin, and may be compared to the radial pattern developed around intrusives and domes where upward vertical pressures were originally dominant.

The Apache fault has a sinuous and continuous trend along the base of the Apache Hills and can be traced by differences in topography and lithology. For much of its length it is marked by bands of massive, resistant quartz ten feet wide (Figure 8). "Horses" of sedimentary rocks within the fault trace were occasionally noted, as east of the Mairland mine where blocks of sandstone are enclosed by quartz veins.

Associated faults and fissures related to the Apache fault are noted in the eastern block of the Apache Hills whereby parallel step faults have repeatedly elevated the massive cliff-forming Rudistid Limestone member (Figure 9). The minor thrust in this area is evidently related to the step faulting and is probably due to a local compressional adjustment to the major tensional forces affecting the region at that time (Figure 10). Quartz-filled fractures parallel with the Apache fault south of the Apache mine may also illustrate a genetic relation (Plate 2).

The vertical displacement along the fault is estimated to be about 2,500 feet (section C-C' of Plate 1), in general accord with the relief on either side of the fault, taking into account subsequent erosion. The displacement along the fault was probably not uniform so that variations from the above figure are to be expected.

The dating of the major fault is somewhat obscure but it appears probable that the last large movement occurred during and after the eruption and intrusion of the rhyolite sequence which would date the fault as late Miocene or Pliocene (?). This is indicated by the exposure of rhyolite on either side of the fault, and by the abrupt termination of isolated monzonite plugs on the northern side of the fault. Probably faulting became active as vulcanism subsided. Furthermore, it is believed that a zone of weakness extends from the rhyolite breccia domes on the northern fringe of the Apache Hills to the Coyote Hills (the northern termination of the Little Hatchet Mountains) which can well be considered a concomitant of the Basin and Range type of faulting exemplified by the Apache fault. It seems likely, too, that the Miocene or Pliocene (?) movement was not the first or last expression of uplift. The present of isolated fanglomerate outcrops throughout the range is evidence that upwarping, possibly operative along this fault, occurred in the late Cretaceous and was perhaps of some influence in preceding periods, accounting for nondeposition of certain sediments. Possibly there were similar recurrent movements of more recent origin. Recent faulting of Pleistocene and later gravels in the Rio Grande Basin in New

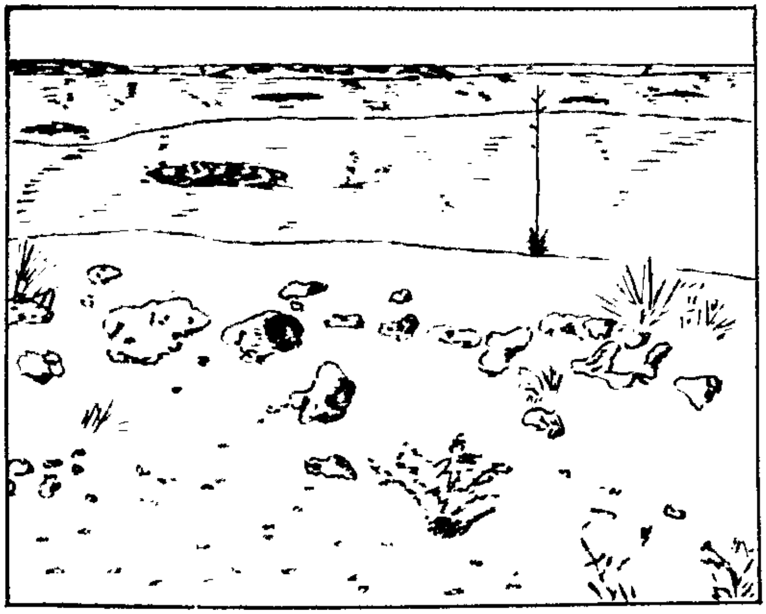


Figure 8

Midway between the Apache and Chapo mines. A quartz vein delineates the Apache fault. In the foreground is a small plug of quartz monzonite; in the background are andesite flows.

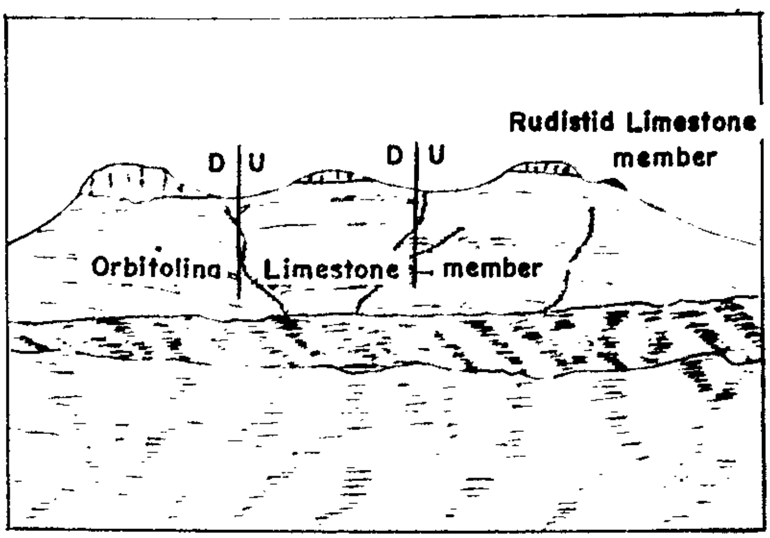


Figure 9

Step-faulting in the eastern Apache Hills affecting the Rudistid Limestone member and the Orbitolina Limestone member. View looking northwest from the International mine.

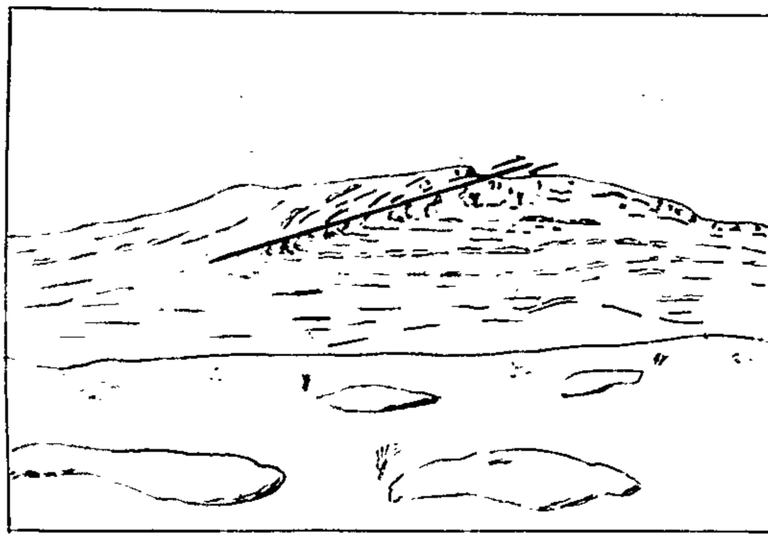


Figure 10

View looking north from Border Post No.39 toward a minor thrust fault. Note the drag folding of the thin beds of the Orbitolina Limestone member against the fault plane.

Mexico attests to the persistence in time of such structures.[1]

Although the Apache fault has a more westerly trend than is characteristic for the Basin and Range type of faults its remarkable continuity from its northern end in the mapped area southward into Mexico and beyond suggests a genetic similarity to faults of that type. Other facts pointing toward the same conclusion are its steep dip with vertical displacement and the sharp lithologic and topographic contrast on opposite sides of the fault throughout much of its course.

Relation of Mineralization to Faulting

In regard to mineralization, structures relegated to the second and third episodes of faulting contain the major ore deposits of the ranges. These faults may be considered pre-mineral in origin. With minor exceptions all other faults are post-mineral. The exceptions include the minor ore-filled fissures at the Big Shiner mining area, the Luna mine, the Christmas mine, and the Queens Taste mine, all of which are associated with the intrusion of rhyolite porphyry or related felsites.

REGIONAL COMPARISON OF STRUCTURAL RELATIONS

The Apache Hills and Sierra Rica generally conform to the regional structure pattern of southwest New Mexico (Figure 11):

[1]Callaghan, Eugene (1953), Basin and Range structure in southwest New Mexico, Guidebook, 4th Field Conference, New Mexico Geol. Soc., p. 117.

the major folds and faults and notably the thrusts, possesses a west to northwest trend characteristic of this part of the state. In particular the trend resembles that which occurs in the region to the east and north rather than that to the west at the New Mexico-Arizona line, where a north-south attitude is more dominant. In that respect, the Apache Hills apparently represent a zone of structural transition in which both tensional and compressional forces have undergone a slight but noticeable shift in direction.

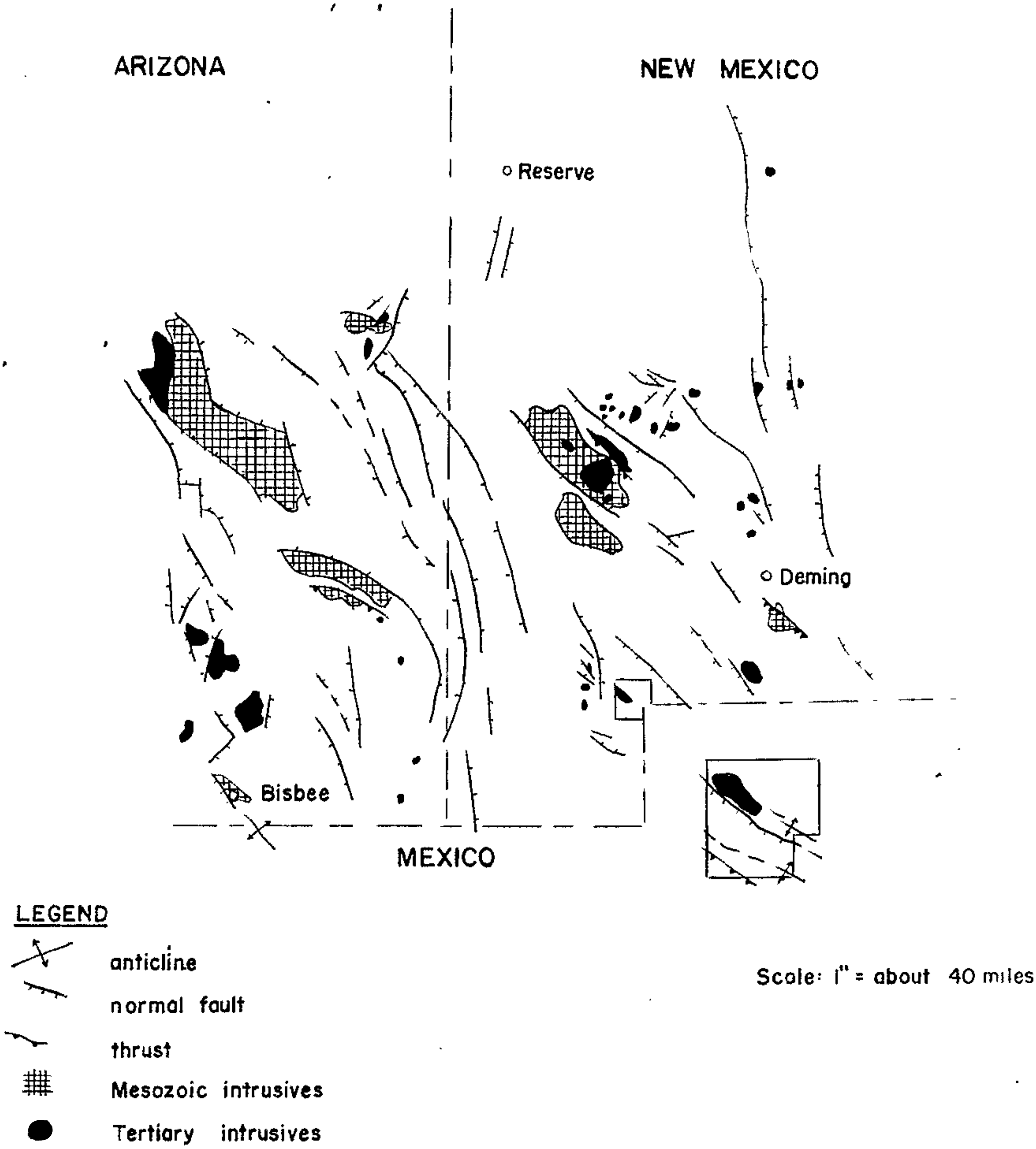
GEOLOGIC HISTORY

The exposed rocks of the Apache Hills and Sierra Rica undoubtedly overlie Paleozoic rocks, including Pennsylvanian and Permian sections. A thick section of autochthonous Permian occurs in the Big Hatchet Mountains. However in the region under discussion, regional history commences in the early Cretaceous. During that time, southwest New Mexico and southeast Arizona were at or near the head of the southeast-trending and plunging geosyncline that continued through central northern Mexico and was separated from the site of Gulf Coast deposition by the Coahuila platform. Deposition had been initiated in the "autogeosyncline"[1] in the Jurassic and continued throughout the Cretaceous. Jurassic and Lower Cretaceous sediments comprise a section generally over two miles in thickness and consist of limestones with basal and marginal orthoquartzites.[2] The lack

[1]Kay, G.M. (1951), North American geosynclines, Geol. Soc. Amer. Mem. 48, p. 62.

[2]Ibid, p. 62.

Figure 11. Tectonic relations of Apache Hills and Sierra Rica to southwest New Mexico and southeast Arizona (Base map: Tectonic map of the United States, 1944)



of Jurassic sediments in southwest New Mexico indicates that the area was a highland during this time and most probably during the Triassic as well.

In the early Cretaceous, however, the sea encroached upon the present position of the Apache Hills and Sierra Rica. Both the Howells Ridge and Corbett formations reflect marine and shallow water environments. Even the Red Beds member, the oldest unit of the Howells Ridge formation, demonstrates these conditions as sandy and clayey matter are intermixed with occasional thin beds of limestone indicative of near-shore deposition. Off-shore sedimentation continued throughout Howells Ridge time. The Oyster Limestone member illustrates deposition in shallow and turbulent marine waters in which sandy material was still an important detrital constituent. The Orbitolina and Rudistid Limestone members represent conditions wherein the marine waters were completely free of clastic detritus or else these limestones were deposited a sufficient distance from the shore line to be uncontaminated. This condition did not persist too long since the overlying Limestone-Sandstone member contains Orbitolina-rich limestones and interbedded orthoquartzites and siltstones. Arenaceous and subordinate argillaceous debris characterize the upper half of the Lower Cretaceous and probably indicate a retreat of the sea, resulting in shallow, marine conditions whereby the detritus has been severely washed and generally reworked, producing well-worn, rounded, and frosted quartz grains. The Corbett formation may be considered a marginal facies of the geosyncline, debris having been derived from a more distant source than was the case with the other sandy beds.

In the late Cretaceous, withdrawal of the sea, probably due to uplift of the Apache Hills and Sierra Rica, resulted in the deposition of the Skunk Ranch fanglomerate upon the erosion surface developed on the underlying Mesozoic and Paleozoic rocks. The uplift was great enough to expose Pennsylvanian limestones, boulders of which are included in the formation.

Late Cretaceous or early Tertiary vulcanism, presumably affiliated with the Laramide orogeny, then affected the two ranges. The first indication of this was the introduction of the Last Chance volcanics extruded upon the eroded surfaces of the Lower Cretaceous sediments. An accurate detailing of sequences is difficult but in general, after diorite and quartz diorites were intruded, the beds, both volcanic and sedimentary, were subjected to tangential pressures which formed the folds previously described. Deformation continued with the thrusting of Paleozoic sediments from an unknown source upon the folded indigenous rocks.

Subsequent to this deformation, igneous rocks intruded the anticlinal crests and limbs in the western Apache Hills forming various structures, notably a stock of mixed composition. Metasomatism and mineralization of the surrounding sediments probably started before the resulting stock had completely cooled and continued after the associated dikes and sills were intruded. Fissures radial to the stock developed during its emplacement and served as channels for filling and metasomatism, in part by ore solutions. Lesser displacements occurred after mineralization.

A period of relative quiescence was then succeeded by another period of vulcanism commencing in the Miocene (?) in which latite flows were extruded and later covered by rhyolite flows, tuffs, and breccia. Profuse intrusion of rhyolite porphyry earlier than its equivalent flows introduced a second period of mineralization, but this was weaker than the first. It was followed by a major period of faulting in which the Apache Hills were uplifted to their present state. Volcanic action had a brief resurgence in the Pleistocene with the outpouring of basalt flows, similar to those that have continued into the Recent epoch in other parts of New Mexico.

CONTACT METAMORPHISM

INTRODUCTION

Much attention was given by the author to the contact metamorphic relations expressed on the southwest slopes of the Apache Hills, where a contact aureole of limited size is exposed. It was hoped that this deposit, though of small areal extent, would shed some light on certain questions about this phenomenon long raised by geologists. During the course of the field work, other features were also observed which have received little attention elsewhere.

TERMINOLOGY

The term contact metamorphism as used here is all-embracing, referring to changes which rocks adjacent to intrusive masses have undergone as a result of intrusion. The alteration is two fold in nature. One phase is purely thermal metamorphism, whereby the loss of heat from the intrusion is responsible for the baking and recrystallization of the surrounding rocks. In this phase, also called isochemical metamorphism,[1] the bulk chemical composition of the rock is unaffected since there is no migration of material into the rock. A second phase, to which some restrict the term "contact metasomatism" and which others call allochemical metamorphism,[2] is characterized by fluids, generally considered pneumatolytic, emanating from a source within the crystallizing magma or from an independent source, and responsible for the formation of new minerals either by reaction with previously recrystallized rocks or by deposition from solution at high temperature. In this phase, there is a change in the bulk chemical composition, since the fluids may account for substantial addition and removal of matter from the rocks.

Although the first phase precedes the second phase chronologically, the later effects of contact metasomation may completely obliterate any vestiges of purely thermal origin.

[1] Rankama, Kalervo, and Sahama, Th. G. (1950), Geochemistry, Univ. of Chicago Press, Chicago, p. 250.

[2] Ibid, p. 250.

The new minerals formed may be composed wholly or in part of elements foreign to the country rocks and may occur as replacement masses or in veins. Usually the minerals thus deposited are silicates to which the term tactite or skarn is applied; the term tactite is preferable as skarn more specifically refers to a garnet-epidote-pyroxene rock.[1]

LOCATION AND OCCURRENCE

The distribution of the contact metamorphosed zone is indicated on the areal geologic map, Plate 1. A more detailed study is shown on Plates 2 and 3. The general geologic setting is one in which the Apache Hills composite stock, consisting in part of a late quartz monzonite facies, has intruded the Limestone-Sandstone member of the Howells Ridge formation and is directly or indirectly responsible for the alteration of the sediments. The effects of the quartz monzonite intrusion consist of recrystallization of the sediments followed by a late introduction of fluids which metamorphosed and metasomatized the rocks. Toward the end of this process, rhyolite dikes were intruded into the sedimentary succession and along the contact between the sediments and the stock. As illustrated in the last two plates, the metamorphic effects extend outward from the sediment-rhyolite contact to the abrupt termination of the sediments at the Apache fault. The contact zone forms an aureole approximately

[1]Hess, F.L. (1918), Tactite, Amer. Jour. Sci., vol. 48, p. 377.

1,000 feet wide and two miles long extending from the Chapo mine to the McKinley fault. West of the fault, an even thicker section has been metamorphosed.

Contact metamorphic features are also noted at the Occidental mines (Plate 9) where tactite and ore minerals fill prominent fissures in limestone. This occurrence is all the more unusual since there are no associated intrusives visible, with the exception of thin trachyte sills which are not apt to have been a causal factor in this type of mineralization. Similar tactite veins, in many places of great length and seemingly unrelated to intrusions, have been reported by Jacob[1] from Calera, a small mining camp in Chihuahua, Mexico.

No!!

There are abundant porphyry dikes just like the ones that control contact metamorphism in the Apache Hills WEE

SEDIMENTARY SEQUENCE INVOLVED

The sedimentary sequence included within the contact aureole between the McKinley and Mairland faults is as follows:

Stratigraphic top of section

	Thickness
Limestone-rhyolite breccia	20-50 feet
Indian fault	
Limestone, tremolitized; contains occasional argillaceous lenses	15
Impure, slightly calcareous shale; occasional arenaceous lenses	40
Interbedded shales and sandstones, minor thin limestones, and conglomerates	400
Total	465 ±

Rudistid Limestone member

[1] Jacob, Leonard, Jr. (1954), Personal communication.

Features peculiar to this sequence include 1) the lenticular and intertonguing nature of the beds and 2) the remarkable persistence with which thermal and metasomatic alteration may extend parallel to the stratification. The lenticular nature of some of the beds is exemplified by the lens of massive recrystallized limestone confined to the area around the open cut of the Apache mine - a type of limestone not found elsewhere in the district. The occurrence of thin conglomerate and limestone lenses near the Chapo mine also illustrates the inhomogeneity of some sedimentary units. The persistence of alteration parallel to the beds is illustrated by the limestone abutting against the Indian fault which has been tremolitized and otherwise silicated, accounting
laterally?
for a mineral assemblage that continues literally unchanged from the Indian shaft to the Chapo fault, a distance of about two miles. At either extreme, subsequent faulting and erosion have removed the bed from the observed sedimentary sequence.

MINERALOGY

The metamorphosed rocks of the Apache-Chapo mining district possess a variety of silicates and other minerals characteristic of a contact zone. The minerals below are all post-diagenetic in origin and are grouped according to their formulae as listed in Dana's Textbook of Mineralogy, 1950 edition.

Silicates

Actinolite ($Ca_2(Mg,Fe)_5(OH)_2(Si_4O_{11})_2$). The mineral occurs microscopically in shale and limestone as light to dark green fibers associated with hornblende and diopside. In many cases, it is limonitized.

Aluminous hornblende ($Ca_2Na(Mg,Fe,Al)_5(Al,Si)_4O_{11})_2(OH)_2$. This mineral occurs widely but is confined to the impure calcareous shales south of the contact breccia. It occurs as wedge-shaped microscopic porphyroblasts or with diopside in a poikiloblastic manner suggesting the alteration of pyroxene to hornblende. The hornblende noted here is strikingly different from that found in the igneous rocks. It has green to bluish-green pleochroism and $z \wedge c$ of 22°-26°. In some cases, it is apparently pargasite or edenite as shown by its occurrence, association, and positive optic sign.

Andalusite (Al_2SiO_5). Andalusite was only noted microscopically in close association with cordierite, both occurring within an argillaceous lens in the tremolitized limestone bed. It usually has a well developed diamond-shaped outline. Chiastolite, a variety of andalusite observed in the same lens, has wavy extinction, and the characteristic central figure of a cross caused by carbonaceous impurities and rapid crystallization.

Chlorite ($H_8(Mg,Fe)_5Al_2Si_3O_{18}$). Chlorite occurs as an alteration product of the feldspars and ferromagnesian minerals.

Cordierite ($(Mg,Fe)_2Al_4Si_5O_{18}$). This appears with andalusite in an argillaceous lens in the tremolitized limestone bed and also in argillites that are some distance from the contact. The mineral forms microscopic porphyroblasts that commonly contain sillimanite and dark smudgy unidentified inclusions.

Diopside ($Ca,Mg(SiO_3)_2$). A pure diopside, apparently not contaminated with iron, is observed microscopically in the limestone adjacent to the intrusion. Iron-rich diopside or hedenbergite occurs strikingly in a prospect pit in shale along a fault just west of Indian Draw. It was distinguished from diopside by its greater specific gravity and larger extinction angle. Here, it is exposed in grayish-green bladed crystals up to six inches in length. The edges of the crystals have been altered to actinolite and chlorite. It also forms microscopic porphyroblasts in the impure shale unit. Several minerals apparently intermediate between diopside and hedenbergite were only noted in thin section, particularly in the impure shale bed. Of these, two varieties are common, which are apparently salite and ferrosalite. One is coarsely crystalline, with low second order birefringence, and $Z \wedge c$ of 38°-44°. The second occurs as isolated crystals with green pleochroism, low first order birefringence, and $Z \wedge c$ of 45°-48°. Variations in physical properties are not infrequent and may be due to the introduction of aluminum and its replacement of calcium or magnesium or both. In some cases, the mineral may be more accurately termed an aluminous augite.

Epidote. The several varieties of epidote identified include:

Pistacite - $mCa_2(Al,OH)Al_2(SiO_4)_3$ or $nCa_2(Fe,OH)Fe_2(SiO_4)_3$

Piedmontite - $Ca_2(Al,OH)(Al,Mn)_2(SiO_4)_3$

Allanite - analagous to pistacite but with cerium and other rare earth elements

Zoisite - $Ca_2(Al,OH)Al2(SiO_4)_3$

Most of the epidote is of the pistacite variety. Pistacite is fairly widespread and occurs megascopically as green stubby prisms, acicular needles, or granules. It is invariably associated with andradite and diopside in skarn zones, and in other mining centers the world over it is an important constituent of tactite veins. Microscopically, pistacite shows yellow to green pleochroism, high relief, and parallel extinction. It is commonly a late mineral replacing silicates formed earlier. The other minerals of the epidote group are only noted in thin section and are very rare. Piedmontite and allanite resemble pistacite, but the pleochroism of the former is violet and the latter brown. Piedmontite was seen in a garnet-epidote vein and allanite in a metamorphosed shale. Zoisite was observed in sediments west of the Apache mine associated with grossularite. It usually occurs in thin prisms or minute columnar fragments of high relief and blue anomalous polarization colors. Clinozoisite was not observed.

Forsterite(Mg_2SiO_4). The mineral is of minor occurrence and was only observed in part of a metamorphosed shale bed where it forms altered crystals together with diopside, tremolite, and spinel in a matrix of chloritized orthoclase and albite. In thin section, forsterite has an elongated hexagonal outline and appears in remnants of high relief. The interiors of the crystals are so altered as to be almost completely antigorite while the rims are corroded to dark brown pleochroic smudges, probably iddingsite.

Feldspars $(K,Na,Ca)AlSi_3O_8$). Orthoclase and albite are important constituents of all metamorphosed shales. Microcline was noted in one such shale, but it was so rare that it probably represents a residue of the original sediment, unaffected by metamorphic action. Plagioclase was only observed in minor amounts, the major share having been altered to epidote and chlorite.

Garnet. Both andradite $(Ca_3Fe_2(SiO_4)_3)$ and grossularite $(Ca_3Al_2(SiO_4)_3)$ are found though optical and chemical tests indicate that andradite is the only garnet mineral in the rocks east of the McKinley fault. Andradite, ranging in color from brown to green to yellow, generally occurs in well developed dodecahedral crystals. It may also be granular or massive; the massive habit is prominent close to the contact at the Indian fault. Crystals are noted mostly in calcite and more rarely in quartz veins near the contact or several hundred feet from it. In thin section, it possesses excellent zoning of the dodecahedral type and is commonly birefringent even in the core. Andradite was readily distinguished from grossularite, which it so closely resembles, by the fact that andradite fuses to a magnetic globule; it also has a higher refractive index and greater specific gravity than grossularite. Secondary alteration has resulted in the conversion of andradite to chlorite and less commonly to idocrase.

Grossularite is only found microscopically in the recrystallized rocks west of the McKinley fault. It occurs as minute poorly developed zoned crystals 0.1 to 0.2 mm in size in argillaceous limestones. It generally has a dusty appearance which would signify a fairly rapid crystallization.

Mica ($H_2K(Al,Mg,Fe)_3Al_3(SiO_4)_3$). Microscopic plates of brown pleochroic biotite and of muscovite are common in shales.

Prehnite ($H_2Ca_2Al_2(SiO_3)_4$. Though of rare occurrence, prehnite was noted in sheaf-like aggregates as cavity fillings in a metasomatized zone.

Pyrophyllite($H_2Al_2(SiO_3)_4$. Pyrophyllite, in radiating clusters of white transparent short needles, was observed in a chloritized argillite from the dump surrounding the Apache mine. It was evidently found in a lower working, now inaccessible, and was also noted in a micro-veinlet cutting epidote.

Scapolite ($CaCO_3 \cdot 3CaAl_2Si_2O_8$ to $NaCl \cdot 3NaAlSi_3O_8$). Scapolite is extremely rare. It was identified microscopically from a vein in a tactite zone at the Chapo mine.

Sillimanite (Al_2SiO_5). This mineral is confined to shales or shaly limestones; it occurs rarely, usually as clusters of needles or in isolated fibers with short transverse fractures.

Sphene ($CaTiSiO_5$). This is a minor but common constituent of both impure shale and limestone units. It is readily identified by its twinned appearance, rhombic outline, and high relief.

Tremolite ($Ca_2Mg_5(OH)_2(SiO_4)_3$). In the limestone unit, tremolite makes up concretionary masses up to one foot in diameter, composed of radiating and criss-crossing white tremolite needles and fibers surrounded and in part traversed by a black oxidized andradite-epidote rim. The second, distinct mode of occurrence is as an alteration product after diopside from which it can be distinguished by lower relief.

Wollastonite ($CaSiO_3$). Short fibers of this mineral were only observed in some argillaceous limestones west of the Apache mine, associated with grossularite and zoisite.

Phosphates

Apatite ($Ca_5(F,Cl)(PO_4)_3$). Widely distributed, conspicuous, well crystallized hexagonal prisms or cross-sections of apatite are found in tactite zones and veins. It is also particularly prominent in the quartz diorite plugs in the vicinity of the Chapo mine.

Halides

Fluorite (CaF_2). Some crystals of violet-colored cubic fluorite were noted on the dump surrounding the Indian shaft. Many of the tactite veins contain notable microscopic amounts of colorless fluorite generally confined to fractures. It is apparently later than andradite and epidote but earlier than the iron oxide minerals.

Oxides

Bismutite (Bi_2O_3). The only compound of bismuth, bismutite, was observed in some specimens from the dump around the Apache shaft.

Bismutite is a carbonate — bismite has the formula Bi_2O_3 — in Table 5 bismuth is listed !!!!

Hematite or specularite (Fe_2O_3). This most abundant iron oxide, in the contact aureole, occurs in thin isolated plates or groups of plates that are lustrous and have a brown to black color.

It is invariably associated with calcite veins and tactite minerals. A large concentration of massive hematite was observed in a limestone lens east of the Apache shaft.

Magnetite (Fe_3O_4). In the region here described, this is a common mineral associated with the tactite zones.

Quartz (SiO_2). The mineral occurs in recrystallized sandstone and in post-ore veins that cut both silicates and sulfides. The quartz usually fills fissures and faults normal to the trend of the beds. Along the Apache fault and associated fissures in porphyritic rhyolite, it is also massive. Some of the quartz in the later faults is jasper.

Spinel ($MgAl_2O_4$). An iron-magnesium spinel (pleonaste) is ubiquitous in most of the metamorphosed sediments, in which it is characterized by dark green to black color and by isotropism.

Carbonates

Calcite($CaCO_3$). Several types of post-diagenetic calcite are noted in the contact aureole. One represents recrystallization in place, producing a massive limestone composed of perfect rhombic crystals. The second type is in the recrystallized limestone adjacent to the Indian fault in which calcite grains have been enlarged and twinned. A third variety is in veins that contain tactite minerals, oxides, and sulfides. It is also found in post-ore faults and fissures. Much of the recrystallized calcite fluoresces pink as contrasted with the green fluorescence of vein calcite.

Tungstates

Scheelite ($CaWO_4$). Scheelite could only be identified in the field by its blue-white color under the fluorescent lamp. Its occurrence is varied: 1) at the Cochise vein, it is restricted to quartz veins cutting silicified shale in association with copper oxides; 2) it is fairly widespread in quartz veinlets traversing chloritized shale; 3) it forms pods in the massive recrystallized limestones; and 4) at the Chapo mine, it occurs in calcite veins with magnetite.

Sulfides

Chalcopyrite ($CuFeS_2$). Almost invariably chalcopyrite accompanies andradite-epidote veins. It also occurs with other sulfides in veins cutting metamorphosed sediments particularly at the Apache mine.

Galena (PbS). This is a common mineral found with other sulfides and silicates at the Indian shaft and the prospects east of Squaw Creek. It is also in the underground workings of the Apache mine, notably on the 70-foot level.

Pyrite (FeS_2). This is ubiquitous in all the sediments and has probably formed in many cases under purely thermal conditions from the reaction of iron oxide and sulfur originally present. It is also common in tactite veins.

Sphalerite (ZnS). This is closely associated with galena.

Native Metals

Gold (Au) and silver (Ag). These elements were not observed but assays prove that they are present.

METAMORPHISM IN THE CONTACT AUREOLE

Succession of Phases

The general succession of events that occurs during the contact metamorphic processes is believed to begin with the crystallization of magma upon intrusion into a sedimentary sequence; with this comes a loss of heat to the surrounding country rocks and baking and recrystallizing of the latter. Further solidification produces a high partial vapor pressure in the residual liquid, resulting in the escape of gaseous components into the country rocks, thereby causing metasomatism. Among the pneumatolytic gases, water is the primary constituent; this cooled and condensed to an aqueous solution responsible for the precipitation of hydrothermal minerals.[1]

Thus two main phases of metamorphism are noted in the district. Purely thermal or isochemical metamorphism has affected the sediments and some of the igneous rocks in varying degrees. Allochemical metamorphism, has also affected the contact areas, but there is a distinct lack of metasomatic silicates, oxides, and sulfides west of the McKinley fault. It appears that this fault served both as a channel for metasomatizing solutions and as a barrier in preventing solutions

[1]Ramberg, Hans (1952), Origin of metamorphic and metasomatic rocks, Univ. of Chicago Press, Chicago, p. 171.

from penetrating the rocks to the west, with the exception of those in the immediate vicinity of cross fractures. This strongly suggests that the major component of movement of metasomatizing solutions was lateral or at least that the fault extended to such depths that no deeper metasomatizing solution was able to cross it and then move upward. Couldn't the tactite be cut off by post-tactite movement on the boundary fault? WCE

Some of the mineralogical changes in the sediments can be ascribed to pneumatolytic or hydrothermal metasomatism or to pore solutions heated by the magma circulating through the sediments. The effects of the last may be confused with some phase of metasomatism, particularly if there is a remobilization of elements leading to eventual precipitation in a foreign area. For example, the chloritization of andradite in limestone may result in the deposition of chlorite in an adjacent area. The conversion of an anhydrous mineral to a hydrous mineral, such as the uralitization of a pyroxene, concomitant with the introduction of aluminum, iron, and other elements into the amphibole lattice, may be due solely to hydrothermal action or to the dual effect of heated pore solutions succeeded by the entrance of magmatic waters. In some cases, however, distinctions as to the mode of ion transfer can be applied. The presence of epidote due to alteration of anorthite suggests hydrothermal metamorphism with water as the transporting agent, whereas the occurrence of epidote with andradite, hematite, and halide minerals in typical tactite zones is believed to indicate, at least, initial pneumatolytic transport. By whom? why?

What does all this have to do with the problem at hand?
WCE

In general, the effects of contact metamorphism, whether isochemical or allochemical, within the invaded rocks is governed by a number of factors such as the temperature of the magma at the time of intrusion, the confining pressure (hydrostatic pressure), the chemical activity of the solutions percolating through the rocks, the chemical and physical constitution of the invaded rocks, and the structural relations necessary for the transfer of heat and fluids. In the district here described these were exceedingly variable and difficult indeed to generalize. sTress?

Temperature

The temperature of metamorphic reactions in nature can only be estimated since the effect of certain variables, especially water, upon available experimental and calculated results, are not quantitatively known. Circulating pore solutions, composed of water, carbon dioxide, and dissolved elements (which may act as a free phase or as primary catalysts in the reaction and recrystallization of existing minerals) will cause a particular reaction at a given pressure to be lower than that of a pure phase.[1] The occurrence of low water pressure in relation to rock pressure will cause reactions to take place at lower temperatures. For example, in the reaction forsterite + talc = enstatite + vapor, at 500 bars rock pressure and 220

[1]Weeks, W.F. (1955), A thermochemical study of equilibrium during metamorphism of siliceous carbonate rocks, Jour. Geol., vol. 64, p. 254.

bars pressure, forsterite and talc will react at a temperature that is 20° less than if the two pressures were equal.[1] Of course, temperature differences of so small an order, while suggestive, do not greatly affect quantitatively the ranges that are generally estimated for these reactions. They merely reflect the fact that there are such effects.

Then why mention it? wee

The upper range of the temperature of formation of the silicates in the contact zone is believed to lie in the range from 450° to 550° C which is considered to reflect the upper part of the amphibolite facies or the lower part of the pyroxene-hornfels facies. This takes into account recent work, particularly by Yoder,[2,3] on the importance of water in the metamorphic process. The complexity of temperature determination is emphasized by tremolite which is present in different mineral associations in different rocks according to its mode of formation, e.g., tremolite is produced either during initial isochemical metamorphism by the reaction of lime, silica, and magnesia or by the alteration of mafic minerals, such as diopside. It is believed that the high temperatures required for the development of silicates is primarily derived from the metasomatizing fluids emanating from the quartz monzonite magma and that the numerous dikes throughout the sedimentary sequence

Is all this really necessary? wee

[1]Yoder, H.S. (1955), Role of water in metamorphism, Crust of the earth, Geol. Soc. Amer. Sp. Paper 62, p. 515.

[2]Ibid, pp. 505-524.

[3]Yoder, H.S. (1952), $MgO-Al_2O_3-SiO_2-H_2O$ system and the related metamorphic facies, Amer. Jour. Sci., Bowen volume, pp. 569-627.

What does size have to do with [illegible] The field evidence shows very close association of [illegible] dikes & [illegible] WEE

were too small to have any effect on the country rocks.

The temperature of formation of the sulfides is also presumed to be high, as evidenced by the association of chalcopyrite and sphalerite which occur in typical replacement textures along the Indian fault. Chalcopyrite and sphalerite form homogeneous solid solutions at high temperature and unmix at about 350°-400° C.[1]

If they occur in replacement textures, what evidence is there that they were originally in a homogeneous solid solution? WEE

The occurrence of high temperature silicates far removed from the contact aureole suggests more than a mere temperature decline in the system from the silicate to the sulfide stage. It is probable that the influx of hot fluids was of a pulsating nature resulting in a rise and fall of the temperature several times, rather than a simple rise and subsequent decline.

Isochemical Metamorphism

General

In the purely thermal stage, temperature appears to be the primary factor affecting the nature of the resulting mineral assemblage. Pressure has little bearing in this connection but is a factor when a gaseous phase occurs, as in the liberation of carbon dioxide upon recrystallization of an impure limestone to a calc-silicate rock. Rapid evolution of carbon dioxide is common in contact zones and the ensuing development of high carbon dioxide pressures during progressive decarbonation of calcareous rocks may result in minerals that are

[1]Buerger, N.W. (1934), The unmixing of chalcopyrite from sphalerite, Amer. Miner., vol. 19, pp. 525-530.

apparently anomalous in certain mineral assemblages. The stability of the calcium and magnesium silicates thus formed would depend on a low partial pressure of carbon dioxide. An illustration of this is the formation of diopside from a lime-magnesia-silica rock (as in the impure limestone bed at the Apache mine) that would have been retarded or even inhibited by increasing pressure of carbon dioxide evolved during the reactions. Increased concentration of carbon dioxide would have resulted in the formation of carbonates. However, structural features generally provide avenues of escape for the gases.

This whole paragraph can be summarized; [illegible] metamorphism took place in an open system. Consequently (a) CO_2 evolved during silication of limestone could escape and (b) the chemical reactions were irreversible.

The transfer of heat from the intrusion during this phase of the metamorphic process is probably accomplished by gases and other vapors emanating from the stock since the conductivity of rocks and the resulting rate of conduction is too low to account for the recrystallization of rocks so far removed from the source of heat. In addition, much of the heat could be carried by carbon dioxide which was released in large quantities by the initial metamorphic reactions in limestone. The heat was applied by fluids rather than by conduction; this conclusion is reached since it is probable that metamorphism occurred after the quartz monzonite had partially cooled. Furthermore, fluid transport is necessary in order to account for the fact that some parts of the contact aureole are more intensely affected than those closer to the igneous contact.

During this period of chemical reconstitution, it is believed that the metamorphosed rocks remained essentially solid as evidenced by the similar thickness of beds within and outside of the contact aureole. Reactions involving recrystallization and recombination of ions in the affected rocks are generally thought to occur in the solid state though probably facilitated by aqueous pore solutions circulating through the sediments. The migration of ions along structural disorders of various magnitudes including mineral interstices, crystal boundaries, or even through solids, has been suggested by some workers in the field, but it is generally believed that, at best, this process is insignificant under the usual conditions of contact metamorphism. Measurements of diffusion in silicates indicate that the rate of transfer in solids of this type are much too slow to produce extensive changes even in the time available during the metamorphic cycles.[1] Moreover, the prevalent occurrence of water in the host rock and the invading rock provides an effective agent for the transport of heat and material. The activity of water in isochemical metamorphism is indicated by the occurrence of hydroxyl-bearing minerals and by the larger width of aureoles around the more aqueous acidic intrusions than around mafic ones. Investigations by Yoder[2] further emphasize the role of water for it is demonstrated that in an aqueous environment at 600° C and 15,000 lbs/in^2, almost every mineral characteristic of thermal

by whom? Evidence?

[1] Mason, Brian (1954), The geochemistry of metamorphic processes, The earth as a plane, Univ. of Chicago Press, Chicago, p. 290. ?

[2] Yoder, H.S. (1952), $MgO-Al_2O_3-SiO_2-H_2O$ systems and the related metamorphic facies, Amer. Jour. Sci., Bowen volume, p. 615.

metamorphism may be produced, irrespective of temperature. ?

Zoning of silicates is a feature common to contact metamorphic halos although this concept cannot be readily applied to the district here discussed. The development of silicates in concentric zones is primarily dependent upon the availability of fissures to provide access for the transfer of heat, the variation in temperature from the contact outward, the duration of metamorphism, and the composition of the affected bed. Generally, the concentric zones are characterized by a succession of silicates expressive of the temperature gradient at the time of metamorphism and are most recognizable where the temperature gradient outward from the intrusion has affected similar beds (ideally those where the strike is perpendicular to the igneous contact) and has produced different minerals at varying distances from the contact. In the Apache-Chapo district, accession of material during the metasomatic stage, the thin bedded character of the sediments, the strike of the beds parallel to the contact, their varying lithology along the strike, and the varying bulk water contents of the beds makes it difficult to ascertain a zoning relation. Despite these deterrents, however, some examples were noted of evidences for temperature decline outward from the source. In the trench just northeast of the Apache shaft, the shale beds closest to the contact contain cordierite and biotite whereas the argillites to the south, exposed at the north end of the open cut have undergone mostly mineral recrystallization and enlargement but without the evolution of new minerals.

No, not in calcareous rocks. See Harker, 3rd Ed., Chap 6

Similarly, the impure shale unit closer to the contact generally contains larger and more abundant pyroxene porphyroblasts than the same unit away from the contact. At the 1936 shaft, however, specimens from the dump contain an abundance of tactite minerals and again in the underground workings north of the open cut, andradite-epidote veins cutting silicified shale were observed (Figure 12). East of the Chapo fault, tactite veins, outlined by the position of the workings, occur in the quartz diorite plugs and sediments an appreciable distance from the contact whereas the sandstone beds close to the contact are merely recrystallized. If zoning were a pervasive feature of this area, then tactite mineralization would normally be expected only close to the contact where the temperatures are presumably higher, though structural control might make the zones anomalously asymmetrical as at Leadville.[1,2] Certainly, then, any concept of zoning as applied here is vague. pp 120 - 124 could be summarized in one short paragraph

Effects on Sedimentary Rocks

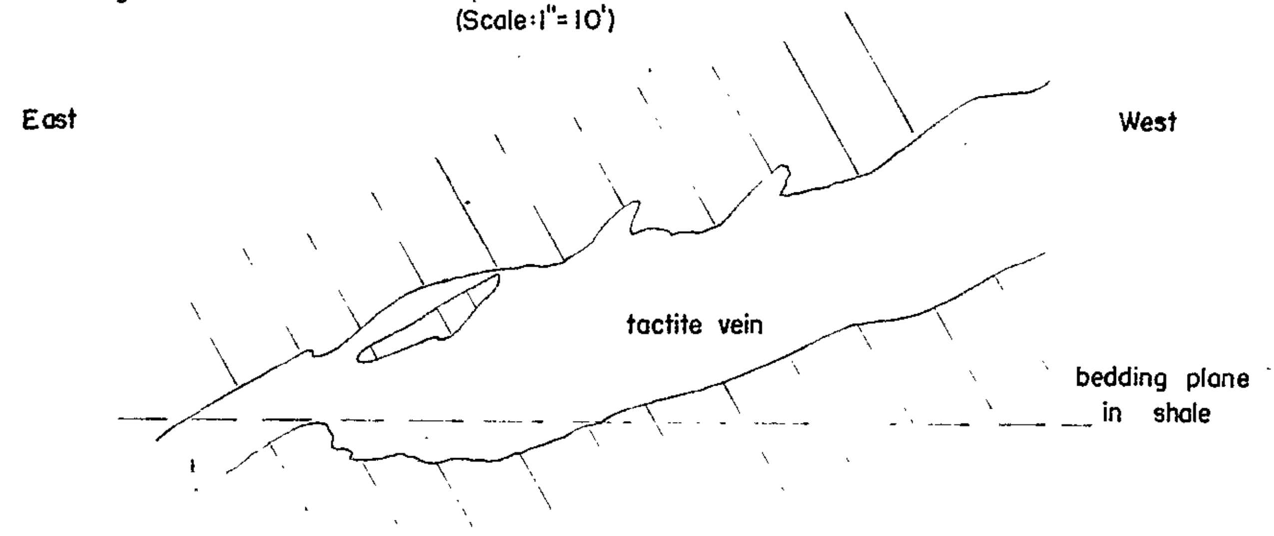
The sediments within the contact aureole generally behave according to the classic recrystallization theories of Harker[3]

[1]Loughlin, G.F., and Behre, C.H., Jr. (1934), Zoning of ore deposits in and adjoining the Leadville district, Colorado, Econ. Geol., vol. 29, pp. 241-242.

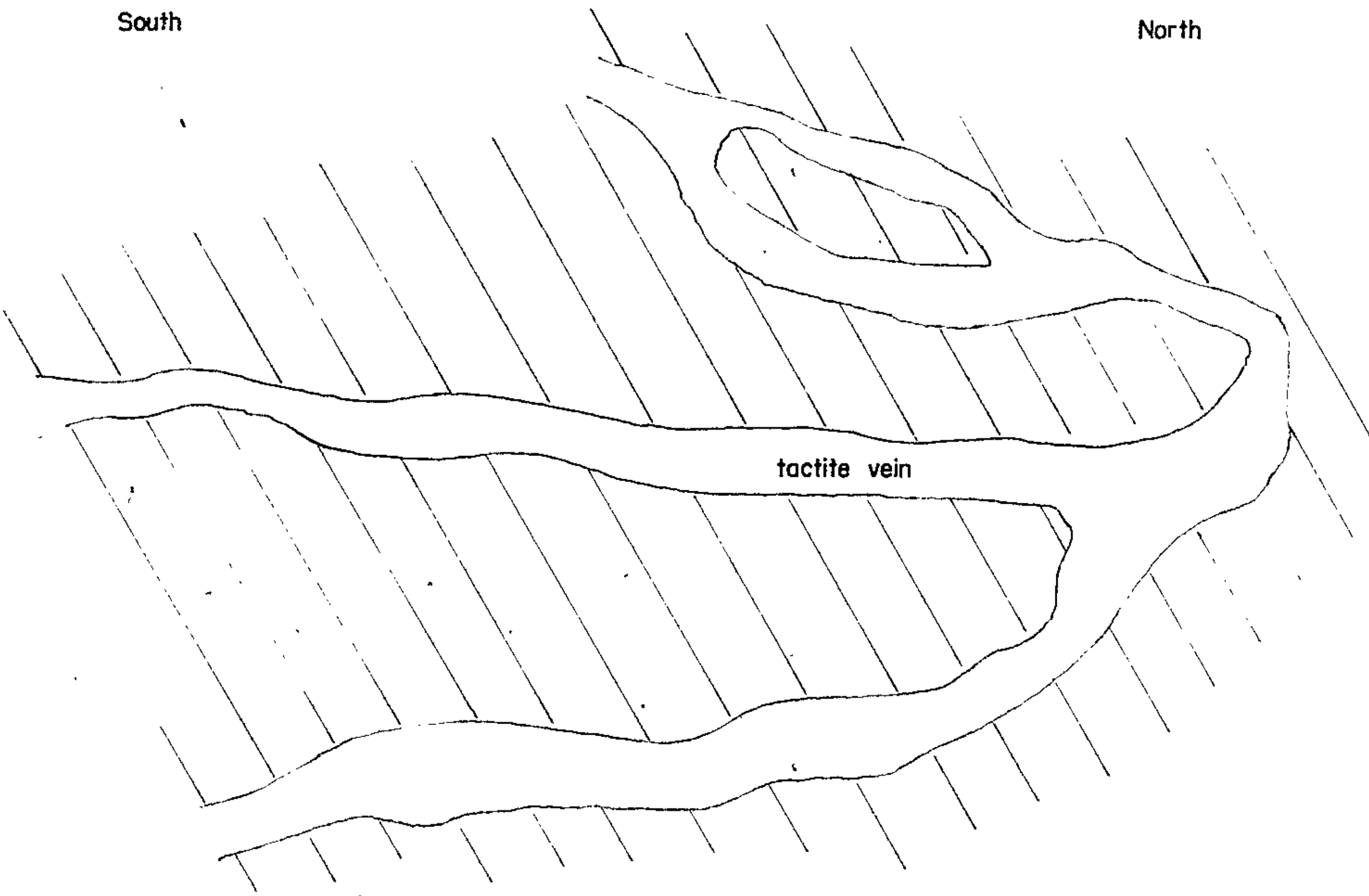
[2]Behre, C.H., Jr. (1953), Geology and ore deposits of the west slope of the Mosquito Range, U.S. Geol. Survey Prof. Paper 235, p. 89.

[3]Harker, Alfred (1939), Metamorphism, Methuen and Co., London.

Figure 12. Sketch of tactite veins in chamber at 50' level of Apache mine
(Scale: 1" = 10')



Located on wall east of flat stope and below massive limestone bed



Located at back of chamber east of flat stope and above massive limestone bed and they can be distinguished according to grades as developed in Eskola's classification of metamorphic facies.[1] Closest to the intrusion, believed to be the source of heat, the sediments apparently conform to the upper limit of the amphibolite facies and indicate an area of moderately high temperatures and low pressures. More distantly from the contact, they agree with the critical mineral assemblages developed in rocks of the epidote-amphibolite facies, as confirmed by the lack of calcic plagioclase, the presence of large amounts of chlorite, the instability of pyroxene, and the stability of epidote or zoisite in preference to anorthite. Exact temperatures cannot be assigned to either of the two facies as the presence of circulating pore solutions could induce the formation of metamorphic minerals at a much lower temperature than would normally be expected. A temperature of approximately 500° C has been suggested for the amphibolite facies.[2]

In the preceding pages, [illegible] explains that the [illegible] is most sound!

The mineral assemblages of the impure calcareous units in the Apache-Chapo district reflect the low temperature end of Bowen's series[3] in which the metamorphism of siliceous limestones and dolomites is postulated to exhibit thirteen successive reactions or steps in order of increasing temperature,

[1]Turner, F.J. (1948), Mineralogical and structural evolution of the metamorphic rocks, Geol. Soc. Amer. Mem. 30, pp. 54-60.

[2]Barth, T.F.W. (1952), Theoretical petrology, John Wiley and Sons Inc., New York, p. 343.

[3]Bowen, N.L. (1940), Progressive metamorphism of a siliceous limestone and dolomite, Jour. Geol., vol. 48, p. 257.

resulting in the formation of ten minerals, as follows: tremolite, forsterite, diopside, periclase, wollastonite, monticellite, ackermanite, spurrite, merwinite, and larnite. In addition, talc is believed to precede tremolite,[1] and garnet is commonly associated with the diopside zone.[2] As far as can be determined in this district, there is no evidence that metamorphism went beyond the wollastonite stage which is usually the highest grade achieved in contact aureoles around granitic to intermediate intrusives. Moreover, there is no evidence that periclase was ever produced by partial dissociation of dolomite, since the supply of magnesia was probably exhausted by the previous steps of alteration. In this regard, recent experimental data indicate that perhaps steps 4 and 5 of Bowen's series should be reversed, since Harker and Tuttle[3] have demonstrated that at carbon dioxide pressures between 5,000 and 40,000 psi, calcite and quartz react to form wollastonite about 100° to 150° C below that at which periclase is formed. These pressures corresponding to depths of 4,400 to 35,000 feet probably represent the extreme ranges between which metamorphism occurred in this area.

[1]Tilley, C.E. (1948), Earlier stages in the metamorphism of siliceous dolomites, Miner. Mag., vol. 28, pp. 272-276.

[2]Eskola, Pennti (1922), On contact phenomena between gneiss and limestone in western Massachusetts, Jour. Geol., vol. 30, p. 283.

[3]Harker, R.I., and Tuttle, O.F. (1956), Experimental data on the P_{CO_2} - T curve for the univariant reaction: calcite + quartz = wollastonite + CO_2, Amer. Jour. Sci., vol. 254, p. 249.

Additional reversals are suggested by the almost complete absence of forsterite and corresponding abundance of diopside in the contact aureole. According to Weeks,[1] the formation of diopside generally occurs before forsterite mainly because of the general presence of water, in which case more complex reactions involving tremolite take place. In these reactions, relative reaction temperatures based upon the heats of formation, in addition to other thermo-chemical data, suggest that diopside occurs before forsterite. When this happens, the formation of diopside will not leave sufficient magnesia to produce forsterite since diopside has almost the same Ca/Mg ratio as the original sediment.[2] Thus forsterite in association with diopside, like the occurrences in some of the local shale beds, indicates that magnesia has been introduced.

Evidence for the formation of talc, the initial step in the metamorphism of siliceous limestone, is also lacking. Even if it was originally produced, it could presumably form tremolite according to the equation: talc + quartz + calcite = tremolite + water + carbon dioxide.

The mineral assemblage within the impure limestone immediately south of the limestone-rhyolite breccia zone conforms to the pattern of metamorphism described for the upper part of the temperature range corresponding to the amphibolite facies or the lower part of the temperature range of the pyroxene-

[1]Weeks, W.F. (1956), Heats of formation of metamorphic minerals in the system $CaO-MgO-SiO_2 - H_2O$ and their petrological significance, Jour. Geol. vol. 65, p. 470.

[2]Weeks, op cit, p. 261.

hornfels facies. The sediment appears to be transitional between the two facies since calcite appears to have been the stable phase rather than wollastonite.

The limestone unit is characterized by tremolite rather than actinolite probably because of the lack of ferrous iron in the sediment. With the exception of metasomatic silicates, the mineral assemblage has been developed by the interaction of calcium oxide, magnesia, and silica under conditions of rising temperature. Tremolitization typifies this unit and has resulted in conspicuous nodules and concretions reaching almost a foot in diameter (Figure 13). They are embedded in a recrystallized calcite groundmass. In some specimens, the source of silica for the tremolite is obviously indigenous in that it is derived from nearby microscopic chert lenses and stringers (Figure 14). In others, it is apparently introduced, in solutions, as it were, possibly from the alteration of aluminous rocks and minerals below the area now exposed. In this case, the prominently developed epidotization of the monzonite porphyry may have liberated sufficient silica. The low percentage of silica (Table 3) likewise indicates its introduction why ? into the sediment. Occasionally the amphibole is actinolite, as was noted at the easternmost prospect of the Apache mine division (Plate 2). Other minerals associated with tremolite include diopside and sphene. The latter, found in well developed rhombs of high relief, is most prevalent in some of the more shaly lenses of the limestone. It was probably formed by the reaction of calcite, silica, and titanium oxide. The

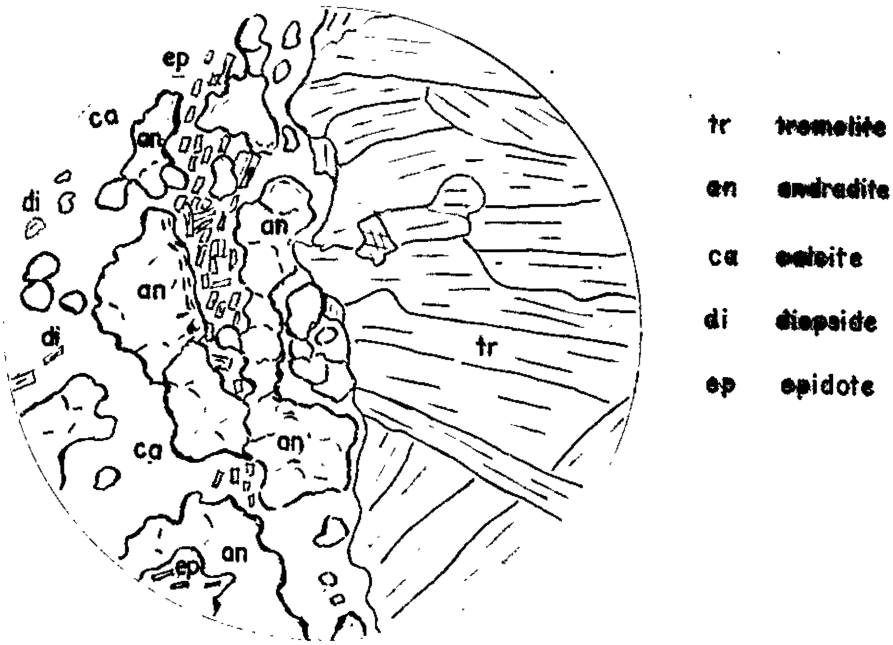


Figure 13. Thin section of tremolite concretion west of the V-E Day shaft composed of tremolite prisms cut by tactite veins. A few diopside crystals are embedded in recrystallized calcite (Nicols crossed, diameter 4.4 mm).

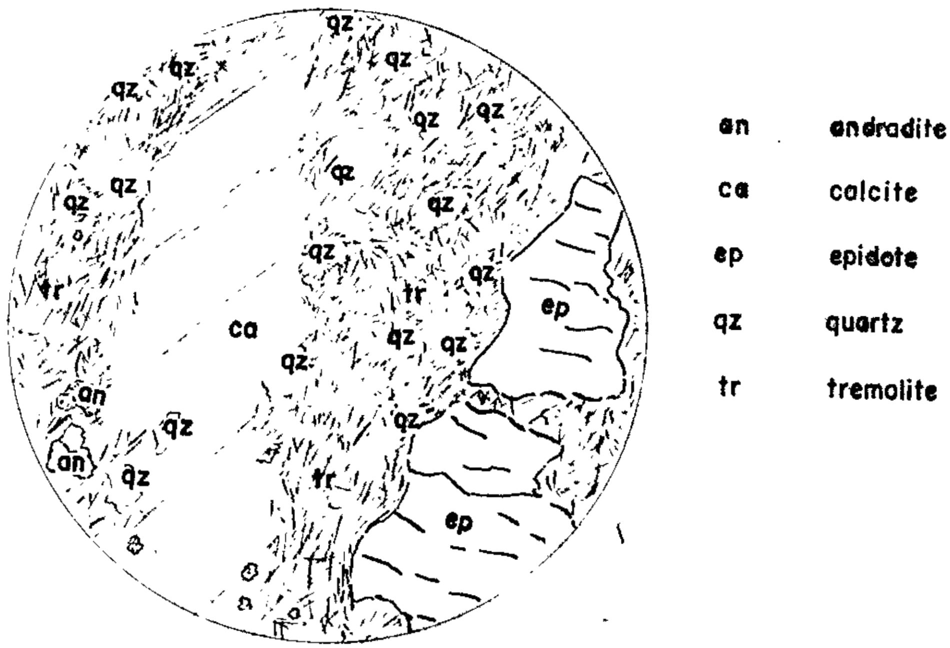


Figure 14. Thin section of tremolitized limestone east of Squaw Creek illustrating an indigenous source of silica for the development of tremolite (Nicols crossed, diameter 1.45 mm).

titanium oxide may be derived from rutile (commonly a minor constituent of argillaceous beds) or from minerals such as amphibole and pyroxene in which TiO_2 substitutes for other elements. In the cases here found some of the TiO_2 may have been introduced. The occurrence of andradite and epidote with the above suite of minerals can be attributed to metasomatic action. why?

The formation of tremolite, the initial step noted in the metamorphism of the limestone unit must have occurred in a hydrous environment, since forsterite would have developed in a dry environment. Further reaction of tremolite, calcite, and silica resulted in the formation of diopside and involved replacement of tremolite by diopside. This reaction was the highest temperature phase attained during the metamorphic cycle of this bed. Perhaps, minerals indicative of a higher metamorphic grade were formed in this unit, but, with silica in excess, only tremolite and diopside are the stable minerals. All the reactions involved caused the liberation of carbon dioxide and its eventual release to the outer margins of the contact aureole through the numerous fractures and fissures traversing the unit.

Mineral assemblages apparently characteristic of higher temperatures than those above were noted in argillaceous lenses within the limestone which have been recrystallized to andalusite, cordierite, and plagioclase. Andalusite is commonly of the chiastolite variety. Cordierite generally contains enclosed sillimanite needles (Figure 15). Sillimanite can be developed from the reaction of quartz with either muscovite or biotite. However, when muscovite becomes unstable in reaction with quartz at 600° to 700° C, orthoclase is the associated mineral; the reaction between biotite and quartz at somewhat lower temperatures, about 550° C, produces cordierite.[1]

These relations can perhaps best be expressed in an ACF diagram, this being used to describe a triangular composition diagram in which the apices represent three chemical components - Al_2O_3, CaO, and (FeO,MgO) - which to a large extent control the mineral development in many metamorphic rocks. The assemblage described lies in the upper triangle in the ACF diagram for pelitic rocks which contain excess silica and are deficient in potash (Figure 17). A hydrous environment is also necessary. Any potash present may crystallize as orthoclase or albite. In this high-temperature, nonpotassic, and relatively lime-free environment, andalusite and cordierite are generally the stable constituents; conversely muscovite and biotite are a stable combination. Only Or. K in albite

Isolated parts of these lenses contain spinel in association with andalusite and cordierite. This assemblage further indicates the heterogeneity of the unit since the mineralogy generally reflects the metamorphism of a sediment rich in magnesia and deficient in silica.

Certain deductions may be made concerning the temperature gradient immediately following intrusion. It seems apparent

[1]Yoder, H.S., and Eugster, H.P. (1955), Synthetic and natural muscovites, Geochim. et Cosmochim., acta 8, p. 263.

that the rise of temperature was rather rapid but did not reach any high extremes (except in isolated areas as shown above) since tremolite occurs in abundance in contrast with diopside which was only noted microscopically, i.e., the rise in temperature had barely arrived at the point where diopside could develop. Moreover, the rapidity of the elevation of temperature is demonstrated by the formation of chiastolite which is usually considered a product of incomplete and rapid crystallization in which there was insufficient time to eliminate the carbonaceous impurities. Similar crystallizing conditions prevail for the sillimanite needles incorporated within the cordierite porphyroblasts.

The sediments west of the McKinley fault illustrate conditions of isochemical metamorphism free from complexities attributable to later metasomatism. In some of the argillaceous limestones close to the stock, the mineral assemblage developed illustrates features of chemical recombination in a sediment devoid of magnesia and with a relatively low silica content. Individual beds contain crystals of grossularite, wollastonite, and zoisite in a matrix of quartz, calcite, and altered feldspar shreds (Figure 16). All the crystals are small and average about 0.1 to 0.2 mm. in diameter. This development represents a simple reconstitution of the calcareous and aluminous material as indicated by the assemblage illustrated in the upper right triangle of the ACF diagram (Figure 18). Temperatures were evidently high enough to allow for the reaction of quartz and calcite to form wollastonite. The temperature of reaction

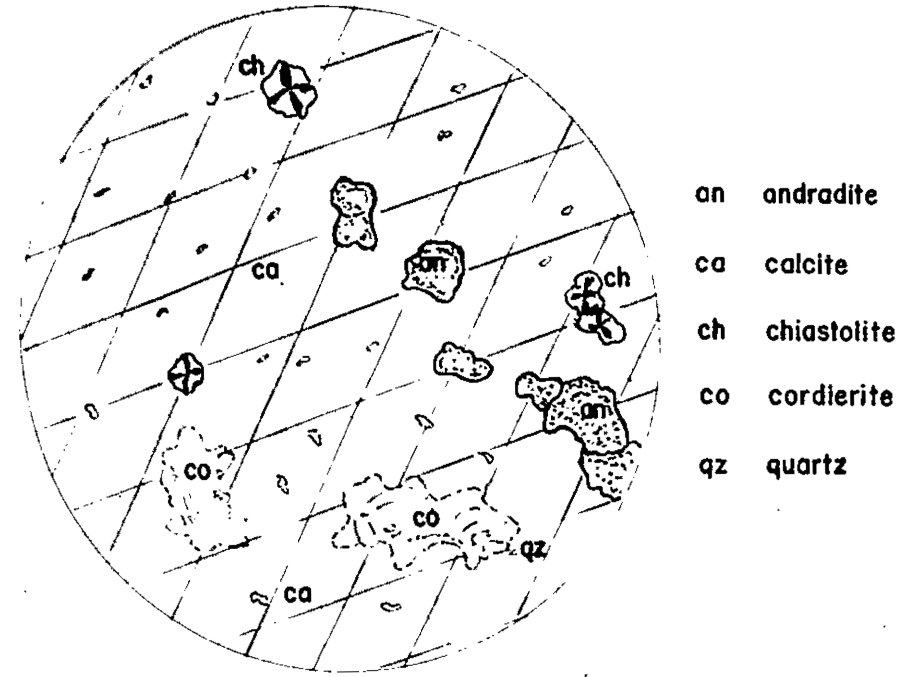


Figure 15. Thin section of argillaceous lens within the tremolitized limestone west of the Chapo fault. It contains chiastolite with the characteristic "iron-cross" extinction, cordierite with included sillimanite needles, and chloritized andradite. The recrystallized calcite matrix contains abundant quartz (Nicols crossed, diameter 1.45 mm).

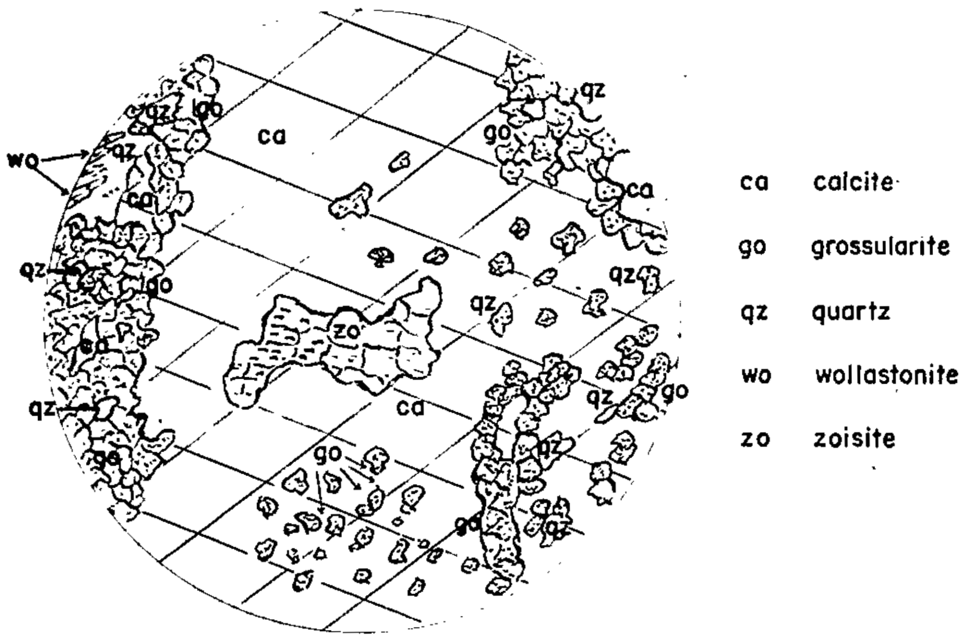


Figure 16. Thin section of argillaceous limestone west of the McKinley fault containing zoisite and minute grossularite crystals (shaded) and wollastonite needles (Nicols crossed, diameter 1.45 mm).

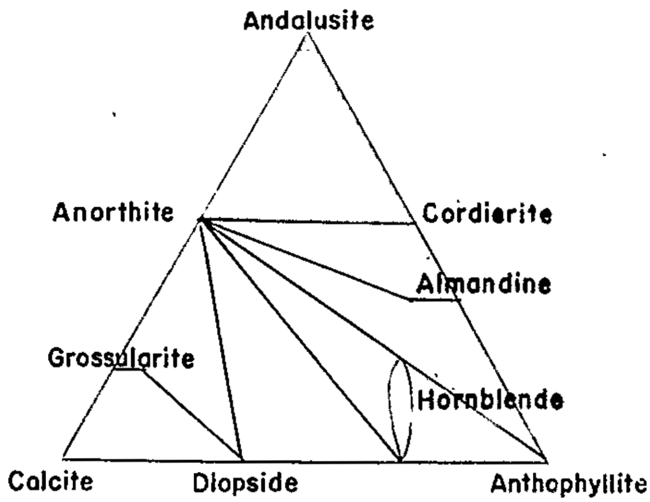


Figure 17

ACF diagram for argillaceous rocks with excess SiO_2 and K_2O deficient (Barth, 1952, p. 342).

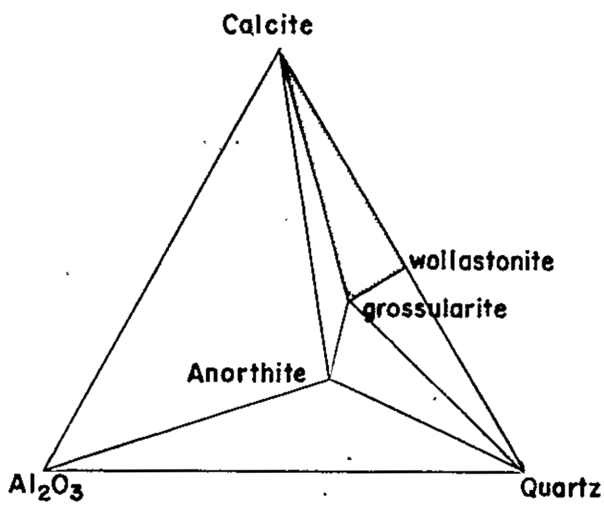


Figure 18

ACF diagram for CaO-SiO_2-Al_2O_3 system; CO_2 in excess (Turner, 1948, p. 74).

ranges between 280° and 850° C; however, this depends upon the partial pressure of carbon dioxide, i.e., if the pressure is low due to escape of gas, then wollastonite may form at lower temperatures.[1] The middle range of the two temperature extremes is believed to be the most probable for this reaction. Excess calcite in combination with available silica and the anorthite component of feldspar reacted to form grossularite at similar temperatures suggestive of a stable association representative of the pyroxene-hornfels facies. At these high temperatures, anorthite will be totally lacking.

Although the mineral assemblage reflects a so-called high grade of metamorphism, the presence of zoisite indicates an adjustment of the mineral sequence to a lower temperature. Zoisite may have resulted from the interaction of anorthite, excess calcite, and water. In this case, the formation of zoisite may be attributed to the saussuritization of feldspar whereby the anorthite component is acted upon by water, either connate or from an extraneous source, thus liberating lime, silica, and alumina, which recombined to form zoisite. Ferric iron may also enter into the reaction, forming pistacite rather than zoisite.

The impure shale unit has an interesting mineralogy and generally illustrates the effect of isochemical metamorphism. However, the effects of circulating pore solutions or hydrothermal solutions or both account for the fact that the original

[1]Danielsson, Allan (1950), Das Calcit-Wollastonitgleichgewicht, Geochim. et Cosmochim., acta 1, pp. 55-69.

mineralogy, once indicative of the amphibolite facies, is now representative of a somewhat lower grade. The unit is usually green colored, very fine grained, and massive, although bedding was occasionally noted in thin sections. Microscopically, the sediment consists of porphyroblasts of badly altered diopside and occasional hedenbergite in a matrix of feldspar now so heavily chloritized as to be almost unidentifiable. The feldspar was probably originally orthoclase and plagioclase. Lesser quantities of actinolite and recrystallized quartz and calcite were also observed. The ACF diagram for this facies shows that the mineral assemblage developed through the interaction of alumina, lime, and magnesia in the presence of excess silica and potash. Since potash was excessive, andalusite and cordierite were prevented from developing, and orthoclase could crystallize within the three phase assemblage (as shown in the shaded triangle of Figure 19).

Diopside has undergone two different alterations. In one, the reaction with water and carbon dioxide at lowered temperature has resulted in the formation of tremolite which occurs as needles and prisms in replacement fashion along the outer edges of diopside crystals. Analogous alteration of hedenbergite has resulted in the development of actinolite. The second alteration process, presumably under the influence of hydrothermal solutions, promoted the conversion of diopside to aluminous augite whereby silica is replaced by aluminum (Figure 21). To compensate for the valency change thereby produced, aluminum may also enter the magnesium position.[1] Since the ions involved in this substitution are of a comparable size, there is no apparent distortion in the resulting crystal. Further substitution in an aqueous environment has caused the formation of aluminous hornblende. As the crystal structure of hornblende allows it to literally act like a sieve, it is most probable that many elements have entered its structure and altered its composition. Certain thin sections point to the replacement of lime by soda causing the formation of pargasite. In addition, the hydroxyl radical may be replaced by fluorine. As in pyroxene, aluminum replaces both silicon and iron, and magnesium.[2] The alumina for aluminous pyroxene and hornblende is probably derived from the breakdown of the anorthite molecule of plagioclase feldspar in areas removed from the sediment. Excess alumina has doubtless been utilized in the development of chlorite.

The latest alteration process affecting the sediment is the conversion of ferromagnesian porphyroblasts and the feldspar matrix to chlorite. Hydrothermal solutions are assumed to be responsible for the decomposition. The lime released during chloritization has become fixed as calcite probably by reaction with carbon dioxide derived from the silication of the adjacent limestone unit.

[1]Ramberg, op cit, p. 65.

[2]Mason, Brian (1952), Principles of geochemistry, John Wiley and Sons, Inc., New York, p. 108.

Since the composition of most argillites is markedly heterogeneous, minor amounts of minerals not in complete agreement with the common mineral assemblage of the above shale unit were observed. Some of the shale beds closer to the contact in the western part of the Chapo mine division characteristic of an impure marly sediment deficient in silica are composed primarily of a diopside-forsterite-spinel assemblage. There forsterite occurs as relicts almost wholly converted to antigorite and possibly brucite which is believed to develop in the presence of water vapor at temperatures generally below 400°C and at pressures varying between 2000 and 40,000 psi.[1] Spinel is noted in black or dark green isotropic crystals. Orthoclase or plagioclase, which compose the altered groundmass, can exist as an additional mineral in equilibrium with the above assemblage. Minerals of lesser abundance scattered throughout the bed and attributed to purely thermal origin include magnetite and pyrite. Minerals apparently of metasomatic origin include apatite, fluorite, andradite, and hematite. The principal three-phase mineral assemblage with calcite is indicated in the shaded triangular area of an ACF diagram (Figure 20).

Define "marly" — mean dolomite? [illegible] different [illegible] The diopside-forsterite-spinel assemblage would form from a dolomitic [illegible] of clays [illegible] WEE

Further evidence of the heterogeneity of the shale unit is afforded by some of the other beds which demonstrate the recrystallization of constituents under temperature conditions less extreme than those closer to the igneous contact. The shale stratum exposed at the trench north of the open cut

[1]Bowen, N.L., and Tuttle, O.F. (1949), The system $MgO-SiO_2-H_2O$, Geol. Soc. Amer. Bull. 60, p. 452.

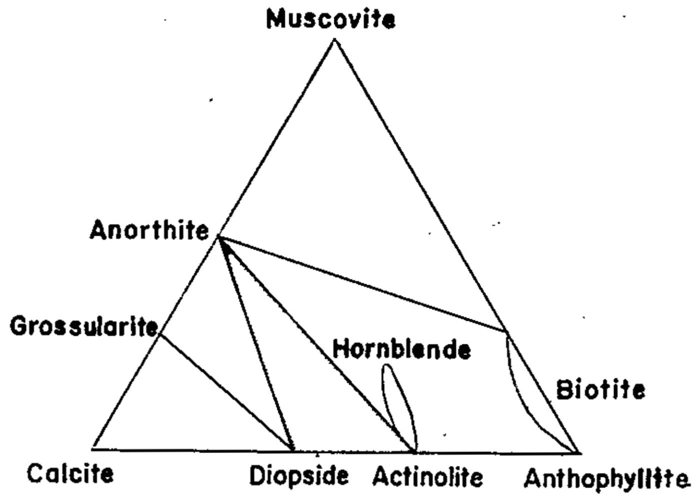


Figure 19

ACF diagram for argillaceous rocks with excess SiO_2 and K_2O (Turner, 1948, p. 78).

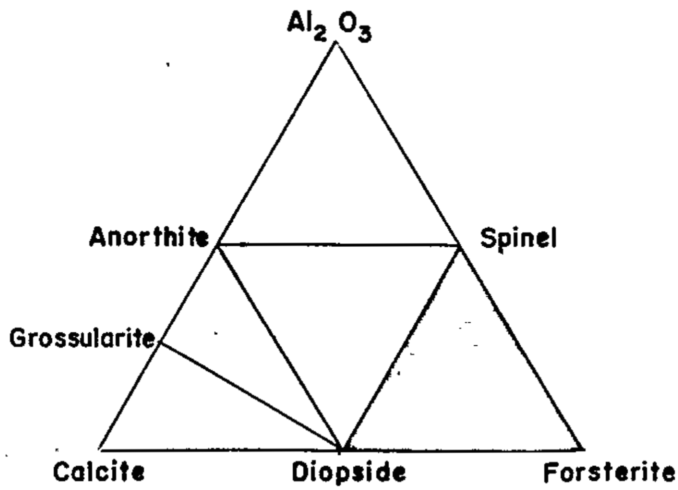


Figure 20

ACF diagram for silica-deficient rock containing calcite in CaO-MgO-Al_2O_3-SiO_2 system (Turner, 1948, p. 75).

contains epidote, cordierite, and biotite porphyroblasts, together with quartz, orthoclase, albite, and oligoclase. The occurrence of cordierite and biotite suggests the interaction of quartz, alumina, and magnesia in a potassic environment. The presence of epidote again indicates the breakdown of anorthite in contact with circulating solutions. As this bed is nearly contiguous with other shale beds of the same unit that contain altered diopside, it is probable that during uralitization there was accession of water, while lime, silica, alumina, and iron were released which reacted with minerals in situ. Those constituents that were in excess were probably then remobilized and transported where they reacted with plagioclase to form epidote.[1] As such, the reaction may be used as a guide to temperature. Equilibrium diagrams indicate that when plagioclase in contact with alkaline solutions is cooled to 400° C, epidote will start to form. Furthermore, the plagioclase of composition 20 An (approximating oligoclase) is in equilibrium with epidote at 300° C.[2]

Shales directly to the south have been relatively unaffected and generally reflect a mineral assemblage characteristic of the intermediate green schist facies. Interpretations of the temperature involved in the reactions occurring in this area are complicated by the presence of abundant hydrous minerals, the production of which is primarily governed

[1]Harpum, J.R. (1954), Formation of epidote in Tanganykia, Geol. Soc. Amer. Bull. 65, p. 1085.

[2]Barth, op cit, p. 285.

by the prevailing water pressure. The overlying argillite at the north face of the open cut consists of a mozaic of minute recrystallized quartz, calcite, and orthoclase grains surrounded by sericite shreds and chlorite. Minor biotite and recognizable crystals of potassium mica were also noted and probably formed from the chlorite, sericite, and iron of the original sediment. The underlying argillite contains recrystallized orthoclase and plagioclase in a fine grained undifferentiated groundmass of sericite and chlorite. In this locale, it seems apparent that the effect of temperature elevation was insufficient to cause other than minor recombination of substances, although recrystallization could proceed to completion as indicated by the marmorization of limestone to calcite.

The interbedded sandstone unit has suffered little metamorphism other than the recrystallization of quartz grains although the interaction of minor amounts of calcite, chlorite, and kaolin with quartz has resulted in the development of epidote, biotite, and spinel (Figure 22). Limestone beds within this unit have been solely recrystallized and accordingly coarsened in grain. Calcareous shale beds, particularly at the Chapo mine, have been subjected to intense metasomatism resulting in the development of mineralization with andradite, epidote, iron oxide, and chalcopyrite.

spinel is unlikely to form in a high-qtz rock

Effects on Igneous Rocks

Igneous rocks intrusive into the sedimentary succession have also been metamorphosed. In almost all of the observed

Figure 21. Thin section of impure shale west of the Indian Draw containing diopside porphyroblasts in part converted to aluminous pyroxene and aluminous hornblende. The groundmass is heavily chloritized, obliterating the original feldspar laths (Nicols crossed, diameter 1.45 mm).

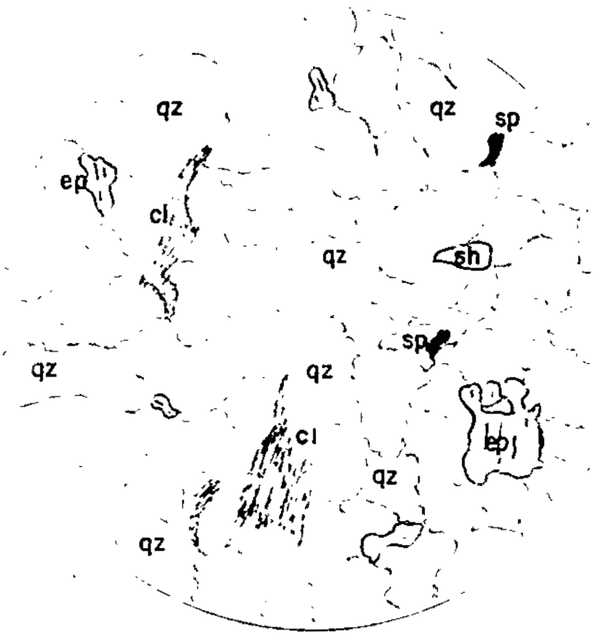


Figure 22. Thin section of sandstone bed west of Chapo fault and just north of the Apache fault. It is composed of interlocking quartz grains illustrative of recrystallization. Other minerals include intersertal epidote, spinel, chlorite, and sphene (Nicols crossed, diameter 1.45 mm).

specimens and outcrops quartz diorite is strongly epidotized; however, this may reflect original deuteric alteration rather than that caused by subsequent metasomatism. Calcite, perhaps derived from the original alteration of plagioclase has been recrystallized. Veinlets of garnet, epidote, magnetite, specularite, and aluminous hornblende are common (Figure 23). Apatite and sphene, though minor constituents, are abundant enough to suggest the introduction of fluorine, phosphorus, lime, and titanium.

Monzonite dikes and plugs within the contact aureole are strongly epidotized and veined with quartz. The matrix is coarse grained due to recrystallization, a factor which distinguishes it from the monzonite north of the Indian fault.

Rhyolite dikes and sills south of the Indian fault are singularly unaffected by isochemical metamorphism. Also, these intrusives, as well as the others mentioned above, have had no metamorphic effect upon the surrounding rocks, probably because there was not enough heat generated relative to their small areal extent. Rhyolite, however, is influenced by metasomatism. Some isolated sills east of the V-E Day Shaft contain epidote veinlets of megascopic size.

Evidence of metamorphic effects within the rocks on the igneous side of the contact is not noticeable in outcrop. Quartz monzonite was only altered at its outer, chilled margin to judge by the fact that in some thin sections epidote veinlets are found containing associated magnetite (Figure 24).

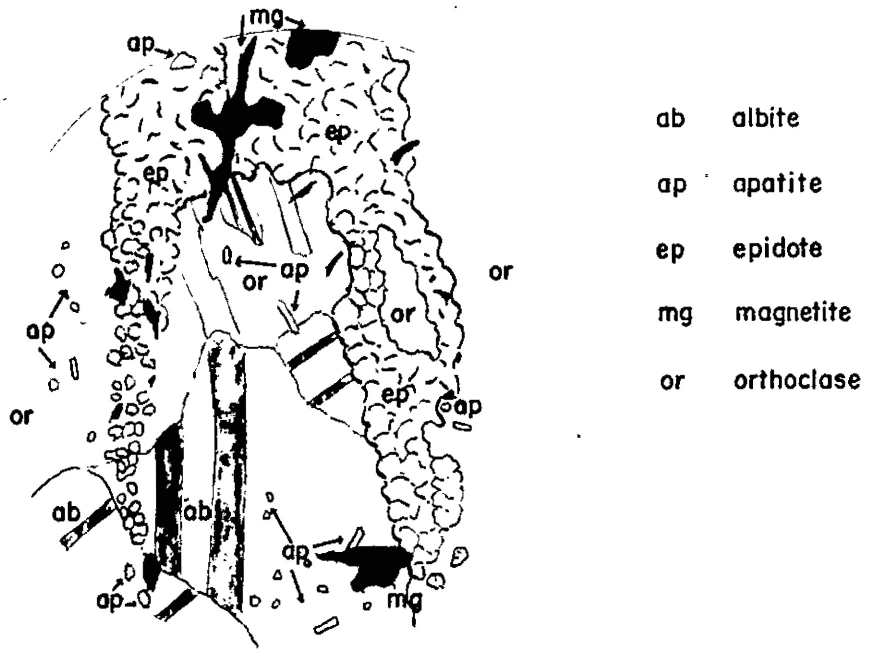


Figure 23. Thin section of quartz diorite porphyry west of the Chapo fault. Veinlets of epidote are cut by magnetite. Apatite, apparently earlier than magnetite, is associated with epidote although seemingly later. Its introduced nature is evident. Orthoclase has been partially albitized (Nicols crossed, diameter 1.45 mm)

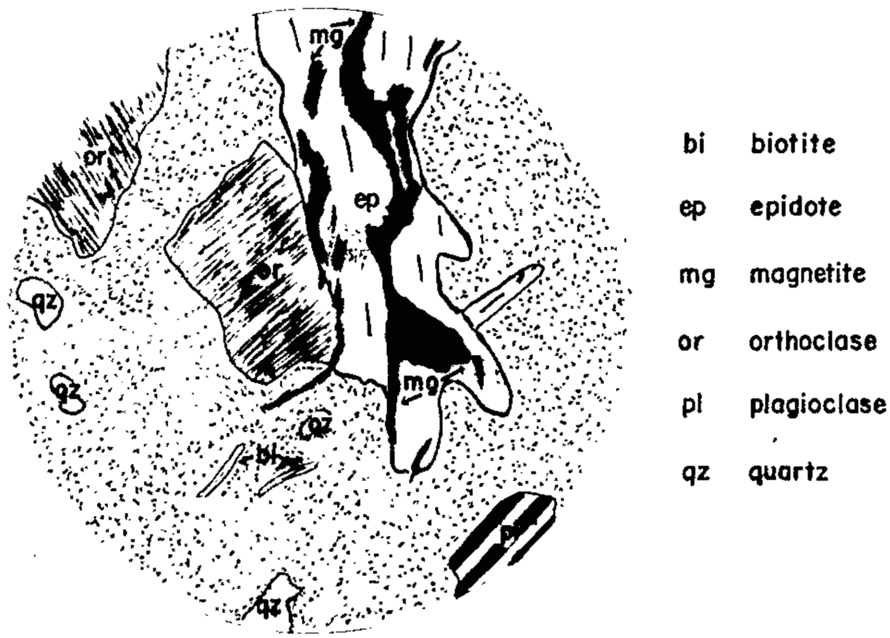


Figure 24. Thin section of the southern chilled margin of quartz monzonite porphyry west of the Chapo fault. The section contains orthoclase, greatly sericitized, plagioclase, biotite, and resorbed quartz phenocrysts in a very fine grained matrix. An epidote-magnetite veinlet traverses an orthoclase phenocryst (Nicols crossed, diameter 1.45 mm).

The porphyritic rhyolite dike intruded between the stock and the sediment similarly shows a lack of features attributable to purely thermal metamorphism. The mineralogy, (of what?) as seen in thin sections, is of the contact metasomatic type. These slides, together with structural and textural relations visible in the outcrop suggest that the porphyritic rhyolite was intruded sometime toward the end of the metasomatic period. This is validated, on the one hand, by the limestone-rhyolite breccia which consists of quartz-cemented fragments of rhyolite, limestone, shale, tactite minerals, and monzonite and quartz monzonite; some of which are shown in Figure 25. On the other hand, the rhyolite immediately north of the breccia zone at the Indian shaft contains microveinlets of garnet and epidote (Figure 26). ?

Allochemical Metamorphism

A Review of the Process

The allochemical metamorphic or contact metamorphic stage is generally believed to be due to an exchange of ions between minerals of solid rocks and extraneous fluids. These may either be aqueous or gaseous and are usually rich in elements that are deficient in the magma.[1] The migration of these fluids and the sebsequent metasomatism is seemingly highest when there is a great contrast in temperature or chemical composition between the intrusion and the surrounding rocks. These conditioss are adequately fulfilled in the quartz-monzonite-limestone zone

[1]Lodochnikov, W.N. (1936), Serpentine and serpentinite der Iltschirlagerstätte, U.S.S.R. Central Geol. Prosp. Inst., Trans. 38 (English abst.).

What an obscure reference for such a commonplace observation! (besides, what has serpentinization to do with the subject at hand?) WEE

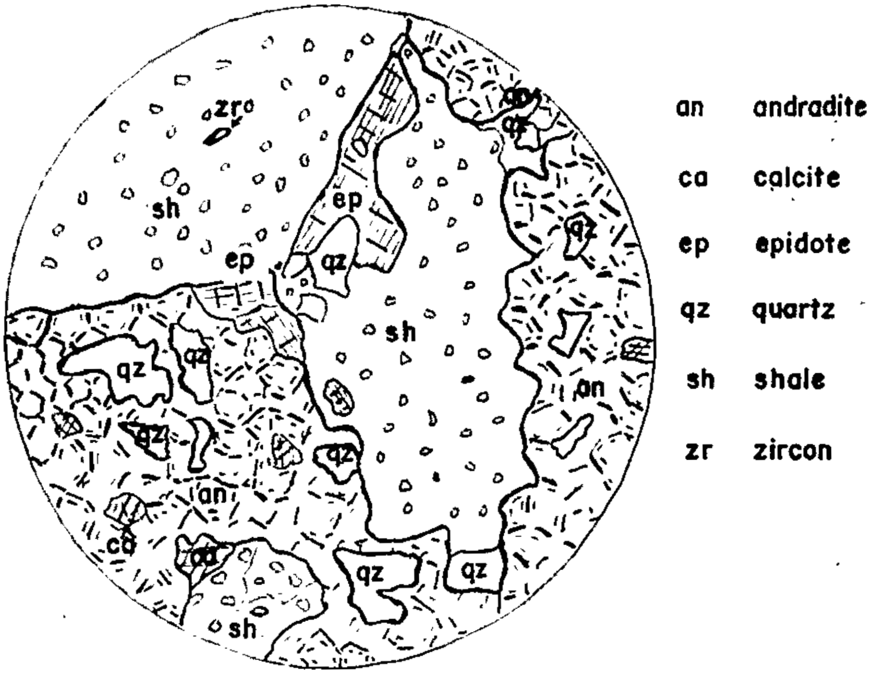


Figure 25. Thin section of limestone-rhyolite breccia just north of the Indian shaft. The section shows the cementation and replacement of of quartzose shale fragments, andradite, epidote, and calcite by vein quartz (Nicols crossed, diameter 4.4 mm).

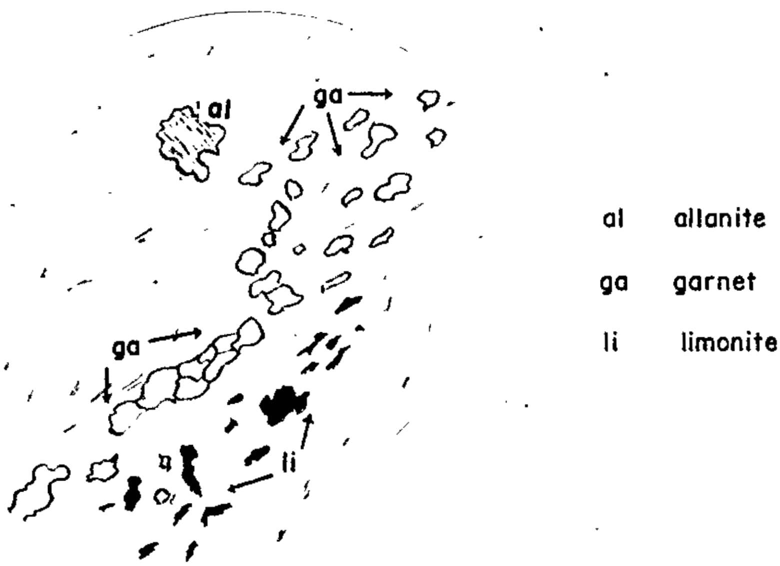


Figure 26. Thin section of porphyritic rhyolite dike intrusive into the stock east of the V-E Day shaft. A string of garnet crystals (of unidentified nature) apparently confined to a fracture traverses the rock. Associated minerals include allanite, with brown pleochroism, and limonite presumably derived from the oxidation of hematite or magnetite. The matrix consists of minute quartz crystals, glass, and sericite shreds (Nicols crossed, diameter 1.45 mm).

here discussed.

The reactions between the solid rocks and the introduced fluids is often conceived in terms of mobility.[1] This is exemplified by the impure limestone unit south of the Indian fault, containing relatively immobile components (such as CaO, SiO_2, and Al_2O_3) subjected only to diffusion transfer over minute distances and reacted upon by a solution of mobile components (H_2O, CO_2, MgO, FeO, and the like) which have relatively constant concentrations. The formation of the andradite-epidote tactite zone in the tremolitized limestone would then be due to a simultaneous adjustment between the immobile constituents and the mobile constituents. The variations in final composition of the tactite zone is thus caused by the addition and subtraction of elements of different mobility. Moreover, it is also probable that differences of temperature and pressure were not necessary to produce this mineral assemblage, although the temperatures were probably higher near the source of the altering solutions.

[illegible] [illegible] (See Korzhinsky [illegible] in [illegible] Int. Geol. [illegible] Vol 2, 1950 (194[illegible] for a [illegible] explanation [illegible] in English of mobility concept)

It is [illegible] difficult to infer the temperature and pressure conditions of an open system similar to that described above namely because the same mineral assemblage may result from dissimilar reactions that occur at different temperatures, generally lower than those determined under ideal laboratory conditions. The formation of a metasomatic mineral suite probably takes place under the very lowest pressure and temperature within the stability field of the respective minerals.

[1] Korzhinsky, D.A. (1945), Formation of contact deposits, Acad. Sci. U.S.S.R. Bull., Ser. Geol. 3, pp. 12-33 (English abst.).

The degree of metasomatism within the contact aureole is largely determined by (1) structural avenues (including pore spaces) for the solutions, (2) composition of the solutions, (3) temperature and pressure of the solutions, and (4) lithologic and chemical character of the invaded rocks. Other contributory factors include surface phenomena such as surface tension of the solution against the various minerals and the shape and size of the mineral grains.[1] The prevalence of fissures and fractures through which the fluids may gain entrance to the country rock is evidenced by the intense metasomatism that the sediments have undergone in the vicinity of major structural weaknesses such as the Indian and Chapo faults. Literally every tactite zone in the area can be attributed to some sort of structural break. It is most probable that fracturing controlled all phases of metamorphism except perhaps the early recombination and recrystallization of the thermal metamorphic stage. The influence of temperature and pressure is important insofar as it affects the chemical potentials of the reactants which in turn determine to some extent the field of stability of the resulting mineral assemblage.[2] In general a higher temperature increases the solubility of solids in solution thereby enlarging the metasomatic effect. The third factor mentioned is illustrated by the fact that close to the contact the more chemically active limestone unit is almost completely replaced by tactite and garnetite masses whereas

Obvious

[1]Verhoogen, Jean (1948), Geological significance of surface tension, Jour.Geol., vol. 56, p. 210.

[2]Turner, F.J., and Verhoogen (1951), Igneous and metamorphic petrology, McGraw-Hill Book Co. Inc., New York, p. 37.

the less active shales and sandstones have only been slightly altered and the metasomatic silicates where present are confined to veins. Perhaps the reason why limestone is more readily replaced in this situation is that it has suffered more crumbling and brecciation and therefore is more accessible to introduced solutions. Furthermore, the confinement of tactite zones to limestones rather than to other beds may be due to its greater susceptibility to thermal activation.[1]

An additional factor governing the extent and intensity of metasomatism is the degree of closure, as an open system allows for considerable and repeated introduction of material into the system and the concomitant liberation of volatiles out of the system. This factor is obviously related to structural features and to the amount of sedimentary cover.

pp. 146-150 contain enough solid information for one (short) paragraph

Effects in the Contact Aureole

Following the intrusion of the composite stock and its subsequent loss of heat to the surrounding rocks, the magma solidified with the separation of solutions containing various associated components. The latter tended to concentrate along the margins of the magma chamber where the temperature and pressure were lowest. Some of the water may have been derived from the sedimentary host rocks in that the heating effect of the magma raised the water pressure causing its diffusion into the magma.[2] These marginal solutions are

Evidence?

[1]Sullivan, E.J. (1957), Heat and temperature in ore deposition, Econ. Geol., vol. 52, p. 20.

[2]Kennedy, G.C. (1955), Some aspects of the role of water in rock melts, crust of the earth, Geol. Soc. Amer. Sp. Paper 62, p. 491

[illegible] on this (or, in my opinion, any) subject

Nonsense; we're dealing with supercritical temp.! (& probably pressure) here! W.E.G.

believed to have remained in the gaseous state if the pressure was low or in the liquid state if the pressure was high.[1] It is generally held that the early formed silicates, particularly those near the contact, resulted from pneumatolysis whereas the oxides and sulfides reflect conditions of lowered temperature and subsequent hydrothermal deposition.

by whom?

Four distinct stages of allochemical metamorphism are observed in this district. The various stages noted may be caused by the change in physical state of the altering solutions, reduction in temperature of these solutions, change in composition of the transgressing fluids as the crystallization of the magma proceeded, or changes in chemical composition due to reactions between solutions and wall rocks and between the solutions or other circulating waters.

The first stage followed close upon or was almost contemporaneous with the initial period of intrusion and subsequent elevation of temperature. It resulted in the precipitation of large amounts of andradite, epidote, and hematite. Associated halide minerals (fluorite, apatite, and rare scapolite), are minor but ubiquitous minerals attributable to a later phase of this stage. In the tremolitized limestone unit, black oxidized rims of tactite surround and partially traverse tremolite nodules. East of the Chapo fault, shales of the interbedded shale and sandstone unit are heavily metasomatized and many of the veins contain scheelite. The tactite veins in the underground workings of the Apache mine usually contain associated chalco-

Not shown at this stage on Table 5

[1]Turner, op cit, p. 110.

pyrite. Epidote is occasionally of the allanite or piedmontite variety, indicative of the introduction of rare earth earth elements and manganese respectively. In general, the first stage is marked by a notable introduction of ferric iron. Some of the element may have been derived from the differentiation of the magma which would be expected since the iron-rich minerals are the first to crystallize in a magma. However, much of it may stem from the decomposition of ferromagnesian silicates of surrounding or underlying rocks. In both cases, the iron was originally in the ferrous state and was subsequently oxidized to the ferric state, probably under well aerated conditions.

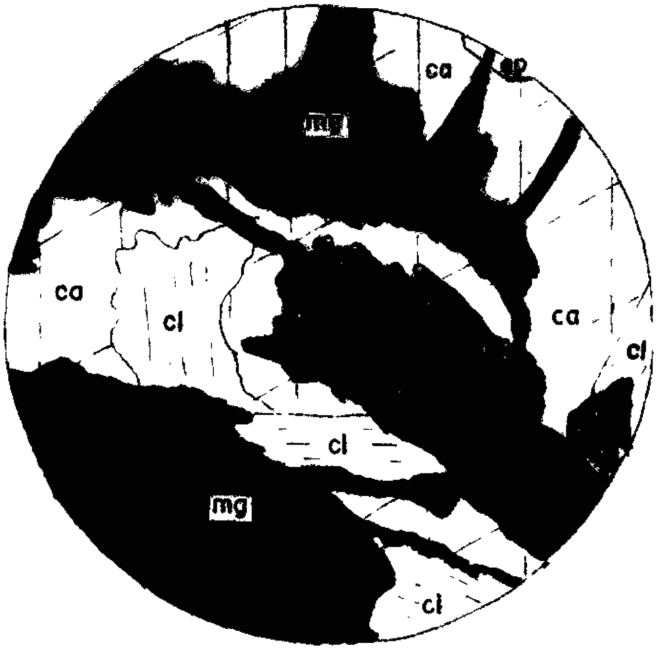
The second stage may be referred to as a period of oxide precipitation in which magnetite and lesser amounts of scheelite are deposited. This stage, though probably not greatly separated in time from the previous one, marks a change in the metasomatizing solutions in that partly ferrous iron oxide is much more conspicuous. Some of the magnetite may be a result of the reduction of hematite by later sulfide solutions. A chlorite-quartz stage may have preceded the magnetite stage, although the evidence for it is not entirely convincing. One of the tactite veins east of the Chapo fault illustrates the replacement of chlorite by both scheelite and magnetite (Figure 27). It is believed that chlorite developed through the breakdown of andradite. Moreover, further evidence is afforded by chlorite-quartz veinlets that traverse andradite and epidote porphyroblasts in limestone and shale, although its relationship to oxides is not known in these cases. Also, the feldspar matrices of shales close to the contact have been almost entirely chloritized. It is thus possible that a "retrograde" effect (conversion of pyroxene to amphibole, garnet to chlorite or idocrase) that have affected the sediments may have occurred during this period (Figure 28).

Metasomatism closed with the deposition of sulfides either in open, uncontaminated fissures, as at the Apache mine, or together with oxides and silicates as at the Chapo mine. A final minor period of deposition is represented by the occurrence of quartz, calcite, and aragonite in fissures usually distant from the quartz monzonite contact. Some of the quartz is of the jasperoid variety, suggesting the deposition of excess iron.

by whom?

It is generally believed that the deposition of tactite silicates and oxides results from pneumatolytic introduction whereas the occurrence of sulfides and alteration minerals is caused by hydrothernal activity, albeit in certain cases at a high temperature. For example, pyrophyllite, noted in some specimens on the dump around the Apache shaft, is believed to be caused by the action of acid solutions upon feldspar in the presence of excess water at temperatures ranging between 420°C and 575°C.[1] At a somewhat lower temperature, the formation of prehnite due to the effect of hydrothermal solutions upon calc-aluminous silicates is a further illustration.

[1]Roy, Rustum, and Osborn, E.F. (1954), The system Al_2O_3-SiO_2-H_2O, Amer. Miner., vol. 39, p. 881.



ap apatite
ca calcite
cl chlorite
mg magnetite
sc scheelite

Figure 27. Thin section of tactite zone from a tunnel just east of the Chapo fault. Chlorite and calcite are cut by scheelite and magnetite. The magnetite has the platy habit characteristic of specularite thereby indicating replacement. It is also strongly magnetic. An apatite crystal is cut by magnetite (Nicols crossed, diameter 1.45 mm).

am amphibole
an andradite
ca calcite
di diopside
qz quartz
id idocrase

Figure 28. Thin section of tactite zone in one of the shallow shafts north-east of the Chapo shaft. It illustrates: a) conversion of andradite to idocrase and b) alteration of diopside, in part to aluminous hornblende. The groundmass consists of recrystallized calcite and vein quartz (Nicols crossed, diameter 1.45 mm).

Replacement

The metasomatic selective replacement of the country rocks in the contact aureole due to the introduction of fluids probably involves a volume-for-volume change as suggested here by structural conditions. The form of the folded sediments abutting against the quartz monzonite intrusion is due to tangential pressures operative toward the end of the Cretaceous period. Comparison with other folds in the central Apache Hills shows that there was no appreciable flowage and subsequent thickening or thinning of beds following the intrusion of the composite stock. Metamorphism in this district apparently affected the gently folded beds without altering its original form. Variations in width of outcrop and apparent thickness of beds are due to north-south fault fissures of pre-mineral origin.

That material has been introduced in abundance into the sedimentary rocks surrounding the intrusion can be shown by a comparison of metasomatized and non-metasomatized portions of the same bed as exemplified by the analyses of the altered and unaltered limestone bed that crops out along the Indian fault from the McKinley fault to the Chapo fault (Table 3). In the following paragraphs, an attempt is made to demonstrate quantitative estimates of gains and losses of various chemical compounds according to Lindgren.[1]

[1]Lindgren, Waldemar (1924), Contact metamorphism at Bingham, Utah, Geol. Soc. Amer. Bull. 35, pp. 507-534.

Table 3. Comparative Analyses of Unaltered and Metamorphosed Limestone
(W.H. Herdsman, Edinburgh, United Kingsom, Analyst)

	Analysis 1 (unmetamorphosed limestone)	Analysis 2 (tactite zone)
SiO_2	5.40	35.46
Al_2O_3	nil	4.13
FeO	0.44	2.64
Fe_2O_3	0.37	19.92
CaO	52.73	32.56
MgO	0.76	1.23
CO_2	39.62	3.44
Cl	nil	0.02
F	0.02	0.05
	99.34	99.45

The two analyses above are taken from the same limestone unit that crops out on the inner edge of the aureole which is separated from the quartz monzonite stock by a limestone-rhyolite breccia zone. In computing the gains and losses in the sediment, certain exceptions should be noted. For purposes of recalculation, fluorine and chlorine have been omitted from the quantitative estimates since their percentage is too small to have any significant results, particularly since they can either pass through the system or fill voids in silicate lattices.

Table 3a. Calculated Mineralogical Composition

What is the actual composition?

Analysis 1		Analysis 2	
calcite	91.33	calcite	7.81
magnesite	1.52	diopside	6.64
siderite	0.70	epidote	29.28
quartz	5.40	andradite	33.18
iron oxide	0.37	magnetite	8.80
		hematite	1.16
	99.32	quartz	14.84
			101.71

There is a calculated excess of 1.89% in epidote as the amount of water in the rock was not analyzed. In addition, there is a slight excess of alumina in epidote because the composition was determined on the basis of Al:Fe = 3:1. The first analysis is deficient by 2.8% carbon dioxide.

The bulk specific gravities of the two analyses (Analysis 1 - 2.73; Analysis 2 - 3.37) were obtained by dividing the mineral weights by the densities of the individual minerals. The figures thus calculated compare favorably with those obtained by laboratory determination. The gains and losses in grams per 100 cubic centimeters were derived by multiplying the calculated specific gravity by the several analyses assuming that no expansion or contraction has occurred. Constant volume of the folded sediments is evidently a valid assumption in view of similar thicknesses of beds within and out of the contact aureole.

Actual or calculated?

conflicts with Table 3b, where these are actual S.G.

Table 3b. Gains and losses in Grams/100 cc

Analysis 1		Analysis 2	Differences
SiO_2	14.74	119.51	+ 104.77
Al_2O_3	.....	13.91	+ 13.91
FeO	1.20	8.89	+ 7.69
Fe_2O_3	1.01	67.13	+ 66.12
CaO	142.86	109.92	- 32.94
MgO	2.07	4.14	+ 2.07
CO_2	108.16	11.59	- 96.57
	270.04	335.09	65.05

The tabulation of gains and losses in this case apparently indicates that the metasomatized zone has gained large amounts of silica and ferric oxide, and only moderate amounts of magnesia, ferrous oxide, and alumina. Correspondingly, there is a large loss of carbon dioxide and less of lime in the unaltered portion of the limestone. The considerable transfer of material to and from this unit cannot be accounted for by local exchange of material but implies a mass introduction of ions, notably silica and ferric oxide, from an external source.

The lack of alumina in the unaltered limestone points toward its introduction in the formation of the calc-silicate minerals. Presumably, alumina is derived from the magma though the analyses may reflect a chance selection since lateral variation in the composition of sediments is not uncommon. An analogous explanation may likewise hold for magnesia. There does not appear to be any general addition of magnesia; however, the removal of lime may have increased the (Mg,Fe)O/CaO ratio to a point where the silicates are now relatively richer in magnesia than normally anticipated.

Al + Mg could have come from adjacent shale or igneous rocks see H. Schmitt (GSA, 1939) on Pewabic mine. Variation trend of magmas shows increase in Al [illegible] + (especially Mg in late stages) WCT

A comparison of analyses from the metasomatized and unaltered parts of the impure shale unit immediately adjacent to the limestone bed discussed above, similarly indicates the mass introduction and removal of chemical compounds. Quantitative relations, analogous to those previously prepared, may also be developed, but considering the incompleteness of the analyses - 92% or so in both cases - they were not computed. A glance at Analyses 3 and 4 listed below (Table 4), indicates a situation in some respects the reverse of that in the limestone. Lime, magnesia, and lesser amounts of ferric oxide,

Aha! see above

carbon dioxide, and alumina have been added whereas silica and minor amounts of ferrous iron have been removed. It appears probable that some of the lime added to the shale to form epidote and calcareous amphibole in part compensates for the loss of lime endured by the adjacent limestone during metamorphism. The silica lost by the shale can also be partly accounted for by the numerous quartz veins that occupy the north-south faults and fissures. The loss of accompanying ferrous oxide is probably responsible for the formation of jasperoid veins, some of which were observed at the eastern edge of the Apache mine division.

Since analyses are only 92% complete, all variations except SiO_2 & CaO lie within the margin of error

Table 4. Comparative Analyses of Unaltered and Metamorphosed Shale (W.H. Herdsman, Edinburgh, United Kingdom, Analyst)

	Analysis 3 (unaltered shale)	Analysis 4 (metamorphoshed shale)
SiO_2	72.02	55.03
Al_2O_3	13.37	15.43
FeO	4.93	3.34
Fe_2O_3	nil or trace	0.58
CaO	0.62	11.84
MgO	1.16	6.03
CO_2	Nil	0.48
Cl	traces	traces
F	0.04	0.03
	92.14	92.76

No alkalis?

RELATION OF CONTACT METAMORPHISM TO STRUCTURE

As previously stressed, the availability of fissures through which solutions may gain access to the sediments is a fundamental consideration of the extent of contact metamorphism. Fractures seem to have controlled all phase of metamorphism with the possible exception of the early recrystallization. Moreover, the transfer of heat was undoubtedly facilitated by fissures and fractures as the conduction of heat through solid rocks probably proceeds at too slow a rate to account for the wide zone of recrystallized rocks encountered in this district. The lack of such fractures may be responsible for the unrecrystallized or only slightly recrystallized rocks found at various points within the contact aureole. These include isolated lenses of limestone and shale close to the igneous contact from which Analyses 1 and 3 were derived.

The fissures and fractures have been primarily caused by the relief of tensional stresses following the intrusion of quartz monzonite and associated porphyritic rhyolite dikes; the results were a series of more or less vertical faults generally normal to the margin of the intrusion. The only major faults parallel to the stock are the Indian fault and perhaps the McKinley fault, which can be considered a counterpart of the Indian fault at the turn in the margin of the composite stock. Moreover, it seems probable that the emplacement of the stock was a concomitant result of movement along the two faults, in that the magma rose along the area bounded by them.

In addition, it is believed that the magma was at least partially solidified prior to fracturing and metamorphism, since the tensional stresses responsible for fracturing would only be ~~operative~~ after an undetermined period of cooling. The partial solidification of the magma was probably followed by subsidence and the formation of normal faults. The source of

To whom? Why?

heat and solutions poses another problem. It appears doubtful that the heat after solidification from so small an intrusion could have been sufficient to appreciably raise the temperature of the surrounding rocks for distances as much as 1,000 feet away from the igneous contact. It is more probable that upon incomplete consolidation of the magma, the residual emanations moved to marginal portions of the stock and that stresses and strains most pronounced in the border zones produced pathways for the egress of these fluids. Where chilled borders of the intrusion blocked the transfer of heat and fluids, mineral anomalies could readily have resulted which would account for the presence of uncrystallized calcite and silica. The lack of alteration of the lens within the limestone unit west of the Chapo fault is probably such a case.

As a general rule, the volume and nature of the intrusive stock controls the pattern of metamorphism on a regional scale, but fracturing determines it locally. The effect of such features as faults, breccia, and shear zones is particularly evident. Numerous examples may be cited from this district; for purposes of brevity, the reader is referred to Plates 2 and 3 where the above relations are clearly expressed.

Metasomatic silication is notably prominent in the sediments immediately adjacent to the stock since the emplacement of the magma has created a favorable breccia zone. In this location, brecciation is further enhanced by the intrusion of rhyolite dikes between the stock and the sediments. Where the brecciated rock is limestone, as in this case, the precipitation

I agree with this statement although it contradicts p.56, pr.2

The breccia zone between rhyolite & sediments would be favorable for metasomatism if metasomatism is younger than rhyolite, not older as stated on p. 56

of introduced minerals is greatly facilitated.

The localization of sulfide and associated hydrothermal mineralization is probably due to post-silicate deformation. This is suggested by the occurrence of quartz and calcite in fissures that are believed to have formerly served as channels for silicate metasomatism. On a smaller scale, intermineral shattering may play an important role as evidenced by chlorite-quartz microveinlets traversing andradite and the replacement of andradite by specular hematite and magnetite along dodecahedral faces (Figure 29). Although not observed here, sulfides may similarly replace calc-silicate minerals; however, their role as neutralizers may not be sufficient to cause deposition. Generally, calcite, rather than silicates is selectively replaced by sulfides. This is probably due to the fact that limestone is more amenable to brecciation than siliceous sediments as shown by the considerable replacement of the limestone unit whereas the argillaceous and arenaceous sediments are relatively less disturbed and commonly contain metasomatic silicates confined to veins. Another suggestion to account for the preferential replacement of limestone during sulfide mineralization is that calcite has a lower packing index than any of the silicates e.g., calcite has more open space through which ions can be diffused.[1]

How about high chemical reactivity of carbonates as against silicates?

[1]Ridge, J.D. (1949), Replacement and equating of volume and weight, Jour. Geol., vol. 57, p. 546.

RETROGRADE METAMORPHISM

Contact metamorphism has probably occurred during a considerable but limited period of high temperature within a much longer period of changing temperature and pressure which closes with the exposure of the rocks at the earth's surface. The rocks now visible are certainly not expressive of the highest temperature to which they have been exposed. The process commences with the intrusion of the stock, at which time the rocks are subjected to an initial wave of high temperature and simultaneously or shortly after this there comes a wave of aqueous or gaseous solutions. This front of advancing fluids may precede the advancing high temperature front. Ample evidence of this sequence of events is visible in the workings east of the Chapo fault, where otherwise unaltered sediments contain pockets and veins of metasomatic silicates, oxides, and sulfides.

During this initial period of a sharp rise in temperature and accompanying introduction of material, the metamorphic reactions tend to proceed at their most rapid rate since physical conditions are such that chemical adjustment of the solid and fluid phases most nearly approached completion. A reduction in further reaction during the ensuing period of gradually waning temperature is caused by the increased size of sedimentary grains and the deposition of minerals in fissures, fractures, and intergranular spaces, all of which tend to exclude available fluids and reduce the chemical potential of the country rocks. Therefore, the reactions during the cycle of lowered temperature would be slow and mineral assemblages formed during the period of higher temperatures would be apt to persevere until their exposure at the surface.

The second phase is one in which the effect of decreased temperature and pressure is believed to be responsible for the alteration of silicates formed during the stage of progressive metamorphism. It is termed retrograde metamorphism and is supposedly exemplified by the alteration of garnet to idocrase. However, Yoder[1] has demonstrated that this particular alteration may occur during the period of rising temperature by merely varying the bulk water content. It does not seem probable that during the second phase, there will be sufficient time for changes to occur since the rates of reaction are probably too slow. Moreover, it is likely that effects formerly attributed to the retrograde metamorphic stage are caused by either changes in water content or by hydrothermal activity subsequent to the main stage of metamorphism. The so-called retrograde changes can be compared to the deuteric alterations encountered in igneous rocks, which are fundamentally a result of hydrothermal activity rather than decreased temperature, although the latter condition is a requisite in some cases. Sufficient examples of the effect of either circulating pore solutions or hydrothermal solutions in this district have been previously mentioned, such as the conversion of pyroxene to hornblende and plagioclase to epidote.

Says who?

Why can't retrograde metamorphism involve hydrothermal alteration?

?

[1]Yoder, 1952, op cit, p. 614.

Until recently, the effect of water in both progressive and retrograde metamorphism has been somewhat neglected. It is becoming more and more apparent to geologic investigators that there is probably sufficient water (derived directly from the magma or from connate water) to accelerate the reactions of metamorphism and to also account for the slightly hydrated minerals, such as tremolite and actinolite, characteristic of initial metamorphic mineral assemblages.

PARAGENESIS

The paragenetic sequence illustrated below (Table 5) was determined from numerous megascopic observations and from some 50 thin and opaque sections. The broader stages reflect a succession characteristic of most if not all contact metamorphic deposits. An early silicate stage is followed by an intermediate oxide stage in turn concluded by a late sulfide stage.

Certain variations naturally arise in regard to the relative age of some of the minerals. Quartz and calcite occur at various points in the sequence ranging from post-silicate, pre-sulfide time to post-sulfide time. Hornblende, though locally in veins, may in part be due to recrystallization and remobilization. The formation of pargasite from aluminous hornblende indicative of the entrance of soda-rich solutions is difficult to assign to a specific interval. Bismuth, of which only the oxide bismutite was noted, occurs in the massive recrystallized limestone without any associated minerals. The problem is noted particularly with chlorite which occurs as an alteration product after andradite, as andradite pseudomorphs cut by iron oxide, and in veins traversing hematite.

The sequence has only been determined for those minerals ascribed to contact metasomatism. Minerals due to earlier thermal recrystallization such as tremolite, diopside, sphene, and spinel have been omitted. However, new minerals, derived from the latter by later solutions have been included. One such example is aluminous hornblende. Garnet and epidote, together with the halogen-bearing minerals (fluorite, apatite, and scapolite) represent the earliest introduced minerals though the three halogen-bearing minerals are generally later (Figure 30). Aluminous hornblende occurs in veinlets cutting tactite veins. Hematite is older than magnetite as strikingly illustrated both megascopically and microscopically by the replacement of specularite plates by magnetite. Scheelite is earlier than the iron oxides as evidenced at the Chapo mine by the cross-cutting hematite veinlets. The sulfides are later than the silicates and oxides, thus according with the usual observations of previous investigators.[1,2,3] Chalcopyrite is

[1]Spurr, J.E., Garrey, G.H., and Fenner, C.N. (1912), Study of a contact metamorphic ore deposit; the Dolores mine at Matahuala, S.L.P., Mexico, Econ. Geol., vol. 7, pp. 444-484.

[2]Behre, C.H., Jr., Osborn, E.F., and Rainwater, E.A. (1936), Contact ore deposition at Calumet, Colorado, Econ. Geol. 31, pp. 781-804.

[3]Schmitt, H.A. (1939), Geology of the Pewabic mine, Hanover, New Mexico, Geol. Soc. Amer. Bull. 51, pp. 777-818.

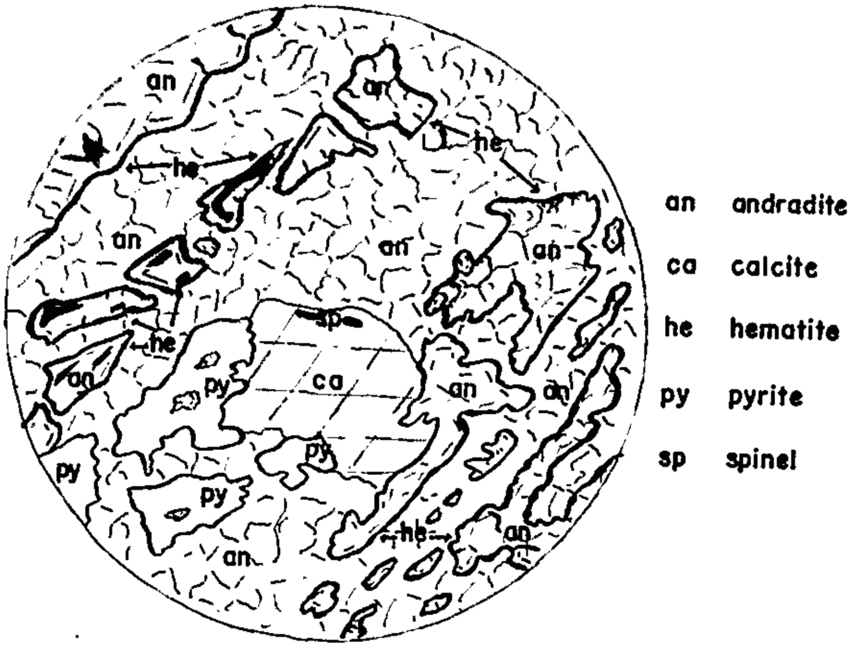


Figure 29. Thin section of tactite vein east of Chapo fault. It contains andradite which has been replaced and outlined by hematite along crystal boundaries and intermineral cleavages (Nicols crossed, diameter 1.45 mm).

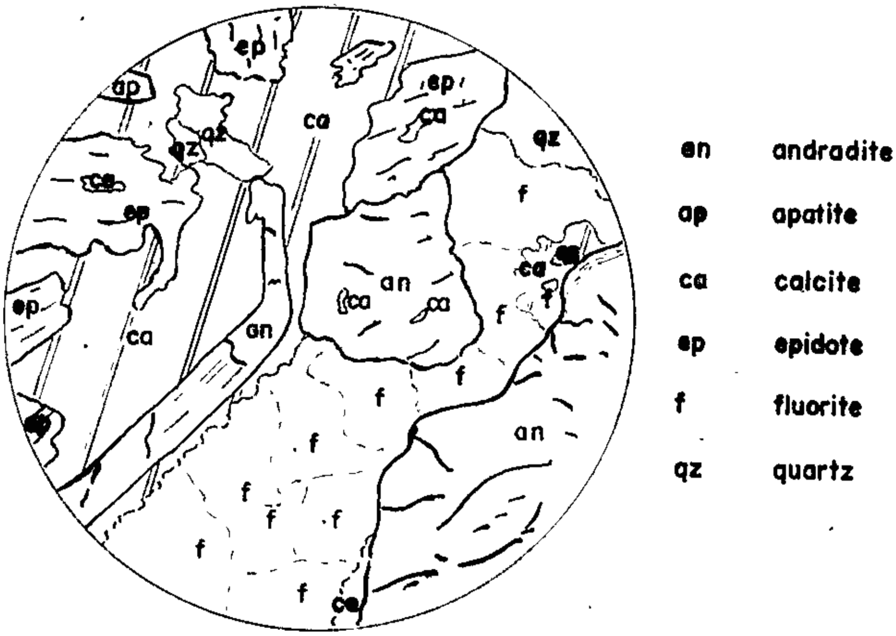


Figure 30. Thin section of tactite vein from easternmost prospect of Chapo mine division showing a fluorite veinlet traversing earlier silicates and calcite (Nicols crossed, diameter 1.45 mm).

a common late associate of tactite zones (Figure 31); with other sulfides it occurs as cuneiform splotches in sphalerite suggestive of exsolution although microveinlets indicate a later time of deposition which favors attributing the splotches to replacement. The end stages of metasomatism are characterized by chloritic alteration. Fissure filling by quartz, calcite, and aragonite complete the cycle of mineralization.

ORIGIN OF CONTACT METAMORPHISM

Any theory of the origin of these contact metamorphic deposits must explain conditions existent at the time of thermal metamorphism, the subsequent nature of the metasomatism, the original composition of the altering fluids and their still later change, the probable source of the solutions, their relation to the stock and their affects on the invaded rocks.

As previously mentioned, thermal metamorphism has been conventionally pictured in terms of facies of increasing temperature and pressure whereby various minerals are formed at different pressure and temperature levels. Neither absolute temperatures nor the temperature gradient can be determined because of the presence of circulating pore solutions.

The second stage in the process, contact metasomatism, involves at first the question of the probable source of the solutions. In the Apache Hills, tactite minerals and associates are noted in both the quartz monzonite and rhyolite dikes, indicating that metasomatism occurred after the stock had been

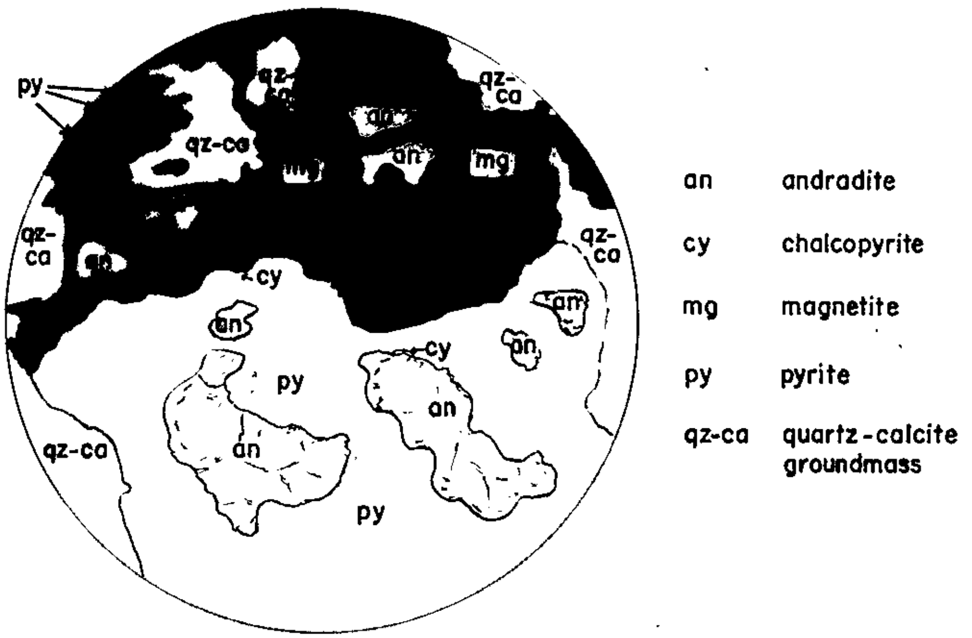
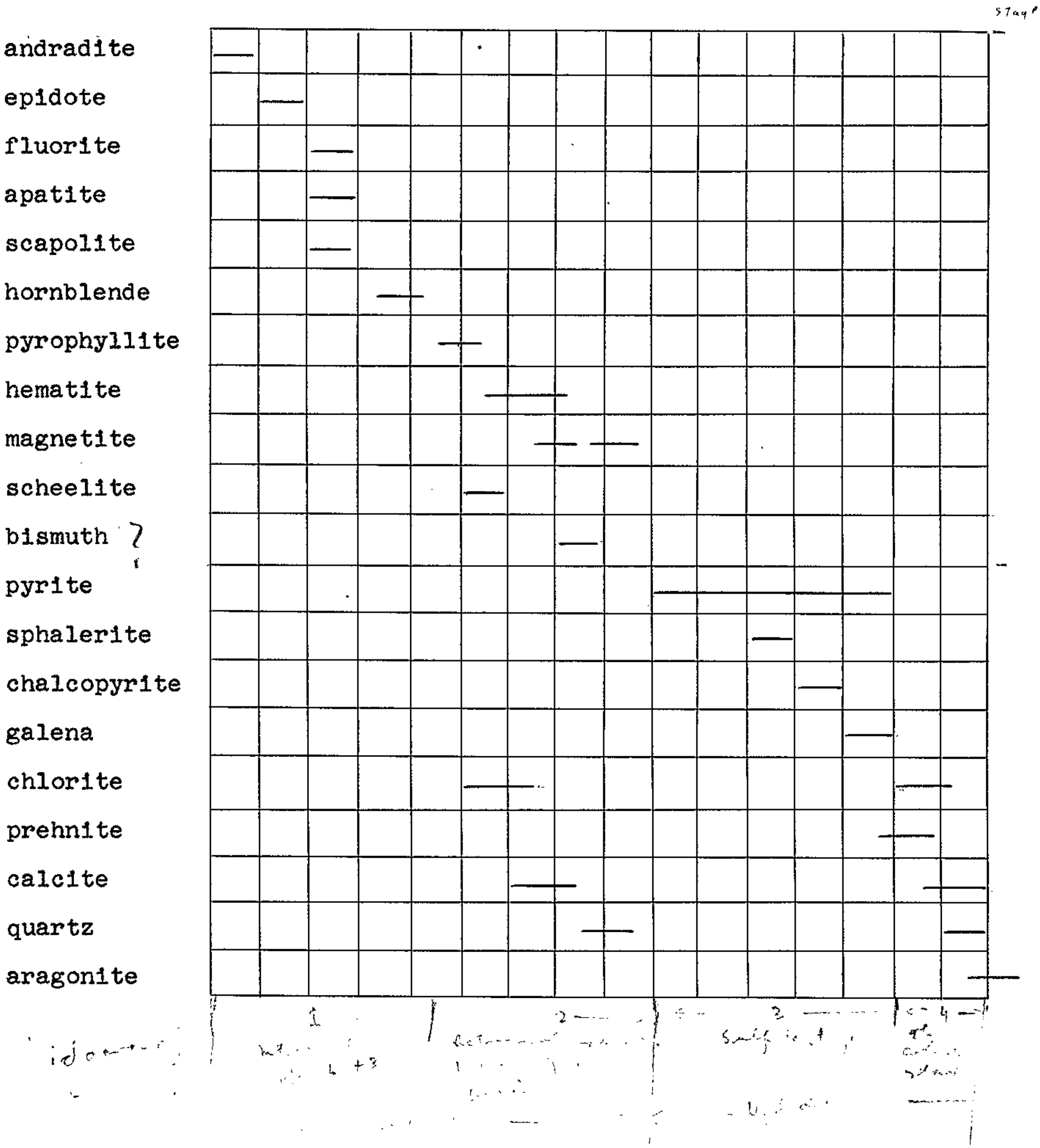


Figure 31 . Thin section of tactite zone from the dump surrounding the 1936 shaft. Pyrite has replaced andradite and magnetite. Chalcopyrite occurs along intermineral boundaries (Nicols crossed, diameter 1.45 mm).

Table 5. Paragenetic Sequence



emplaced and at least partially solidified, and that it continued until after the rhyolite had cooled. This suggests that the solutions are not derived from the intrusion but rather from a nearby independent source, perhaps from a source near the contact. In this respect, it would possibly be more logical to consider the contact as a localizing fault rather than attributing the introduced silicates strictly to the intrusion. In addition, the intrusion of the stock and associated dikes is responsible for the development of drag folds, and fissures adjacent, concentric, and radial to the stock, which have provided egress for mineralizing solutions. An expansion of this belief would lead to the generalization that structural conditions rather than proximity to an intrusive body is responsible for contact metamorphism. The occurrence of tactite zones in this area remote from a visible source intrusive further supports this suggestion.

Why?

why don't major structures not assoc with intrusive rocks show "contact" metamorphism

Where?

The nature of the metasomatizing solutions is in doubt. Any idea must account for the composition of the fluids, the high ratio of ferric to ferrous iron, and the occurrence of specularite before magnetite. It has long been known that iron can be transported in the form of chlorides and fluorides.[1] However, there are apparently not enough halogen-bearing constituents in the foregoing mineral assemblages to account for the abundance of iron since it presumably takes 14 tons of

[1]Goldschmidt, V.M. (1922), On the metasomatic processes in silicate rocks, Econ. Geol., vol. 17, p. 108.

halides to deposit one ton of iron.[1] Moreover, it is probable that most of the halogen ions, particularly the chloride ions, were not stabilized and could have readily passed out of the system as the very soluble calcium chloride. It has been suggested, however, that the solutions are aqueous and contain halide mineralizers[2] which would keep the solutions above the critical temperature and thus enable the transportation of large quantities of material. This seems probable in view of more recent work[3] which indicates probable deposition of iron oxide when a halogen-rich fluid enters a region of higher water content or when neutralized by limestone. The analyses of the metamorphosed and nonmetamorphosed limestone and shale unit, Tables 3 and 4, show that minor amounts of halides have been introduced, but certainly not enough to account for the abundance of ferric oxide. However, halide ions may be present in sufficient but undetermined quantities since fluorine can be confined to the micas and to a lesser extent in the amphiboles where it replaces other ions in the crystal lattices, since the ionic radius of the fluoride ion is similar to that of the hydroxyl ion. Chlorite, rather than fluoride ions, occur in amphiboles replacing hydroxyl ions probably because the band

[1]Geijer, Per (1925) Contact metamorphic processes, Econ. Geol., vol. 20. p. 690.

[2]Schmitt, op cit, p. 801.

[3]Holser, W.T., and Schneer, C.J. (1953), Deposition of high temperature, nonmagmatic magnetite, abst., Geol. Soc. Amer. Bull. 64, p. 1435.

structure of amphibole is better able to accommodate the larger chloride ions.[1] Further quantities of fluorine may occur as either solid or liquid inclusions in minerals. Solid inclusions would include fluorite, apatite, or fluorite-rich mica; liquid inclusions, probably enriched in fluoride ions, are abundant in quartz and feldspar. Many halogen compounds are, of course, highly soluble, and especially in the presence of water, as in volcanic ejecta, might well have been present originally but later removed.

The high ferric-ferrous ratio was believed by Butler[2] and others to be due to the oxidation of original ferrous iron in the solution to ferric iron by carbon dioxide released upon recrystallization of limestone according to the formulae:

$$3\ FeO + CO_2 = Fe_3O_4 + CO_2$$
$$Fe_3O_4 + CO_2 = Fe_2O_3 + CO$$

The first formula is believed essentially correct, given sufficient concentration of carbon dioxide. Lasky[3] believes that the second reaction will not occur since there is not enough CO_2 present. Hawley and Robinson[4] state that the second

[1]Correns, C.W. (1956), Geochemistry of the halogens, Physics and chemistry of the earth, McGraw-Hill Book Co. Inc., New York, p. 224.

[2]Butler, B.S. (1923), Suggested explanation of the high ferric oxide content of limestone contact zones, Econ. Geol., vol. 18, p. 400.

[3]Lasky, S.G. (1934), Ferric-ferrous ratios in contact metamorphic deposits, Econ. Geol., vol. 29, p. 495.

[4]Hawley, J.E., and Robinson, S.C. (1948), The supposed oxidation of Fe_2O_3 by CO_2, Econ. Geol., vol. 43, p. 410.

reaction proceeds to the left and is irreversible at temperatures between 400° C and 600° C where magnetite is the stable phase. But if the solutions are aqueous and above the critical temperature due to halogens, the iron could be deposited in the ferric state to form the early silicates (andradite, epidote) and hematite. To account for the change from hematite to magnetite deposition, as illustrated in Figure 26, a change in the nature of the solutions is necessary particularly in regard to pH values, since ferric iron would be precipitated from an acid oxidizing environment and magnetite from a weakly acid or alkaline reducing environment. This condition is satisfied by the second equation above proceeding to the left, i.e. after hematite had formed in an acid oxidizing environment, magnetite would be precipitated according to the second equation, the necessary carbon monoxide derived from the partial reduction of carbon dioxide by the hydrogen of the original magmatic emanations.

Additional experimental results[1] illustrate that at room temperature and pressure and under well aerated conditions, when ferrous chloride solutions react with calcite, the only iron deposited is of a ferric nature. However, with decreasing oxygen saturation, the probability of precipitating ferrous iron increases. Therefore with decreasing oxidation potential, the ratio of ferrous to ferric iron becomes so large that not even extremely insoluble ferric hydroxide can be precipitated.

[1]Garrells, R.M., and Dreyer, R.M. (1952), Mechanism of limestone replacement at low temperatures and pressures, Geol. Soc. Amer. Bull. 63, p. 345.

Mason[1] similarly states that the deposition of ferrous compounds demands a low oxidation potential. In more recent work derived from thermodynamic calculations[2] it is shown that in cooling from a magnetite-hematite-water equilibrium, there is a continual production of excess oxygen, so that any magnetite formed is continually oxidized to hematite. Although the work by Garrels and Dryer was carried out at low temperature and pressure, it apparently explains the high ferric-ferrous ratio observed in the Apache-Chapo Mining District, and also the occurrence of ferric minerals prior to ferrous minerals, and in particular the replacement of specular hematite by magnetite.

Thus the solutions which deposited the early silicates were presumably acid in composition and rich in ferrous iron and silica. These solutions reacted with the calcareous sediments resulting in the deposition of andradite whereby lime and carbon dioxide were released. Hematite was also precipitated during this time under the conditions previously outlined. Some of this lime could be easily fixed in the formation of epidote. Lime might also go into solution as it traveled outward from the contact in fissures. These solutions with excess lime, iron, and silica (the last possibly originally in excess but more probably derived from the surrounding sediments) could then be precipitated to form the

[1]Mason, Brian (1949), Oxidation and reduction in geochemistry, Jour. Geol., vol. 57, p. 70.

[2]Baker, D.R. (1955), Stability of magnetite and hematite a hydrothermal environment from thermodynamic calculations, abst., Geol. Soc. Amer. Bull. 66, p. 1528.

tactite veins of the shales and sandstones. The resulting alkaline environment probably caused the deposition of fluorite and apatite, both of which occur later than the early silicates but earlier than the ferrous oxides. At this stage, the solutions minus the halide mineralizers will be weakly acid or alkaline, a condition whereby ferrous iron would be precipitated, followed by the subsequent deposition of sulfides.

ORE DEPOSITS

INTRODUCTION

The ore deposits of the two ranges are geographically separable into two major groups, the Apache-Chapo Mining District and the Fremont Mining District. The first has also been referred to as the Anderson or Apache #2 Mining District.[1] Strangely enough, this grouping also expresses a general geologic relation in that the first of the two groups includes the Apache and Chapo mines, which are regarded as contact metamorphic deposits, whereas the other includes deposits in the nature of fracture fillings or replacement veins. The mines and prospects of the Fremont District are listed below and their location is shown on the accompanying geologic map: ?

Occidental mines (includes the Eagle, Barnett, American, Doyle or Conevello, and Napane or Nutshell properties)

International mine (Sierra Rica mine)

[1] Northrop, S.A. (1942), Minerals of New Mexico, N. Mex. Univ. Bull. 379, p. 370.

Daisy mine

Queens Taste mine

Big Shiner mining area

Luna mine

Christmas mine

Ford, Quartz, Vanadium Lead, and Copper Valley prospects

Rattlesnake, Pick and Shovel, and Casher prospects - located in the south central Sierra Rica beyond the area covered by the geologic map.

All the mines were visited and detailed pace and compass maps of the larger workings were made. The Apache and Chapo mines are treated as a single unit because of the contact metamorphism common to both and their mutual contiguity.

APACHE-CHAPO MINING DISTRICT

Location

The Apache mine in Hidalgo County, six miles south of Hachita, is reached by a much used road that leads directly into the former operating area. The Chapo mine is 2-1/2 miles east of the Apache mine and is connected to it by a rutted but passable road. The Chapo mine may also be reached directly over a good road from the Last Chance mine.

History and Production

The mining records obtained for the two mines pertain almost entirely to the Apache mine from which ore was extracted in commercial amounts for many years. The only production information available on the Chapo mine is that in 1940 some copper-gold ore was shipped.[1] This was apparently the only production as indicated by the fact that the workings consist of rather shallow shafts, trenches, prospect pits, and a shaft 180 feet deep from which the shipment mentioned was probably mined. The mine is covered by four claims of unknown location owned by Fred Brown of Hachita.

The Apache mine was first operated in the latter part of the 19th century by Chihuahua Indians who carted the ore to Chihuahua for smelting. The deposit was not worked in earnest until the beginning of this century when Robert Anderson gained control of the mine and operated it for some years. The significant dates of production are as follows:

1900-1908: Rich horn silver ore (cerargyrite) was shipped in the early days of the mine's operation by Robert Anderson. In later years, oxidized copper ore rich in calcite and therefore in demand as a flux was shipped to the smelter. As shipped, the ore contained 3 to 4% of copper, \$1.00-\$1.50 in gold, and 6 ounces of silver per ton.[2]

The following records were obtained from the U.S. Geological Survey and the U.S. Bureau of Mines "Mineral Resources of the United States" and the U.S. Bureau of Mines "Mineral Yearbook":

[1]U.S. Bureau of Mines (1940), Mineral Yearbook.

[2]Lindgren, Waldemar, Graton, L.C., and Gordon, C.H., et al (1910), Ore deposits of New Mexico, U.S. Geol. Survey Prof. Paper 68, p. 344.

1915-1919: Large quantities of silver-copper ore with bismuth in calcite gangue were shipped.

1927-1929: The Apache Leasing Company shipped a considerable tonnage of lime rock averaging 1.5% of copper and 1.5 ounces of silver per ton. In addition, several cars of ore averaging 12 ounces of silver and 10% of lead were shipped.

1936-1938: The mine was controlled by the United States Smelting Refining and Mining Company. Only exploration and development work was carried on.

1942: A lessee shipped zinc ore averaging 30%.

1943: A lessee operating the Monarch and Copper Crown claims shipped 200 tons of copper and 125 tons of lead ore.

1944: E.J. Marsten of Colorado Springs, Colorado, operating the above two claims shipped 230 tons of lead ore containing 1.0 ounce of gold, 1.3 ounces of silver, 597 pounds of copper, and 55,000 pounds of lead.

At present, the mine consists of two claims, the Monarch and the Copper Crown, both of which are owned by Albert W. Fitch of Hachita. Other claims indicated on Plate 2 are from the files of the U.S. Smelting Refining and Mining Company.

Mine Development

The main mine working consists of one major shaft, the Apache shaft, 360 feet deep, sunk by the Anderson-Apache Mining Company in 1907. All the workings were approached from this shaft and include levels at depths of 50, 70, 100, 150, and 300 feet, the names representing depths below the surface. The shaft is at present inaccessible. However, the 50-foot and 70-foot levels may be entered by an adit located in the southwest corner of the open cut (Plate 4); the same levels and the 100-foot and 150-foot levels are accessible through a shaft at the north end of the open cut. This open cut at the Apache mine represents an area of the mine that caved in 1929. All levels other than those mentioned are inaccessible; none of the levels is timbered, and the argillaceous nature of much of the country rock makes drift caving common.

Other workings include the 1936 shaft which was sunk to a depth of 500 feet by the U.S. Smelting Refining and Mining Company. Two drifts extend from this shaft. The workings in this area are completely separate from those of the Apache shaft. A map of the drifts is given in Plate 7.

Shafts on the Indian, Cochise, and McKinley veins were inaccessible in 1953 and 1954 but these were all apparently shallow. Smaller prospect pits and trenches dot the area in the vicinity of the Apache mine and to the east. The V-E Day shaft, midway between the Apache and Chapo mines, is about 75 feet deep but was filled with water in 1954. The Chapo shaft is 180 feet deep and is used as a well by the Faulkner Ranch. All the other workings at the Chapo mine are surficial.

The location and position of accessible and inaccessible workings at the Apache mine are indicated in Plates, 4, 5, 6, 7, and 8. The complete extent of underground workings is not definitely known but there are about 7,500 feet of drifts and crosscuts. This area has been extensively prospected and is marked by a great number of shallow test pits and prospect holes and by numerous claim monuments. Every limonitized or other possible ore zone is indicated by an exploratory hole.

Geology

A composite stock has intruded a part of the Limestone-Sandstone member of the Howells Ridge formation and is directly or indirectly responsible for the development of a contact metamorphic type of deposit. Tactite zones in the limestone beds near the igneous contact have been mined at the Indian shaft for their sulfide content. Galena, sphalerite, and associated cerargyrite were extracted. The ore here is localized along the troughs of drag folds created by the intrusion.

The main workings of the Apache orebody, located in the immediate vicinity of the Apache shaft, are in a mass of interbedded limestones and shales metamorphosed in varying degrees. The stratigraphic succession exposed at the surface and in accessible levels is as follows:

Top of section (from the head of the Apache shaft)

	Thickness
Gray siliceous shale	25 feet
Green chloritized shale	20-30
Massive recrystallized limestone	25
Thin interbedded shales and metasomatized limestones. Upper portion contains some thin recrystallized limestone lenses. Only the upper 20 feet is exposed, but the sequence is reported to extend to the 500-foot level.	425

It should be noted that the massive recrystallized limestone bed only occurs in the area around the open cut where it forms an exposure approximately 400 feet long and 150 feet wide.

Structure

The sediments that crop out from the Indian fault to the Apache fault in the area of the Apache orebody are expressive of a gentle anticline indicated by the slight northward dips near the igneous contact, the general horizontal attitude at the open cut, and the gentle southward dips reported from the 500-foot level to the south. Superimposed upon this is a system of north-south and subsidiary east-west fissure faults. The major structures controlling ore deposition all have a more or less northward trend. The most prominent of these is the McKinley fault which is only slightly mineralized and contains some galena, sphalerite, and chalcopyrite. This nearly vertical fault forms the eastern and western boundary of the quartz diorite plug and quartz monzonite stock respectively. The main Apache orebody is located on the southeast side of the fault. The vertical displacement along this fault is difficult to determine but it is estimated to be of the order of 200 to 300 feet. It is believed that this fault is the companion to the Indian fault but has followed the curving boundary of the main intrusion at this point. As a result, though the McKinley fault is apparently later in age, it is probable that both structures were produced simultaneously.

The east side of the McKinley fault is evidently the upthrown side, the displacement being of sufficient magnitude to expose the stock.

In addition, it is probable that the McKinley fault served as the main ore fissure and that trifurcation of the fault (though the apex is hidden by alluvium) as it emerges from the west end of the composite stock, channeled the ore solutions to their present site of deposition. These fissures may have also acted as avenues of egress for the fluids responsible for silicate metasomatism. Furthermore, it is likely that the eastern fissure of the group of three might have carried the bulk of mineralizing solutions as evidenced by the relative abundance of iron oxide contained within the fissure walls. This particular fracture is exposed at the eastern edge of the chamber on the 50-foot level (Plate 5). The western branch of the McKinley fault is represented by the Cochise vein which is only slightly mineralized as compared with the eastern workings.

Fissures and faults of small displacement having a more or less eastward trend parallel to the Indian fault were noted in some of the accessible workings. They are generally barren and contain either quartz or calcite. These fissures have very little importance as ore localizers. They have however complicated mining procedures since mineralized blocks have been broken up along the strike of the orebody or elevated above the main drifts, thus necessitating numerous overhand or underhand stopes.

The displacement along the fissures of both northward and eastward trend is very small, generally less than ten feet, and in many cases can be observed in outcrop. This is particularly noted at the north end of the open cut where a series of minor step faults occurs (Figure 32). Minor faults were also seen at the entrance to the 50-foot level and also along that level (Plate 4). Drag folds created by the faulting have served as loci for ore deposition. The age of the bulk of the fissures is definitely pre-mineral although some post-mineral fracturing on the 50-foot level was evident; it was probably formed as result of readjustment subsequent to the intrusion and accompanying mineralization.

Mineralization

The orebody that was commercially developed is irregular in shape and without sharp definite boundaries. It consists of large and small stringers, shoots, and pods of ore randomly distributed throughout the sediments. The bulk of the mining was in sediments cut by sulfide-filled fractures which are devoid of tactite minerals, although the sediments contain silicates caused by thermal recrystallization and recombination. However, metasomatic effects attributable to an initial wave of metamorphism were noted. At the 70-foot and 100-foot levels (Plate 5), occasional constricted tactite veins contain andradite, epidote, hematite, fluorite, and chalcopyrite. Another example was observed in the chamber immediately north of the open cut where two tactite veins traverse siliceous shales for

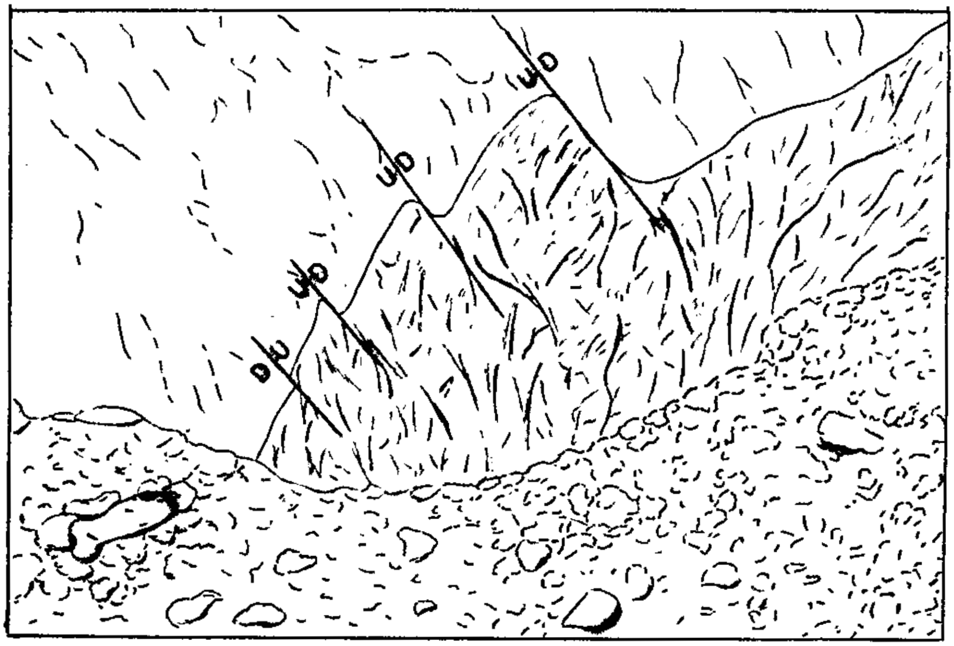


Figure 32. North end of open cut at Apache mine. Jagged contact between the light and dark rocks, both argillites, is due to the eastward dipping high angle faults of small displacement.

the length of the working (Plate 5, Figure 12). Some of the specimens from the dump around the 1936 Shaft exhibit a similar tactite mineralogy. In addition, scheelite, cuproscheelite, and bismutite (all found in specimens from the dumps) occur in massive recrystallized limestone. Generally, however, the sulfides and their oxides that were extracted were free of contaminating metasomatic silicates.

Despite the two different occurrences of the sulfides, they are probably genetically related. They both represent a period of deposition contemperaneous but somewhat later than the silicates and oxides ascribed to contact metamorphism. The association of sulfides with silicates and oxides at the heavily metasomatized Indian fault probably indicates that fissuring was still active during the time of sulfide deposition. This fissuring was probably promoted by the intrusion of porphyritic rhyolite. The silicate-free sulfide veins prominent on the outer edge of the contact aureole at the Apache mine probably were deposited as such because metasomatism was not intense enough to close every available opening.

Ore Occurrence

It is apparent from a study of accessible workings and from reports on inaccessible workings[1] that strong mineralization is generally confined to the upper levels in the form

[1]Maillot, E.E., and Walker, R.T. (1936-1938), Files of the U.S. Smelting Refining and Mining Company.

of replacement veins, particularly in the calcareous sediments. Such veins occurred as far down as 250 feet below the surface; beyond that depth, the presence of hard silicified shales and calcareous shales prevented replacement on any scale.

Mineral zoning, though imperfectly developed, is nevertheless noticeable. There is an apparent concentration of tungsten, bismuth, and copper toward the north end of the orebody. Lead and zinc mineralization is confined to a small zone to the southeast (Plate 4). Still further to the south, quartz-calcite veins seemingly predominate. There is a similar suggestion of mineral zoning in depth, again reflecting a temperature gradient, since silver-rich ores are concentrated in the higher levels of the mine and gold at the lower levels.

The ore zone should not be considered as consisting of a single body of high grade material surrounded by lower grade ore. Rather, it was a wide mineralized area in which bunches of high grade copper and copper-silver ore are found. The latter type ore was generally restricted to the upper levels and occurred as replacement veins in limestone and rarely shale. In later years, this low grade ore with calcite gangue was worked for its fluxing value. The main copper-silver orebody as mined was 450 to 500 feet long and up to 150 feet in depth. The development was confined to the eastern branches of the McKinley fault and there was no ore cross-cutting to the western branches where copper ore in a siliceous gangue was extracted. These siliceous veins are low in silver, whereas the others are rich in silver. Specimens of some of the iron oxide zones on the 70-foot level show an average of 12 ounces of silver per ton. Bismuthinite and scheelite, where present, are reported to be nearly everywhere associated with the copper-silver ore in the massive recrystallized limestone and the presence of either mineral generally indicated a high silver content.

Lead-zinc-silver ores occur in the shale members where they were extensively mined on the 70-foot level. No effort was made to trace this mineralized zone below that level into the more favorable underlying recrystallized limestone. Similarly, there was no attempt to cross-cut from the 100-foot level to intercept the same zone.

The siliceous copper ores occur in fissures in the silicified shales west of the open cut. The Cochise vein illustrates this type of mineralization. The chief ore minerals include various copper oxides in a quartz gangue. Gold and silver values are almost negligible.

Copper minerals, mostly chalcopyrite, occur in the lower levels and are associated with tactite minerals in zones that have been moderately metasomatized. The ore usually shows higher gold values but lower copper values than the higher levels. A representative sample from one of the two fissures on the 500-foot level contains approximately 0.5% of copper and 1-3 ounces of silver per ton. The ore at the lower levels occurs in fissures of northward trend and the lack of replacement veins is directly attributable to the unfavorable rocks.

Oxidation

All the ore extracted from the Apache orebody has been of the oxidized variety. The veins are greatly altered and consist mostly of iron oxide, either limonite or hematite, together with subordinate amounts of copper, gold, and silver values in a quartz or calcite gangue. The ore in the massive recrystallized limestone consists of partly silicified and spongy iron oxide, malachite, and minor amounts of chrysocolla and turquoise. The veins are commonly banded and consist of a wide inner area of banded limonite with occasional pyrite cubes; the outer bands are composed of malachite and chrysocolla. Between the two there is commonly a band of pyrolusite or some other manganese oxide. An illustration of this occurrence is presented in Lindgren.[1]

As a general rule, the dominant oxidized copper mineral has a composition related to the enclosing rock. However, the presence of malachite in veins in shale, as in the workings north of the open cut, indicates the introduction of lime presumably by circulating waters. Conversely, the occurrence of chrysocolla in veins in limestone points toward the deposition of silica. The transfer of these compounds along the veins is not surprising in view of the abundance of these substances in this area. In addition, the porous nature of the oxidized veins permits considerable movement. It has been reported that following a heavy rainfall on the surface, fissures at the

[1]Lindgren, et al, op cit, p. 55.

500-foot level were still dripping five to six hours after the precipitation.

Other copper oxidation minerals were also observed, as at the Cochise vein where linarite and caledonite, together with chrysocolla, are the principal ore minerals. At the 70-foot level, lead and zinc oxidation minerals include cerussite, anglesite, smithsonite, aurichalcite, and rare hydrozincite. Primary lead and zinc ores were not noted on this level. Bismutite and cuproscheelite occur as oxidation products in veins in limestone. Jarosite occurs with oxidized sulfides at both the Indian and Apache shafts. Gypsum here forms a crystalline coating over the altered sulfides.

At the Indian shaft, early reports[1] state that horn silver (cerargyrite) was extracted. Only one such specimen was seen on the dump. Cerargyrite was probably derived from argentiferous galena that was oxidized by descending waters rich in chlorine, common in arid regions. The presence of pyrite greatly facilitated the movement of silver which was eventually deposited as a silver chloride. Its insoluble nature accounts for its presence in the zone of oxidation.

Supergene copper sulfides were not observed in situ in the accessible mine workings but specimens from the dumps surrounding the Apache and 1936 shafts indicate the partial replacement of chalcopyrite by chalcocite and occasionally covellite. Chalcocite has been reported from the 500-foot level. Moreover,

[1]Lindgren, et al, op cit, p. 344.

two carloads of ore containing chalcocite rich in gold values were shipped in 1925 from a winze at the 300-foot level.

The possibility that a thick limestone section and consequently a rich secondary sulfide zone existed at depth prompted the U.S. Smelting Refining and Mining Company to attempt sinking a shaft late in 1936. However, the shaft was abandoned after 500 feet as it never penetrated the water table, which for some unknown reason was at a still deeper depth. This is surprising as all the other wells in the range penetrate the water table 100 to 200 feet below the surface. It appears probable that the water table in this locality once existed at a higher level, but only briefly, since chalcocite is not too common even at lower depths. Thus the supergene zone may still exist below the present workings, possibly at depths between 700 and 1,000 feet.

Origin

The sulfides deposited in the Apache orebody are expressive of the last stages of contact metamorphism that has affected this district. Originally thermal metamorphism resulted in the recrystallization of shales and the conversion of limestone to coarsely crystalline calcite. This was succeeded by metasomatism whereby silicates were deposited in available fissures and then by several phases of ore mineralization. The first phase is probably represented by the deposition of tungsten, bismuth, and gold which reflects the high temperature stage of hydrothermal deposition. Pyrite was also seemingly precipitated during this stage. Chalcopyrite represents the second phase of ore deposition, and probably lead and zinc sulfides together with silver were precipitated simultaneously or slightly preceded the copper mineralization. The last phase of hydrothermal activity is typified by quartz veins which fill the Apache fault and fissures parallel to it. These may contain gold or silver although no ore minerals were observed in outcrop or reported from available assays.

The chief factors responsible for localizing the ore are the faults and fissures roughly parallel to the quartz monzonite intrusion. The location of the Apache orebody is near the projected intersection of the two faults bordering the intrusion where a general zone or weakness has been produced.

FREMONT MINING DISTRICT

Introduction

The ore deposits of the Fremont District are of two types - (1) quartz veins in fractures traversing limestone, orthoquartzite, or various igneous rocks such as rhyolite, basalt, and andesite and (2) replacement veins in limestone. In the former, the veins commonly have north-northeast trends with a dip ranging from almost vertical in the limestone to about 60° in the igneous rocks. In many cases, the veins are stained black chiefly by hydrated iron oxides or by pyrolusite, psilomelane, manganite, or other manganese oxides. The occasional occurrence of malachite imparts a green color to the vein. The unoxidized vein minerals include chalcopyrite, galena, pyrite, and sphalerite. The chief value of the ore lies in galena which is apparently argentiferous.

The replacement veins, primarily exemplified by the Occidental mines, seems to have no preferred trends but rather have followed the most easily replaced beds. There are two major types of replacement veins, both oxidized. One is rich in quartz, limonite-stained, and malachite-bearing. The second type is characterized by its rare malachite and relative abundance of galena or sphalerite or both in a calcite gangue. Both types locally contain sphalerite, chalcopyrite, and galena.

Occidental Mines

Location

The Occidental mines are located in the northeast part of the Sierra Rica (i.e., in the southeastern part of the area shown on Plate 1) and may be reached by a faint branching road half a mile east of the Doyle Well. It is also accessible via the jeep road parallel with the international boundary.

History and Production

The Occidental mines includes numerous shafts (all inaccessible), trenches, and prospects which have been recorded under various names. With the exception of the Wilder property, the names given on Plate 7 were taken from Lindgren.[1]

[1]Lindgren, et al, op cit, p. 345.

Production values for the various properties are from the same source and are as follows:

Eagle mine - 40% lead and 20 ounces of silver per ton in a 200 ton shipment prior to 1906.

Barnett property - a reported value of 20% copper, 15 ounces of silver, and 5 ounces of gold per ton.

Doyle or Conevello property - an analysis of specimens from the dump shows 20% zinc, 10% lead and some silver.

American property - a reported value of 4% copper and 10 ounces of silver per ton.

No values are reported for the Napane mine (formerly called the Nutshell mine). Although several carloads of copper ore were shipped from one of the above properties in 1912 and 1913, the last known operation occurred in 1953 when Carl Wilder of Deming extracted an unknown quantity of lead-zinc ore from the Napane mine. In the eastern end of the area shown on Plate 7 uranium was discovered by a group of Deming people. Six claims were staked covering the area from the border westward for 3,000 feet and 1,800 feet north of Border Post No. 41. Assessment work was done in 1955 but ore has not been shipped to date.

Geology

The rocks in the area (Plate 9) consist of interbedded oyster-rich limestones and orthoquartzites which have been folded to form the Occidental anticline in the northeast corner of the area mapped. In the western section, a major fault, the

Occidental fault, brings the younger Orbitolina member against the Oyster Limestone. The beds generally have a west to northwest strike and dip 20° to 25° southwest. Thin trachyte sills were also observed.

The Napane mine consists of a few prospect holes and shallow, inaccessible inclined shafts of unknown depth in a cherty bed of the Oyster Limestone member. The deposit is a replacement by galena, sphalerite (of typical "blackjack" color), pyrite, and minor chalcopyrite in a rhombic calcite gangue with subordinate siderite. In opaque section the paragenesis is as follows: sphalerite (early), galena, pyrite, and chalcopyrite (late). The succession of the last two minerals may be reversed. Both galena and chalcopyrite occur as blebs in sphalerite suggestive of exsolution but chalcopyrite also occurs in cross-cutting veinlets.

Prospect holes to the east consist of barren quartz veins either heavily limonitized or lead-bearing quartz veins stained with manganese or iron. The lead has been oxidized to cerusite. The shaft in the same general area contains crystalline smithsonite and calcite. Uranium mineralization consists of minor amounts of green autunite embedded in massive but slightly limonitized quartz veins developed along a minor fault. The autunite fluoresces a bright apple-green. Black quartz crystals are a common associate. Choice samples of the vein ran as high as .21% uranium or thorium although a check of the vein by a Geiger counter did not reveal any concentrated areas of radioactive mineralization. In general, the concentration appeared to be fairly localized.

The Doyle property is developed by two shafts, each 30-40 feet deep, which contain partially oxidized galena, calcite, and minor quartz in a replacement vein. Mineralization is probably associated with the nearby minor fault.

The American property consists of two shallow prospect holes. The northern one exposes a heavily manganese-stained quartz vein. The southern working is a tunnel about 30 feet long containing a vertical replacement zone of chalcopyrite in a quartz gangue. The vein has been oxidized to hematite and limonite; it is also manganese-stained.

The workings on the Barnett property consist of a shaft 100 feet deep, now inaccessible, and a few minor workings to the west. The mineralogy is similar to that of the rest of the area. At the shaft and the trench immediately to the east, chalcopyrite occurs with andradite and magnetite in a calcite gangue. The persistent fissure between the Barnett and Eagle mine is composed of a felted mass of gray radial tremolite fibers in a matrix of quartz and calcite. Under the microscope sphene, apatite, and epidote can also be recognized (Figure 33). With the exception of the adjacent trachyte sill, there are no nearby igneous rocks even in the southern extension of the Sierra Rica, to which could be attributed this type of mineralization so generally characteristic of contact metamorphic deposits. It would thus appear that the silicating solutions are derived from an independent source although the possibility of

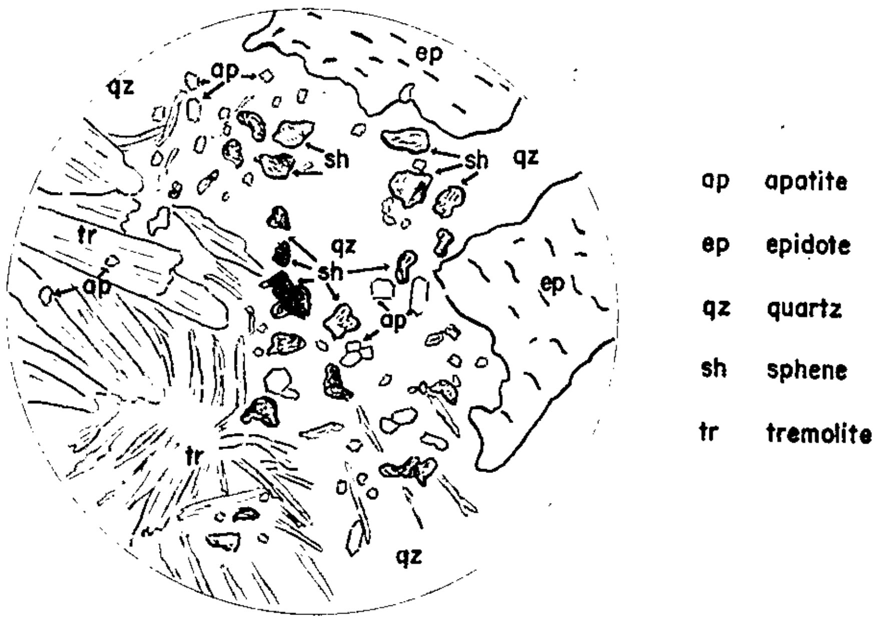


Figure 33. Thin section of tactite vein at Occidental mines between the Eagle and Barnett properties. The vein contains radial tremolite needles and prisms, epidote, sphene, and apatite (Nicols crossed, diameter 1.45 mm).

an intrusive body at depth cannot be ruled out.

Oxidation is very marked and has produced such minerals as chrysocolla, malachite, azurite, and minor amounts of atacamite. The occurrence of chrysocolla with calcite gangue is analogous to that of the Apache-Chapo District and indicates a substantial introduction of silica from circulating waters.

The Eagle mine workings consist of two shallow shafts, two tunnels of small extent, and a few prospect holes and trenches. Lindgren[1] reports that the northern shaft is 30 feet deep and contains limonitized replacement veins of quartz and calcite with a few stringers of galena, partially oxidized to cerusite; the southern shaft is 40 feet deep and at the bottom, a bed, two feet thick, has been replaced by galena with small amounts of quartz-calcite gangue. Lindgren describes an eastward trending drift, 35 feet long, following the widening orebody; at the face there is a thickness of five to six feet of solid galena. The workings have obviously been extended since the above was reported for specimens around the dump also contain chalcopyrite and pyrite associated with galena. Other workings contain a similar copper-lead mineralogy. Secondary alteration is very pronounced and commonly obscures the primary minerals. Nevertheless, the ore has only been partially converted to cerusite, whereas limonite has developed in abundance. Manganese oxides are also prevalent.

[1]Lindgren, et al, op cit, p. 347.

Daisy Mine

Location

The Daisy mine is located in the north central part of the Apache Hills and about 1-1/2 miles southeast of the Queens Taste mine. It is accessible over a faint road that leads from the base of the rhyolite breccia dome east of the Faulkner Ranch.

History and Production

The deposit is covered by two patented claims belonging to the Dave Whaley Estate, whose heirs at present reside in Deming. The last known operation in which ore was extracted occurred about 1908. The shipment assayed 18% of copper, 18 ounces of silver, and $1.00 to $5.00 in gold, according to Lindgren.[1] Scheelite has been reported[2] but was not seen by the author.

Geology

The country rock consists of the Rudistid Limestone member disconformably overlain by thin bouldery beds of the Skunk Ranch fanglomerate (Plate 10). Thin rhyolite porphyry intrusions are also present but have no apparent relation to ore deposition. The mineralization consists of fissure fillings and is primarily confined to faults trending northeast. These are probably pre-mineral faults in which strike-slip displacement is the chief component. Other loci of deposition include older but minor

[1]Lindgren, et al, op cit, p. 347.

[2]Northrop, op cit, p. 272.

parallel and oblique vein fissures and bedding plane veins, the latter largely replacements. The mineralogy is alike in all the deposits and consists of chalcopyrite and pyrite in a calcite and quartz gangue. Oxidation minerals include malachite, azurite, chrysocolla, jarosite, hematite, limonite, copper pitch, and pyrolusite. Other minerals that have been reported include primary bismuth, and secondary tenorite.

The workings at the mine are relatively shallow. The deepest shaft is about 50 feet deep but most workings are less than 25 feet below the surface. The ore is generally confined to veins two or three feet thick which pinch and swell. The total production could not have exceeded $10,000.

International Mine

Location

The International mine (shown on the Victorio quadrangle as the Sierra Rica mines) is located in the extreme southwestern corner of Luna County just north of the international boundary between Border Posts Nos. 38 and 39. It is accessible either by a faint rutted road southeast from Victorio or by the road paralleling the border fence.

History and Production

The first mining here was in 1880 by Volney Rector who intermittently operated the mine for some 20 years. The mine produced about 50 tons of lead-silver ore valued at $25 per ton. All shipments were made prior to 1889. Further production records are vague; the U.S. Bureau of Mines "Mineral Resources of the United States" lists a small production of lead-silver ore in 1917 and in the period 1924-26. Further production occurred in 1940 and 1941 when M.V. Eaves of Lordsburg shipped about 95 tons of ore to the International Smelter at El Paso. According to the settlement sheets for those two years, the ore averaged 21.32% of lead, and 4.1 ounces of silver. A shipment of 65 tons late in 1941 showed an average value of 20.4% of lead, 4.2 ounces of silver, and 0.01 ounces of gold. A few carloads of ore were also shipped in 1947 by M.V. Eaves. The present owner is Joseph Deckert of Deming. The mine consists of two claims, the Keno and the Keno Extension.

Geology and Mine Description

The ore deposit is localized along a normal fault that strikes approximately N.30°E. and has a dip ranging from vertical to slightly northwest (Plate 11). The mineralized International fault is cut by numerous and younger post-ore tear faults of small displacement. The sediments of the footwall are part of the Red Beds member of the Howells Ridge formation. They consist of an eastward-striking, northward-dipping series of red shales, siltstones, and limestone conglomerate. The hanging wall in the southern part of the area is composed of the same unit; however, this unit shows intertonguing relationships and almost wedges out completely near the main shaft. This is probably a sedimentary rather than a structural change since lateral lithologic changes were noted in other parts of the unit. The hanging wall side of the fault is drag-folded and is bounded along its entire length by a reddish-gray, partially silicified sandstone which is overlain by oyster-rich limestones in the northern part of the area. Keratophyre sills are intrusive into the lower unit.

The fault is mineralized up to a point just north of the main shaft. Supposedly it continues as a mineralized vein for some 3,000 feet into Mexico where it is reported to have higher values. The vein occupying the fault ranges from three to ten feet in width and consists of banded massive quartz containing various ore tenors. At the 100-foot shaft near the international boundary, the ore is in a limonitic quartz gangue with scattered amounts of galena, chalcopyrite, and the oxidation minerals malachite and cerusite. The ore at this shaft supposedly averaged 10% of copper and 60 ounces of silver per ton but this is unconfirmed. It is similarly reported that the ore is richer in gold and silver on the Mexican side.

At the northernmost shaft, 250 feet deep, the development work consists of a drift on the 60-foot level that is 65 feet long and trends southwest along the quartz vein. A winze was sunk from the end of the drift and a crosscut was driven from the winze. An ore zone 27 feet wide was exposed in the crosscut and assay values list 10% of lead, 0.5% of copper, 3 ounces of silver and traces of gold.[1] Ore from the dump surrounding this shaft contains galena and minor amounts of chalcopyrite

[1]Horzman, C.W. (1948), Report on the International and Luna mines, unpublished manuscript.

and pyrite in a massive quartz gangue. The same specimens also possess chlorite and siderite as post-ore alteration minerals. Cerusite, limonite, and pyrolusite represent the oxidation effects. Silver values at this shaft were either derived from argentiferous galena or from the chloride cerargyrite. A shallow shaft between the two described above is 80 feet deep. One carload of ore shipped from this working assayed 30% of lead and 7 ounces of silver.

Queens Taste Mine

Location

The mine area is about 1-1/2 miles southeast of the intersection with a road, recently opened by bulldozer, that leads from the hamlet of Continental to the Faulkner Ranch. From Continental to this road intersection is 2-1/2 miles.

History and Production

No trustworthy data on the history, development, or production of this mine could be found. The only production record available is in the U.S. Bureau of Mines "Mineral Yearbook" for 1930, 1931, 1937, and 1949 and is dubious: in each of these a few tons of lead-silver ore were reported to have been shipped from the "Lead Queen Mine" of the Fremont District. The last work at the mine was in 1950 and 1951 when Percy Larsen of Hachita did some assessment work.

Geology and Mine description

The mine (Plate 12) consists of numerous prospect pits and shafts opened in quartz veins in rhyolite and andesite porphyry. Most of the shafts are very shallow; the deepest, about 70 feet deep, is in the extreme northeast corner of the mine area. The major production seems to have been derived from this section.

With a few exceptions, all the veins have a northeast trend and dip southeast about 60°. The exceptions have a westerly trend and are not mineralized, thus conforming to the previous generalization that such veins are chiefly barren.

The rocks include plugs and dikes of rhyolite porphyry and flows and dikes of andesite and basalt porphyry. The oldest of such rocks is andesite; it is intruded by dikes of basalt and by the still younger rhyolite porphyry which contains inclusions of andesite. The mafic rocks are a part of the Last Chance volcanics. The rhyolite intrusions probably occurred in at least two different stages, for in places the dominant violet rhyolite porphyry contains large inclusions of rhyolitic composition having a strikingly different color. Both types are younger than andesite and basalt.

The violet rhyolite is altered in places to a white-colored, "bleached" variety, characterized by intense and almost complete conversion of plagioclase to sericite and kaolin. Sanidine has been similarly affected but to a lesser degree. Other alteration effects include chloritization of hornblende and biotite.

The ore veins range from two to ten feet in width. They are all of the fracture-filling type and their oxidized parts are characterized by malachite, much limonite, and some pyrolusite or related manganese oxides or hydroxides. Specimens from the dumps surrounding some of the deeper shafts contain galena and disseminated pyrite and chalcopyrite, the pyrite usually in part converted to limonite pseudomorphs. The galena is argentiferous and occurs as clusters of cubes in a cryptocrystalline quartz gangue. All of the ore specimens examined were relatively low in galena, although occasional ones contained as much as 10 to 15% of lead.

Wall rock alteration is very common along most of the veins, chloritization being most dominant and commonly confined to the ore shoots traversing the quartz vein. Other alteration minerals include calcite, siderite, and a type of quartz introduced later. The chlorite is the earliest alteration mineral, for in some of the veins the wall rock alteration zone has chlorite breccia fragments cemented by calcite and siderite. The alteration is later than the mineralization.

The mineralization associated with the intrusion of the rhyolite is localized at three different places. One is along the contact between the bleached rhyolite and the violet rhyolite. In one variety, the alteration contact is very gradual and the ore vein usually occurs in the bleached rhyolite. Mineralization was rather lean and the mining activity was confined to the prospect and very shallow test pits. Ore specimens from these veins contain only sparsely disseminated galena and chalcopyrite.

The second place of mineralization is along basalt dikes intrusive into the andesite porphyry. The veins in this group seem to have been the most productive as estimated by the depth of the shafts and the comparative richness of the ore in them. This is illustrated at the northeast group of workings where the mining seems to be the most intense.

The third locus of mineralization is in quartz veins cutting either andesite or violet rhyolite. Mineralization is very slight with the exception of galena cubes and oxidized minerals.

Big Shiner Mining Area

Location

The Big Shiner area is southwest of the Chapo mine and is easily reached by a partially graded road, readily accessible from the direction of the Last Chance mine.

History and Production

The mines in this area include the Big Shiner mine, the Last Chance mine, the Mairland mine, besides unnamed numerous shallow shafts and prospect holes (Plate 13). Production records are scarce and vague. About 80 tons of copper-silver ore were shipped from the Last Chance mine in 1948 and an unknown amount in 1949. Approximately a carload of lead-silver ore was extracted from the Mairland mine in 1950. Production figures are lacking for the other mines.

Last Chance Mine

The workings (Plate 13) at the Last Chance mine consist of a 250-foot shaft and some prospect holes. The ore deposits are localized in more or less steeply-dipping east-west fractures in rhyolite porphyry dikes that are intrusive into the andesites and basalts of the Last Chance volcanics. The fissures are quartz filled and in addition contain disseminations of galena, pyrite, chalcopyrite, and rare sphalerite. Oxidation has produced malachite, limonite, and smithsonite. Alteration of the volcanics is associated with the intrusion of the rhyolite but is earlier as the dikes contain altered volcanic fragments. The alteration minerals include abundant chlorite and lesser amounts of limonite, calcite, siderite, and secondary quartz. Chlorite has also locally given the rhyolite a green color indicating that chloritization continued after the rhyolite was intruded. Shallow workings east of the shaft contain chlorite alteration zones together with some manganese stains. The two holes to the southeast expose an ore zone similar in composition to that of the shaft.

A section of a specimen of ore from the shaft shows the following paragenesis: pyrite (early), galena, sphalerite, and chalcopyrite (late) - the latter as cuneiform blebs in sphalerite.

Big Shiner Mine

Operations at the Big Shiner mine consist of one shallow, timbered, and inclined shaft and an even shallower vertical shaft to the west. The ore in the first shaft is localized along a chloritized part of the volcanics, occurring in a quartz-filled fracture zone, five feet wide, between chloritized and unaltered andesite. The ore minerals are well crystallized marmatic sphalerite, chalcopyrite, and galena cubes. Oxidation has caused the formation of malachite and of smithsonite in well developed curved rhombic plates. No analysis of the ore was available but an estimation of grade from the specimens on the dump would be about 10% of zinc, 5% of copper, and 2% of lead.

Mairland Mine

The Mairland mine is composed of a steeply sloping inclined shaft about 60 feet deep, that follows a quartz vein two to three feet thick. The vein has an east-west trend and is localized in andesite or basalt. The mineralization consists of galena, chalcopyrite, and pyrite in a crystalline quartz matrix. Malachite stains are also present.

Prospects

A few shallow holes approximately N.30°E. of the Last Chance shaft contain sphalerite and siderite in quartz veins and veinlets associated with chloritized zones in andesite. The trench to the east exposes a quartz vein localized along the contact between a felsite dike, forming the footwall, and andesite. The ore zone is about two feet wide and includes disseminations of galena, pyrite, and sphalerite.

The workings just northeast of the Big Shiner mine consist of shallow inclined pits that follow a quartz vein in an altered andesite; the alteration is a result of sericitization of plagioclase. Mineralization in the vein includes chalcopyrite and minor galena. Oxidation has resulted in the formation of malachite, azurite, chrysocolla, and some bornite.

Luna Mine

Location

The Luna mine (Plate 15) is in the north central part of the Apache Hills about a quarter of a mile east of the Faulkner Ranch. It is easily reached by roads from Hachita, from Continental, and from a road that takes off from the airplane beacon on State Highway 9.

History and Production

The mine consists of four claims, the Lobo Nos. 1, 2, 3, and 4. The only known production occurred in the 1940's when M.V. Eaves of Lordsburg shipped 11 tons of ore which averaged 15% of lead, 16% of zinc, and 4.5 ounces of silver. At present, the mine is owned by Richard Faulkner.

Geology and Mine Description

The mine has a shaft 150 feet deep. A tunnel northeast of the shaft, about 50 feet long, designed to intersect the shaft, was never completed.

Quartz veins in latite porphyry flows have greatly chloritized margins. These account for the mineralization. Ore minerals, however, are not everhwhere associated with these alteration zones, which in addition to chlorite also contain calcite, quartz, and siderite; these replace feldspar. The metallic minerals galena, sphalerite, pyrite, chalcopyrite, and copper oxides are later than the quartz of the veins but earlier than the alteration minerals. Chlorite and siderite veinlets traverse the ore minerals.

The rocks here are mainly latitic flows. These are slightly faulted to the west. A thin unaltered and faulted rhyolite porphyry dike is apparently unrelated to the mineralization. The main sulfide concentration is noted at the shaft but parallel fissures occur to the north and south.

Christmas Mine

Location

The Christmas mine (Plate 16) is located on the northwest flank of the Apache Hills about five miles from Hachita. It is reached by a poor trail that begins two miles from the intersection with the Apache mine-Hachita road.

History

The mine is covered by two claims, the Geiger and Geiger No. 2. It was operated by Albert Fitch of Hachita but production records and assays were not available. From indications of the dumps, one carload of ore, at most, was shipped.

Geology and Mine Description

The mine is developed by an inclined stope 100 feet long, 15 feet wide, and about 30 to 40 feet deep on the incline. Other shallow workings occur north and south of the stope.

The ore veins strike approximately north-south and dip westward. They are confined to a felsite dike that traverses the outer margin of the monzonite porphyry facies of the composite stock. The ore zone at the stope is 5 to 15 feet wide and consists of closely fractured, quartz-filled veins and veinlets containing galena cubes, sphalerite, pyrite, and chalcopyrite. Mineralization is weak and the ore content probably does not exceed 5% of lead and 5% of zinc. The felsite adjacent to the ore zone is bleached by intense kaolinization. The metallic minerals have only been slightly oxidized to malachite and chrysocolla. Limonite pseudomorphs after pyrite are common. Manganese staining and addition of ferruginous quartz are noticeable. Other workings show a similar fracture and alteration pattern though chlorite is more evident. The alteration minerals are later than the ore.

<u>Prospects</u>

The Ford prospect about two miles northwest of the International mine is composed of two shallow vertical pits each about 15 feet deep. The claims were staked and are still owned by Alton Ford of the Hatchet Ranch. The mineralization consists of calcite replacements in oyster-rich limestone. Metallic minerals include galena and sphalerite. Oxidation is very marked; where galena and sphalerite are contiguous, sphalerite is reduced or missing and its only vestige is the outline of its crystal form.

The Vanadium Lead prospect is about five miles southwest of the Doyle Well and consists of one claim staked in 1948 by James Hiller and others of Hachita. The claim contains a shallow prospect hole in bedrock, an orthoquartzite. Mineralization occurs in a quartz zone in an area of chloritized and brecciated country rock, with minor amounts of galena, limonite, and manganese stains in the cement.

The Copper Valley (or Silver Valley) prospect is about a mile northwest of the Vanadium Lead prospect. It consists of four pits dug in 1919 and 1926 by Michael Wilcox and others of Hachita. Prospecting was carried on along iron and manganese-stained quartz veins in orthoquartzite. The veins trend east and have a vertical dip. Metallic minerals include galena and chalcopyrite, partially oxidized to malachite. Vanadium was supposedly found here as well as in the Vanadium Lead prospect, but no vanadium minerals were observed.

The Quartz prospect southeast of the Last Chance mine includes three prospect pits developed in andesite flows. Quartz veins parallel to the bedding contain minor amounts of galena and pyrite. The prospect was worked by Michael Wilcox in 1937.

The other prospects listed below are located in the Sierra Rica. The Rattlesnake prospect, about seven miles southwest of the Doyle Well, is reached by a poor road heading west from the well. The workings consist of one inaccessible shaft of undetermined depth and some prospect holes. Some lead-silver ore was shipped in 1923.[1] The mine was claimed by Edward Flynt of Hachita early in 1953. Mineralization occurs in the Limestone-Sandstone member and consists of quartz veins heavily stained by manganese and iron. Jarosite, seemingly lead bearing, is an abundant associate. No sulfides were noted in any of the fragments on the dump.

The Casher prospect, about a mile northeast of the Rattlesnake prospect, consists of a small tunnel in the Rudistid Limestone member following a bedding plane vein composed on calcite and disseminated galena and pyrite. Oxidation minerals include limonite, pyrolusite, and siderite.

The Pick and Shovel prospect, one-quarter mile northwest of the Rattlesnake prospect, consists of a trench 15 feet deep in the Limestone-Sandstone member. Minor amounts of galena and pyrite occur in quartz veins.

The Weatherford prospect staked in 1953 by Ollie Weatherford and others of Hachita is located near the international border about 0.3 miles south of Border Post No. 42. The prospect consists of a shallow pit in limestone which contains a quartz zone rich in chrysocolla and limonite. An unconfirmed report holds that the copper ore averaged about $30 per ton.

SUMMARY OF ORE DEPOSITS

The ore deposits of the Apache Hills and Sierra Rica may be subdivided into two genetic classes. One class would include

[1]U.S. Bureau of Mines and U.S. Geological Survey, 1923, Mineral Resources of the United States.

the Apache-Chapo Mining District, Occidental mines, the Daisy mine, and the International mine. All these are characterized by the following: structures that trend similarly and are usually north to northeast veins and replacement fissures; mineralogy of the high temperature type: tactite zones at the first two, scheelite at the Daisy Mine; a relatively high grade of ore which was operated sporadically; similar gangue minerals; and a country rock predominantly limestone.

The other class of mining prospects occurs in Tertiary igneous flows and is characterized by low grade but generally similar sulfide mineralogy of a spotty and non-persistent character; close proximity to rhyolite porphyry or felsite intrussives with which the ore is genetically related; and similar gangue and alteration minerals. Abundant siderite and chlorite seem to be representative of the alteration haloes of this class of deposits whereas epidote, other silicates, and carbonates are dominant alteration minerals in the first class.

FUTURE PROSPECTING

The outlook for developing new ore bodies or extending old ones appears to be brightest in the Apache-Chapo Mining District and other properties where ore deposition has occurred in limestone. In these areas structural controls are most pronounced and locally fractures and faults antedate the ore. At the Apache mine a most likely place for ore localization is at the postulated intersection of the Indian and McKinley faults. It is surprising that exploration work was not conducted hitherto at this site. Another promising area includes the limestone adjacent to the Indian fault which is mineralized at the surface and has only been explored at the Indian shaft. The tremolitized and silicated limestone shows no sulfide mineralization elsewhere along its length, but the contiguous limestone-rhyolite breccia and the presence of cross-cutting faults suggest that ore deposition would be present in such an environment if anywhere else. Considering the association of chalcopyrite with tactite zones, copper mineralization is most likely.

The sediments of the Apache-Chapo mine are part of the Limestone-Sandstone member. At the Chapo mine, they form a fairly thin section, underlain by the Rudistid Limestone member. East of the Chapo fault, recrystallized sandstones appear and extend to the Indian fault. These sandstones represent the lower portion of the Limestone-Sandstone member. At a depth of 500-600 feet drill holes should intersect the underlying Rudistid Limestone, which under those favorable structural and lithologic conditions might well be the site of ore deposition. In addition, the beds against the fault will probably be upturned. Exploration and development work along the entire length of the Indian fault should show similar favorable conditions. Fair-sized ore bodies might be expected at the intersections of the Indian fault with major faults trending normal to the Indian fault. The trace of these cross-cutting faults, a zone of structural weakness, is invariably the site of an arroyo and is accordingly covered with recent alluvium that obscures any ore deposit present on the surface.

The Occidental, International, and Daisy mines present a somewhat different problem. The workings in these properties are shallow and do not yield a good picture of the extent of mineralization. All possess favorable structures and lithologies and many of the workings show an apparent increase in ore grade with depth. This is especially true in regard to the Occidental mines with which tactite minerals are associated and where many of the workings may be cited as illustrious of increasing grade.

The ore deposits confined to volcanics and associated with rhyolite may be virtually discounted as reserves; for the most part, the ore is confined to thin quartz veins, occurs in sporadic irregular shoots, and is commonly of low grade.

In review, then, the best prospects for the development of future ore deposits in the Apache Hills and Sierra Rica lies in the Apache-Chapo Mining District since ore concentration there should be of higher tenor, probably reaching commercial grade.

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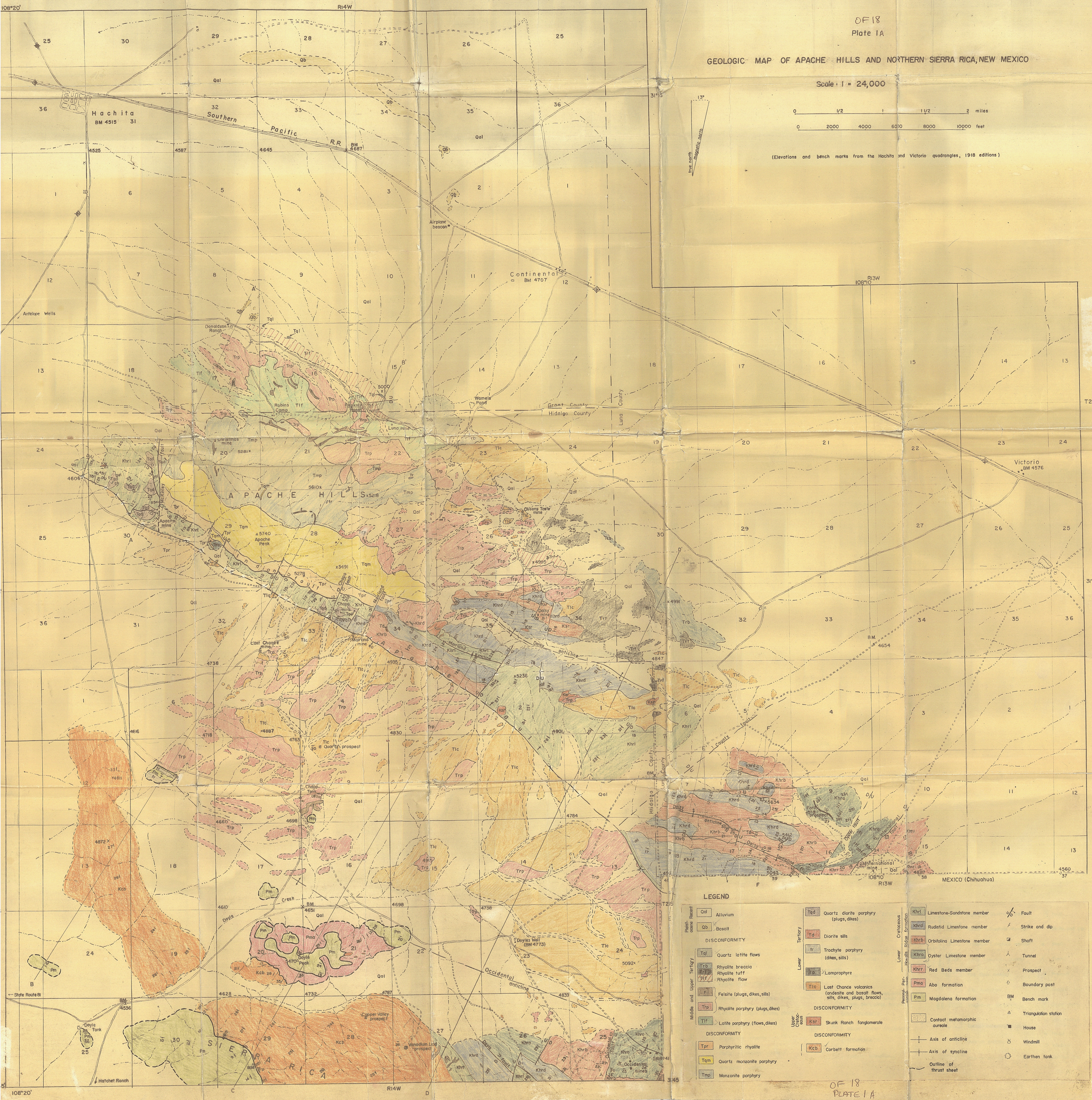
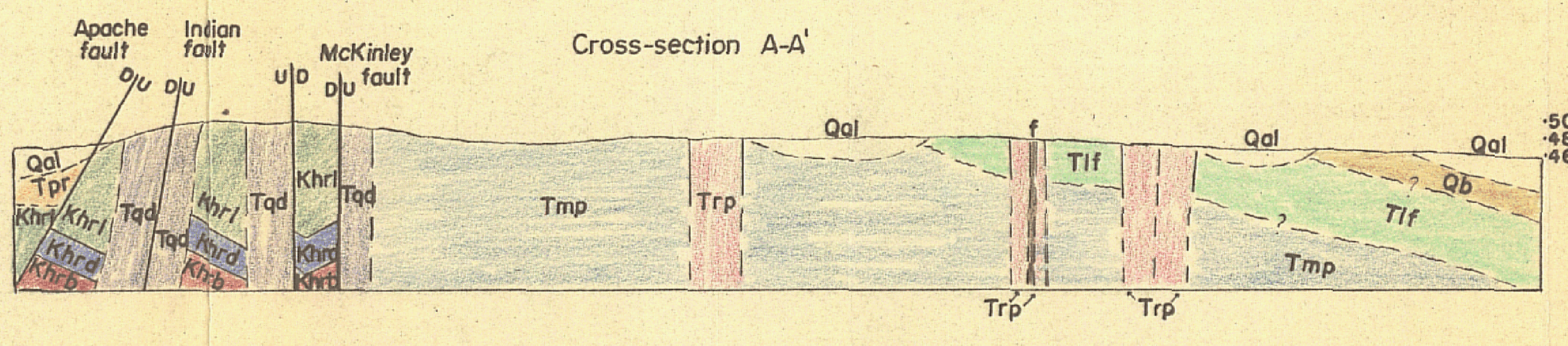
OF 18
Plate 1A



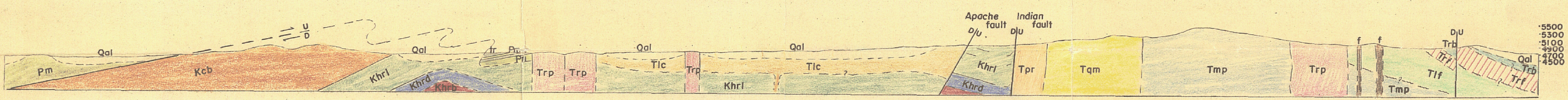
OF 18
PLATE 1A

CROSS-SECTIONS OF PLATE I B

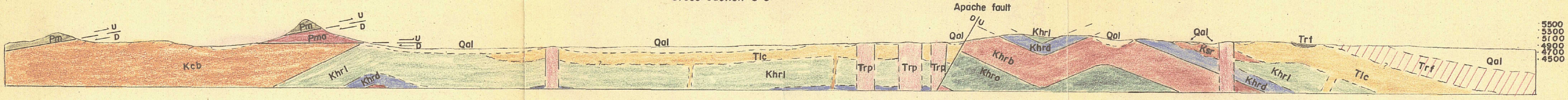
Cross-section A-A'



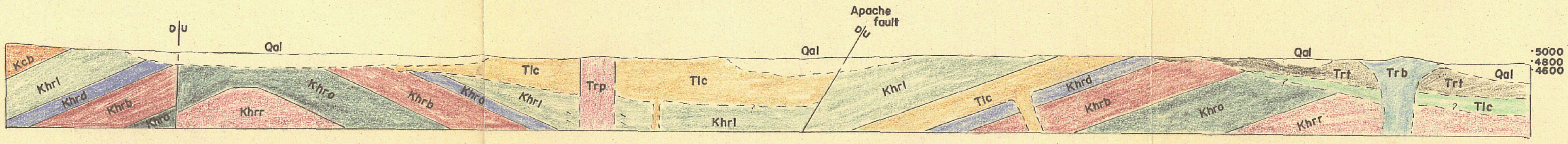
Cross-section B-B'



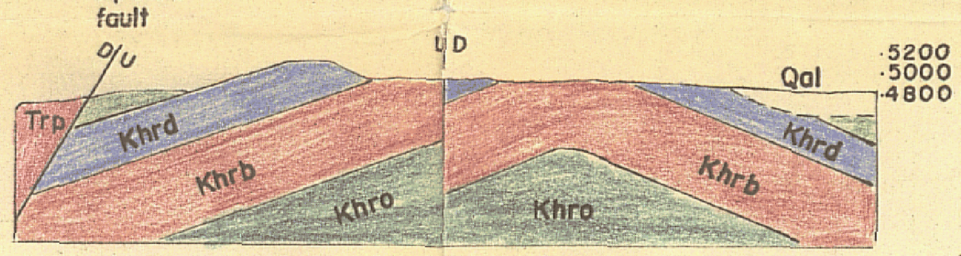
Cross-section C-C'



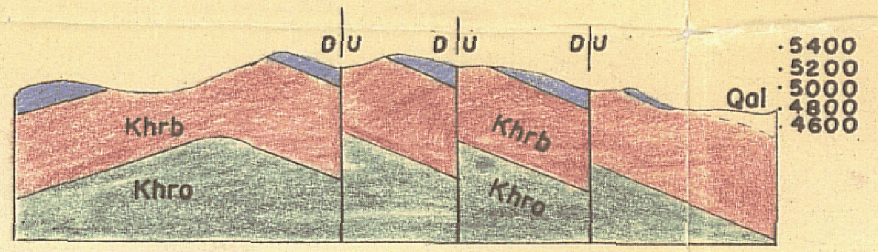
Cross-section D-D'



Cross-section E-E'



Cross-section F-F'



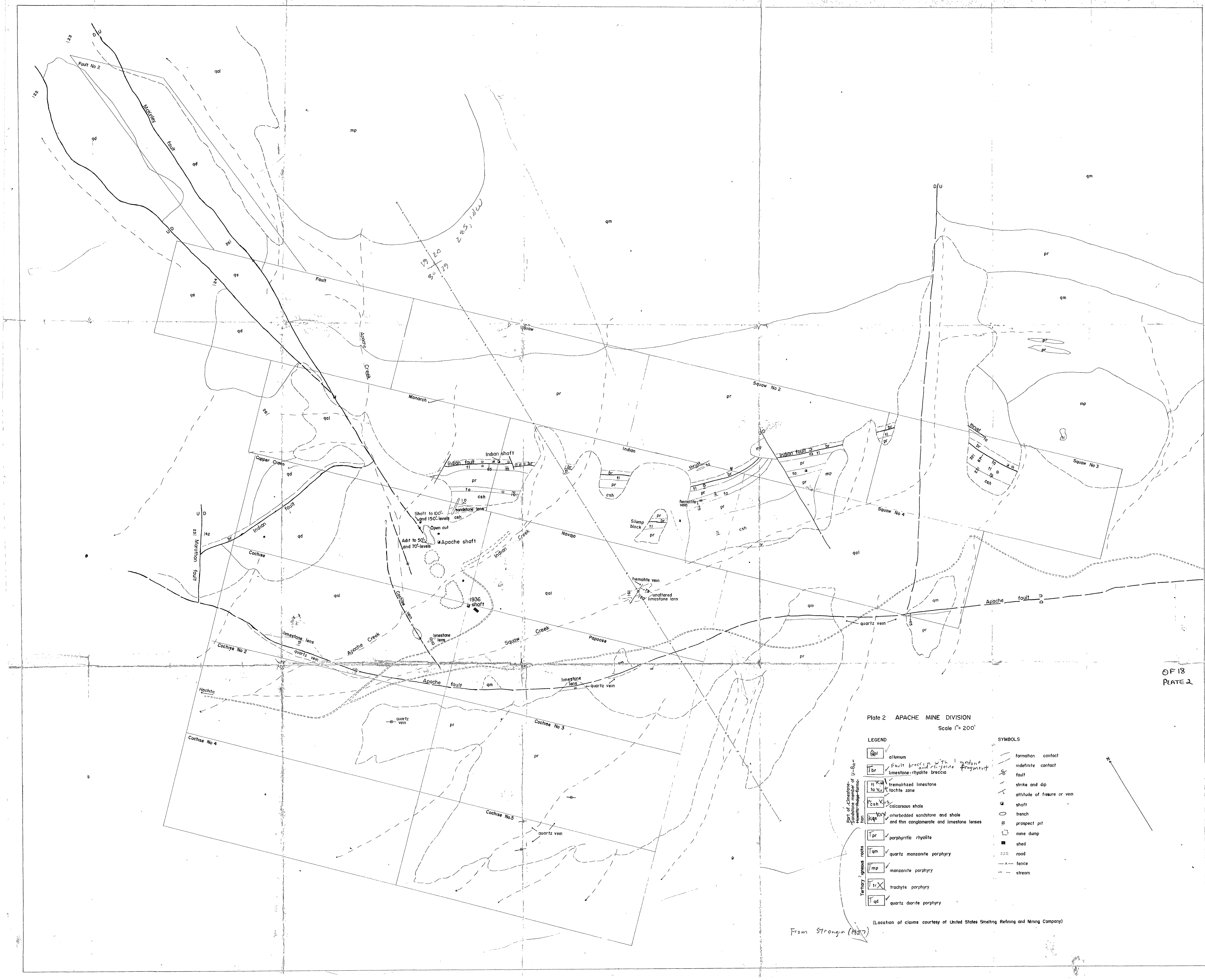
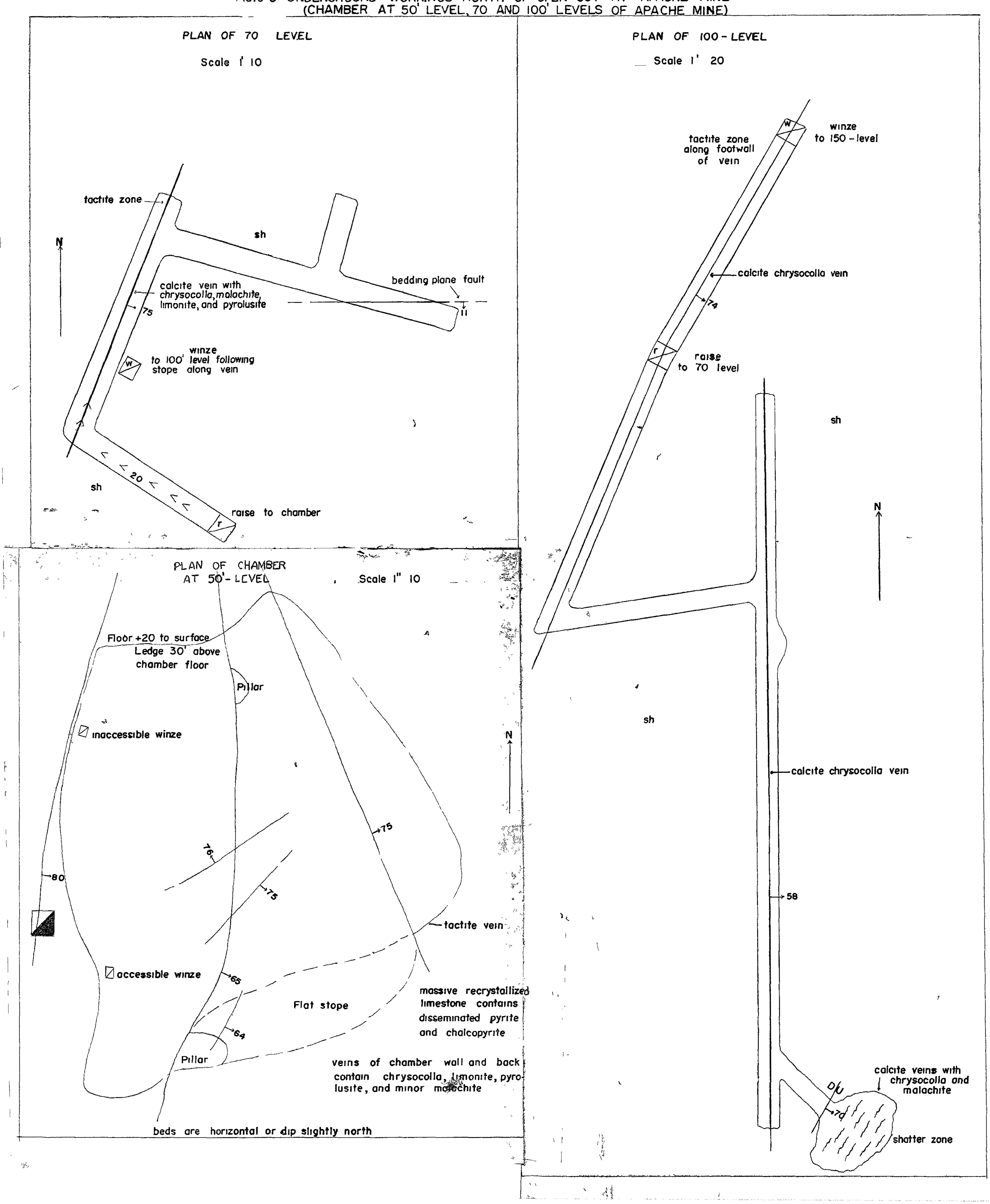

OF 18
PLATE 2
Plate 2 APACHE MINE DIVISION
Scale 1" = 200'
LEGEND
Qal alluvium
Tbr Fault breccia with limestone and rhyolite fragment
limestone-rhyolite breccia
Part of Limestone-Sandstone member of U-Bar Howells Ridge formation
tl Kul tremolitized limestone
ta Kut tactite zone
csh Kus calcareous shale
Kqs Kuv interbedded sandstone and shale and thin conglomerate and limestone lenses
Tertiary ? igneous rocks
Tpr porphyritic rhyolite
Tqm quartz monzonite porphyry
Tmp monzonite porphyry
Ttr trachyte porphyry
Tqd quartz diorite porphyry
SYMBOLS
formation contact
indefinite contact
fault
strike and dip
attitude of fissure or vein
shaft
trench
prospect pit
mine dump
shed
road
fence
stream
N
(Location of claims courtesy of United States Smelting Refining and Mining Company)
From Strongin (1957)
Fault No 2
McKinley fault
Fault
Squaw
Squaw No 2
Squaw No 3
Squaw No 4
Monarch
Indian
Navajo
Papoose
Copper Crown
Cochise
Cochise No 2
Cochise No 3
Cochise No 4
Cochise No.5
Hachita
Indian fault
Indian shaft
Marathon fault
Apache Creek
Indian Creek
Squaw Creek
Cochise vein
Apache fault
Apache shaft
Open cut
Shaft to 100'- and 150'- levels
sandstone lens
Adit to 50'- and 70'- levels
1936 shaft
limestone lens
quartz vein
hematite vein
unaltered limestone lens
Slump block
thrust
qal
qd
qs
mp
qm
pr
br
tl
ta
csh
285 14W
19 20
30 29


Plate 3 CHAPO MINE DIVISION
Scale 1 200
LEGEND
qal alluvium
br limestone-rhyolite breccia
tl tremolitized limestone
ta tactite zone
csh calcareous shale
qs interbedded shale, sandstone and thin limestone and conglomerate lenses
Part of Limestone-Sandstone member of Howells Ridge formation
lsr rudistid limestone
pr porphyritic rhyolite
qm quartz monzonite porphyry
mp monzonite porphyry
tr trachyte porphyry
qd quartz diorite porphyry
ab andesite and basalt porphyry
Tertiary igneous rocks
SYMBOLS
formation contact
indefinite contact
fault
strike and dip
attitude of fissure or vein
shaft
tunnel
prospect pit
windmill
cabin
road
stream
N
Indian fault
argillaceous lens
V E Day shaft
conglomerate lens
copper oxide vein
tactite zone
tactite vein in limestone conglomerate lens
unaltered limestone
tactite-chalcopyrite zone
Chapo fault
Chapo shaft
(rudistid limestone at 150 level)
Lost Chance mine
Marland mine
Apache fault
Indian Draw
tactite scheelite zone
aragonite-filled
limestone lens
brecciated tactite-chalcopyrite zone
tactite vein

Plate 4. PLAN OF OPEN CUT, 50'-LEVEL, AND 70'-LEVEL OF APACHE MINE

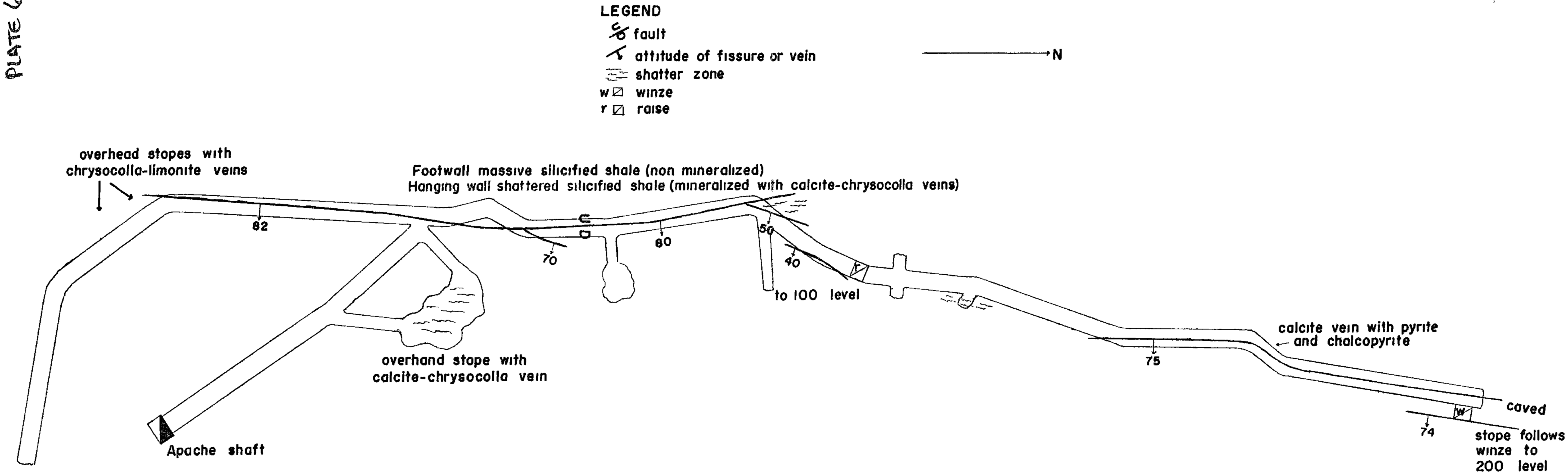
Plate 5 UNDERGROUND WORKINGS NORTH OF OPEN CUT AT APACHE MINE (CHAMBER AT 50' LEVEL, 70 AND 100' LEVELS OF APACHE MINE)



OF 18
PLATE 6

Plate 6 PLAN OF 150' LEVEL OF APACHE MINE

Scale 1 40



OF 18
PLATE 7

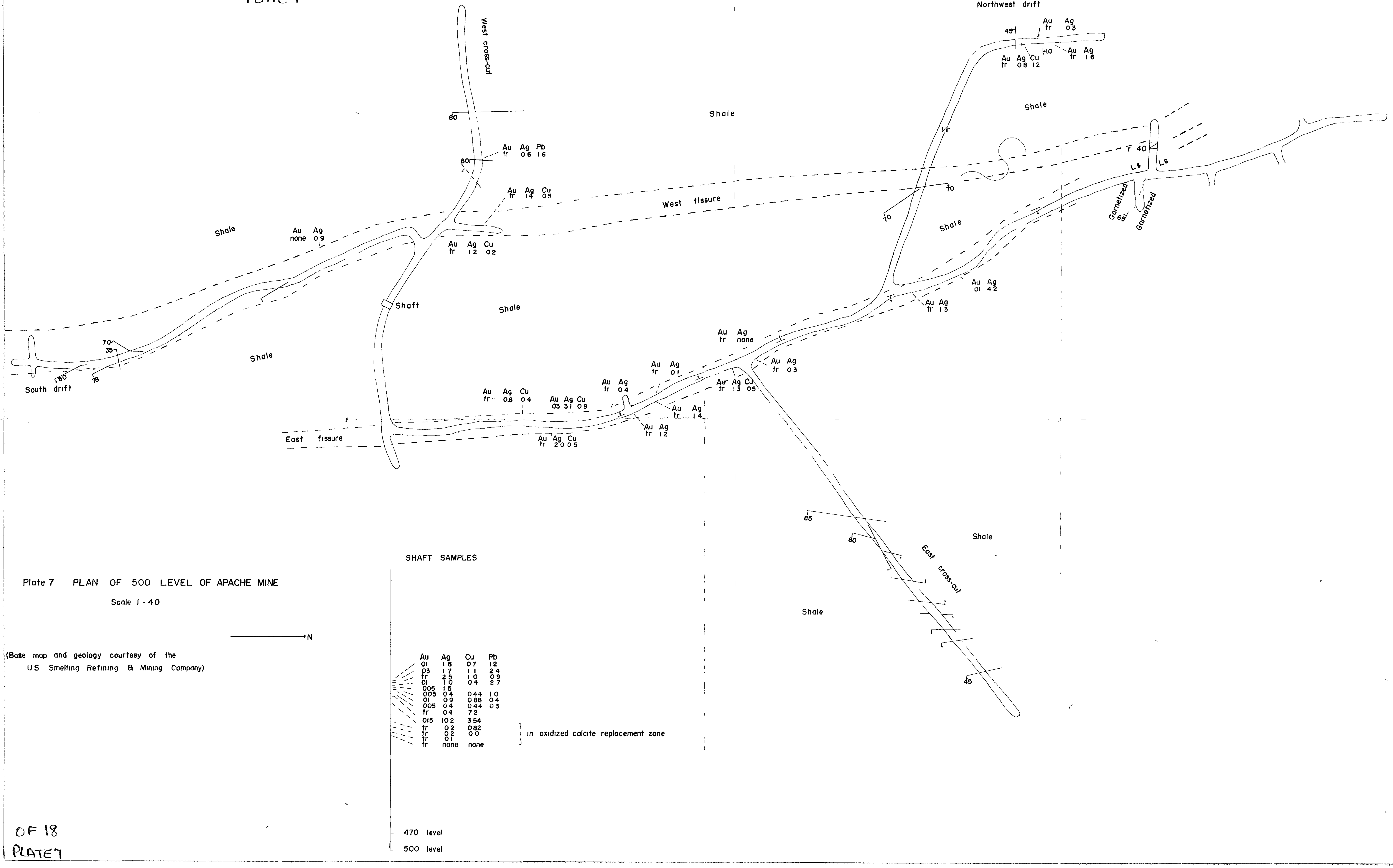


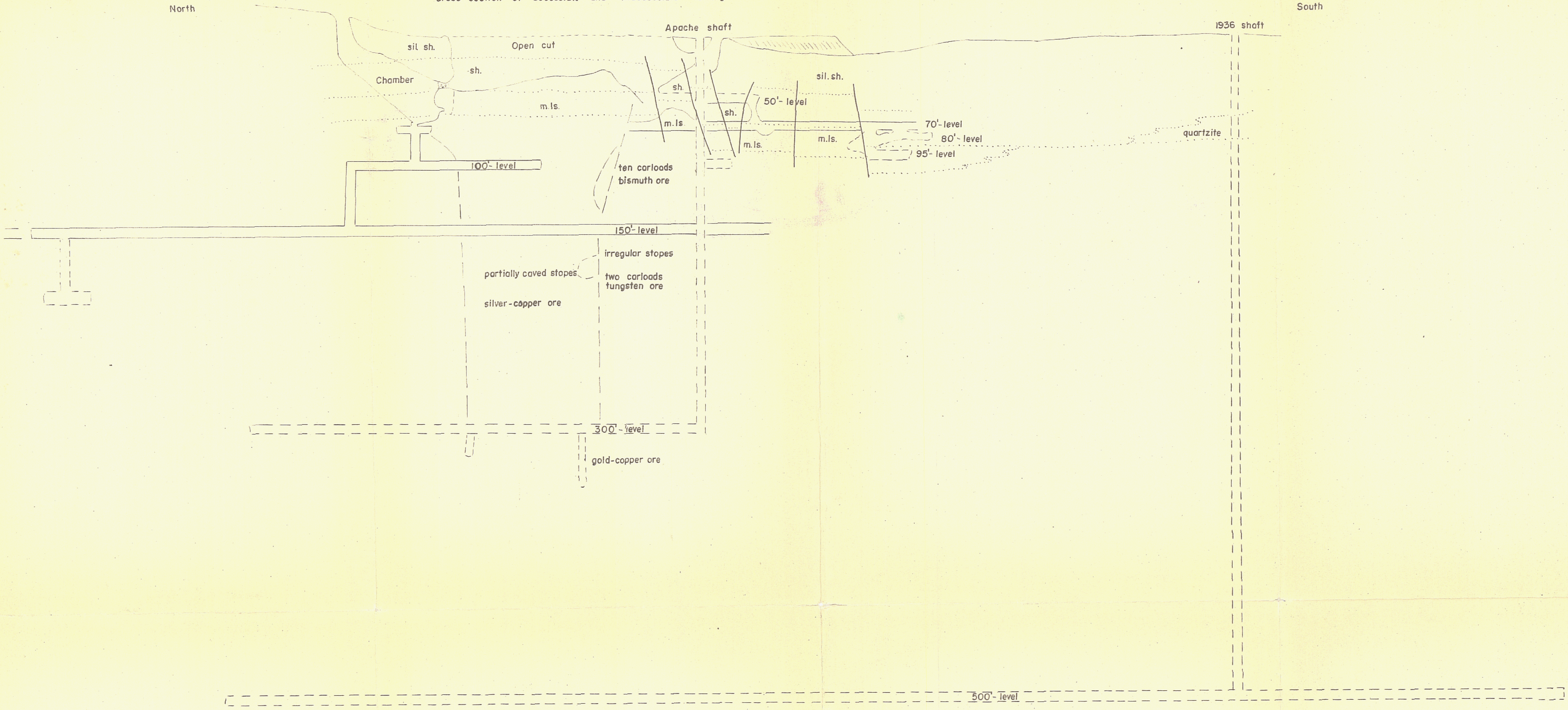
Plate 7 PLAN OF 500 LEVEL OF APACHE MINE

Scale 1-40

(Base map and geology courtesy of the US Smelting Refining & Mining Company)

OF 18
PLATE 7

Cross-section of accessible and inaccessible workings



Plan of accessible workings

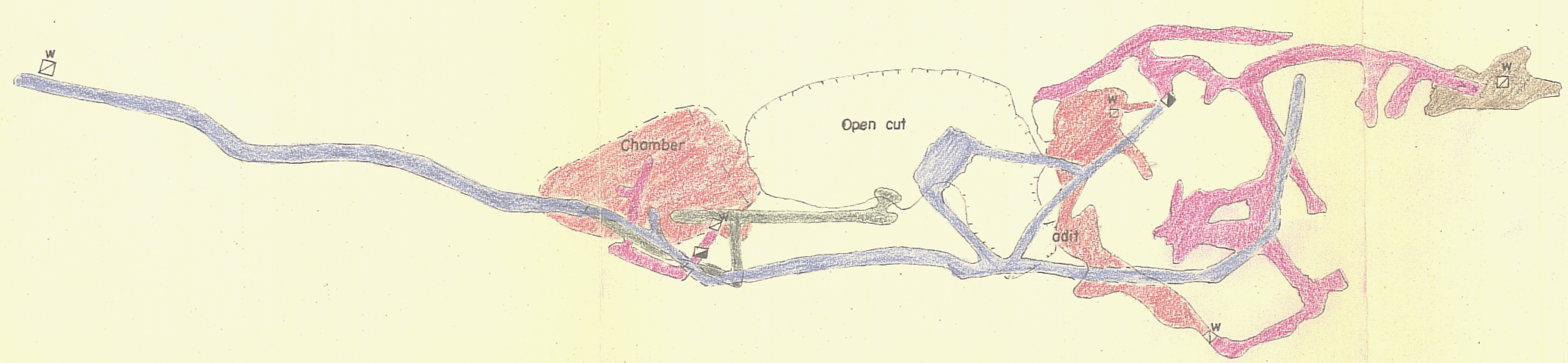


Plate 8. MINE WORKINGS OF APACHE MINE (Caps From Strongin, 1957
linear scale

Scale: 1" = 50'

LEGEND

sil. sh.	siliceous shale
sh.	altered shale (chloritized)
m. ls	massive recrystallized limestone
	formation contact
	accessible workings
	inaccessible workings
	50'- level
	70'- level
	80'- level
	100'- level
	150'- level
	outline of open cut
	outline of chamber
	shaft
	winze

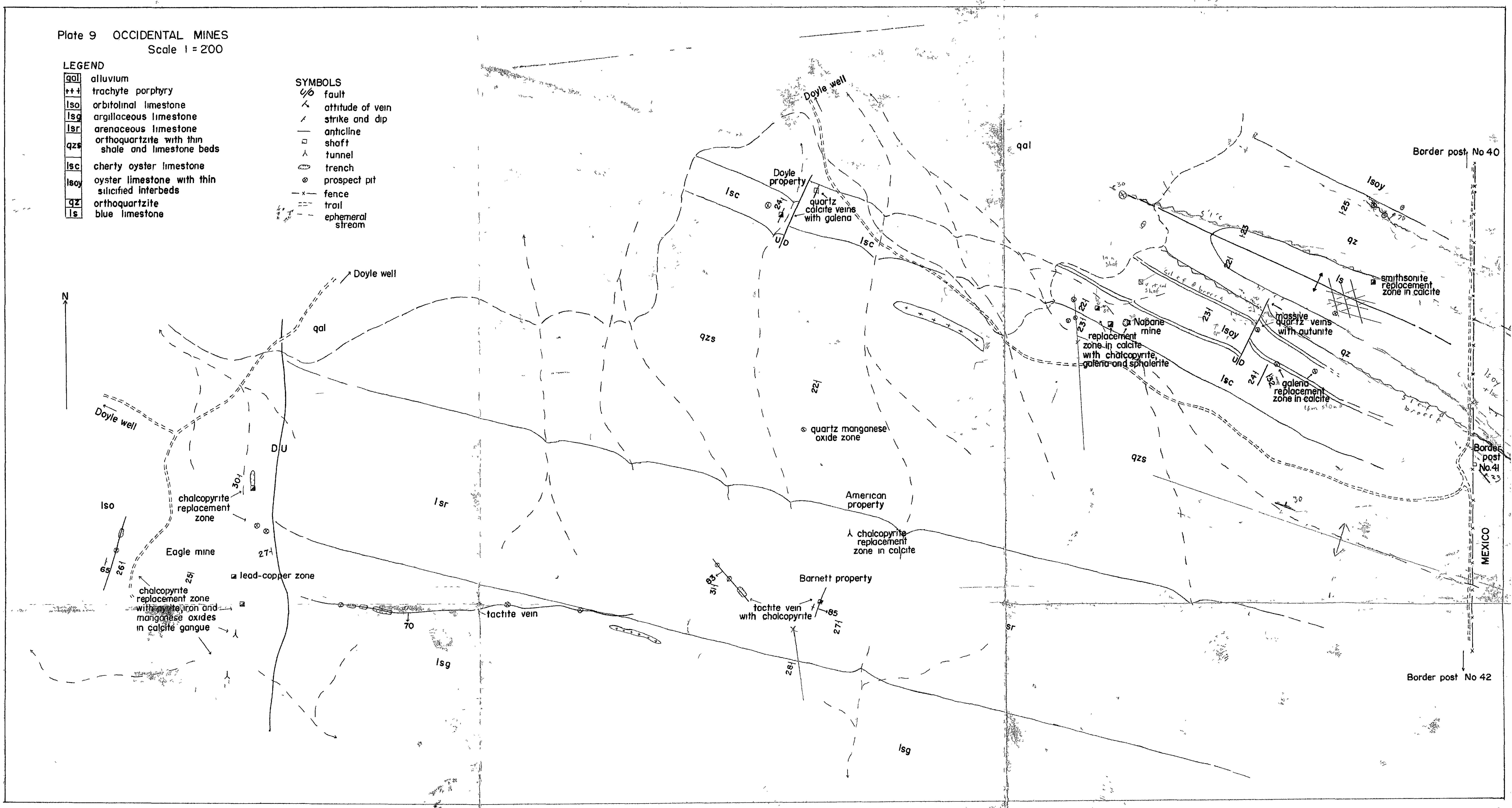
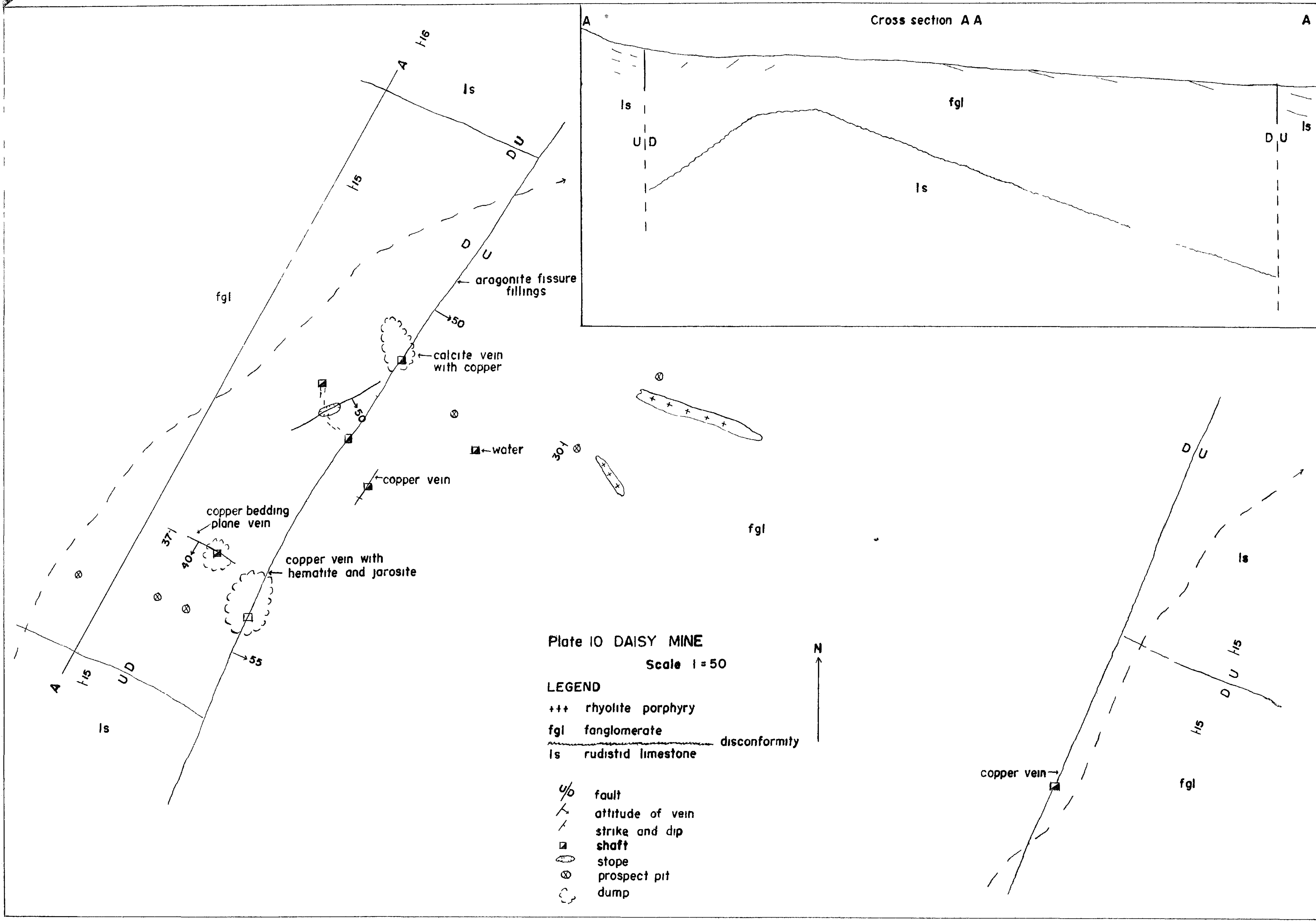


Plate 9 OCCIDENTAL MINES
Scale 1 = 200
LEGEND
qal alluvium
+++ trachyte porphyry
lso orbitolinal limestone
lsg argillaceous limestone
lsr arenaceous limestone
qzs orthoquartzite with thin shale and limestone beds
lsc cherty oyster limestone
lsoy oyster limestone with thin silicified interbeds
qz orthoquartzite
ls blue limestone
SYMBOLS
U/D fault
attitude of vein
strike and dip
anticline
shaft
tunnel
trench
prospect pit
fence
trail
ephemeral stream
N
Doyle well
Doyle well
Doyle well
Doyle property
quartz calcite veins with galena
qal
qal
qzs
qzs
lsc
lsc
lsc
lsoy
lsoy
qz
qz
ls
lso
lsr
lsg
lsg
sr
D U
U/D
U/D
chalcopyrite replacement zone
Eagle mine
lead-copper zone
chalcopyrite replacement zone with pyrite, iron and manganese oxides in calcite gangue
tactite vein
quartz manganese oxide zone
American property
chalcopyrite replacement zone in calcite
Barnett property
tactite vein with chalcopyrite
replacement zone in calcite with chalcopyrite, galena and sphalerite
Napane mine
massive quartz veins with autunite
galena replacement zone in calcite
smithsonite replacement zone in calcite
Border post No 40
Border post No.41
Border post No 42
MEXICO

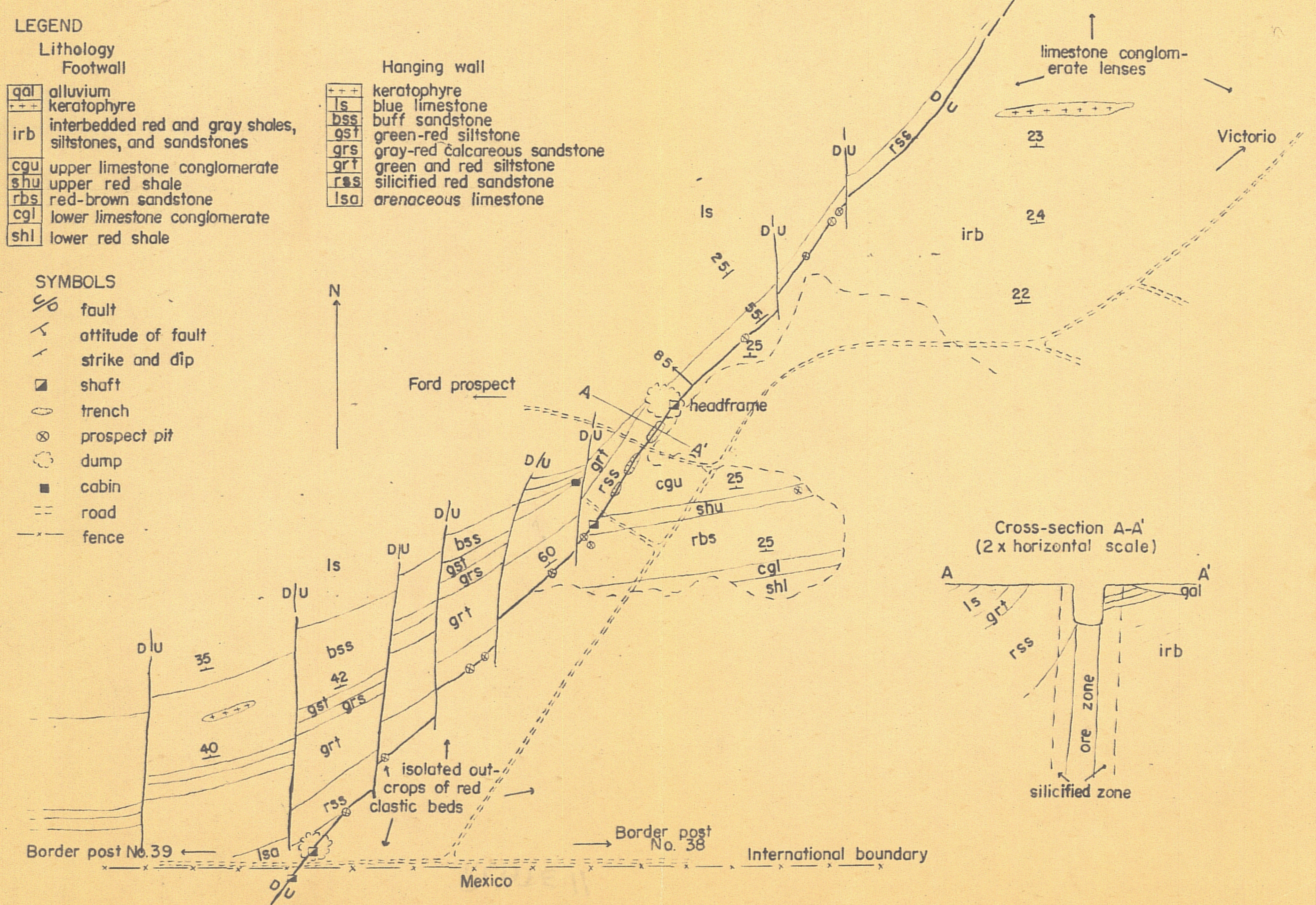


Cross section A A
A
A
ls
fgl
ls
U D
D U
ls
ls
A
A
1-16
1-15
1-15
D U
D U
fgl
aragonite fissure fillings
50
calcite vein with copper
50
water
30
copper vein
fgl
copper bedding plane vein
37
40
copper vein with hematite and jarosite
55
U D
ls
D U
ls
1-15
U D
15
copper vein
fgl
Plate 10 DAISY MINE
Scale 1 = 50
N
LEGEND
+++ rhyolite porphyry
fgl fanglomerate
disconformity
ls rudistid limestone
fault
attitude of vein
strike and dip
shaft
stope
prospect pit
dump

Plate II.

INTERNATIONAL MINE

Scale: 1" = 200'



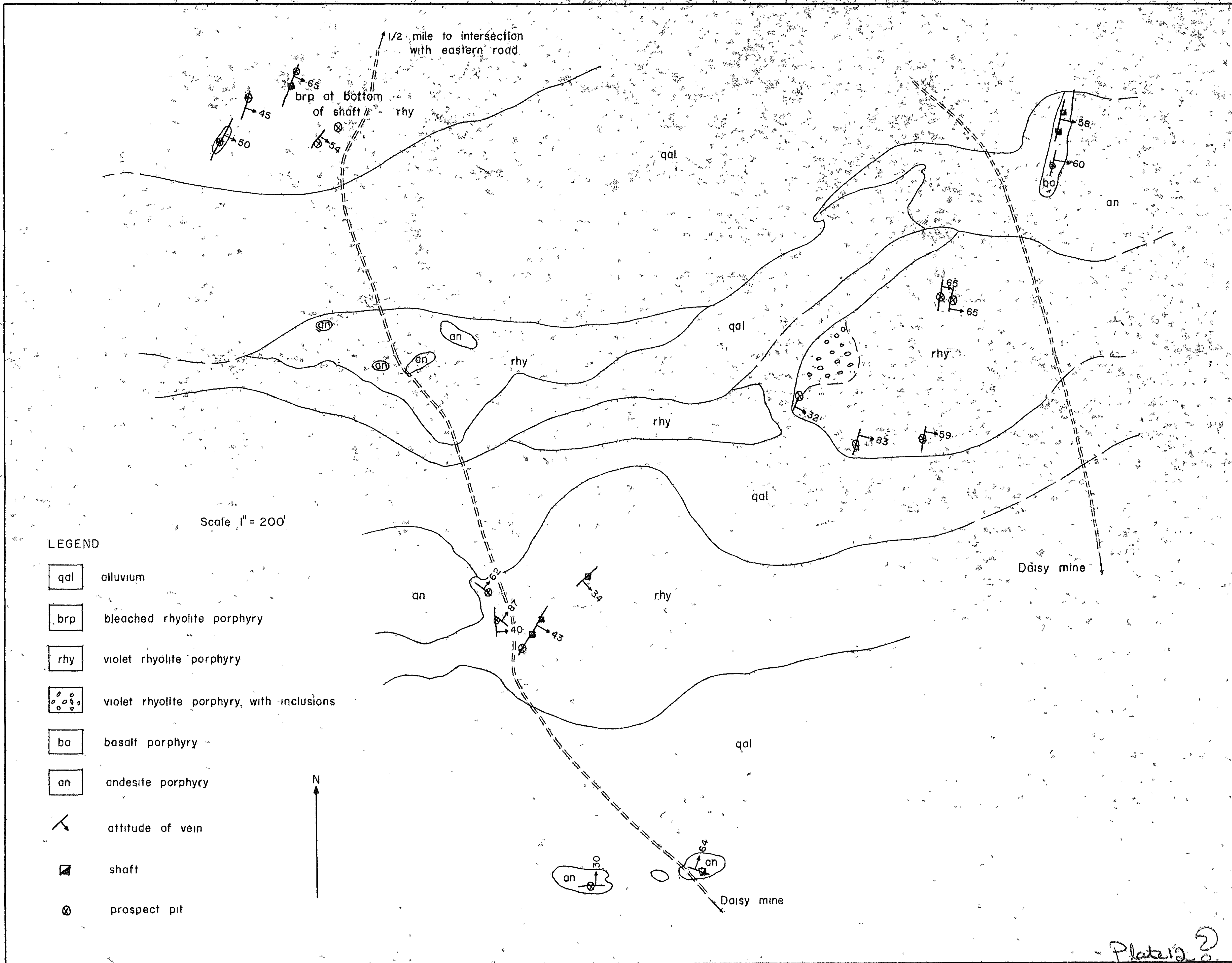

1/2 mile to intersection with eastern road
brp at bottom of shaft
rhy
qal
an
ba
Daisy mine
Scale 1" = 200'
LEGEND
qal alluvium
brp bleached rhyolite porphyry
rhy violet rhyolite porphyry
violet rhyolite porphyry, with inclusions
ba basalt porphyry
an andesite porphyry
attitude of vein
shaft
prospect pit
N
Daisy mine

Plate 12

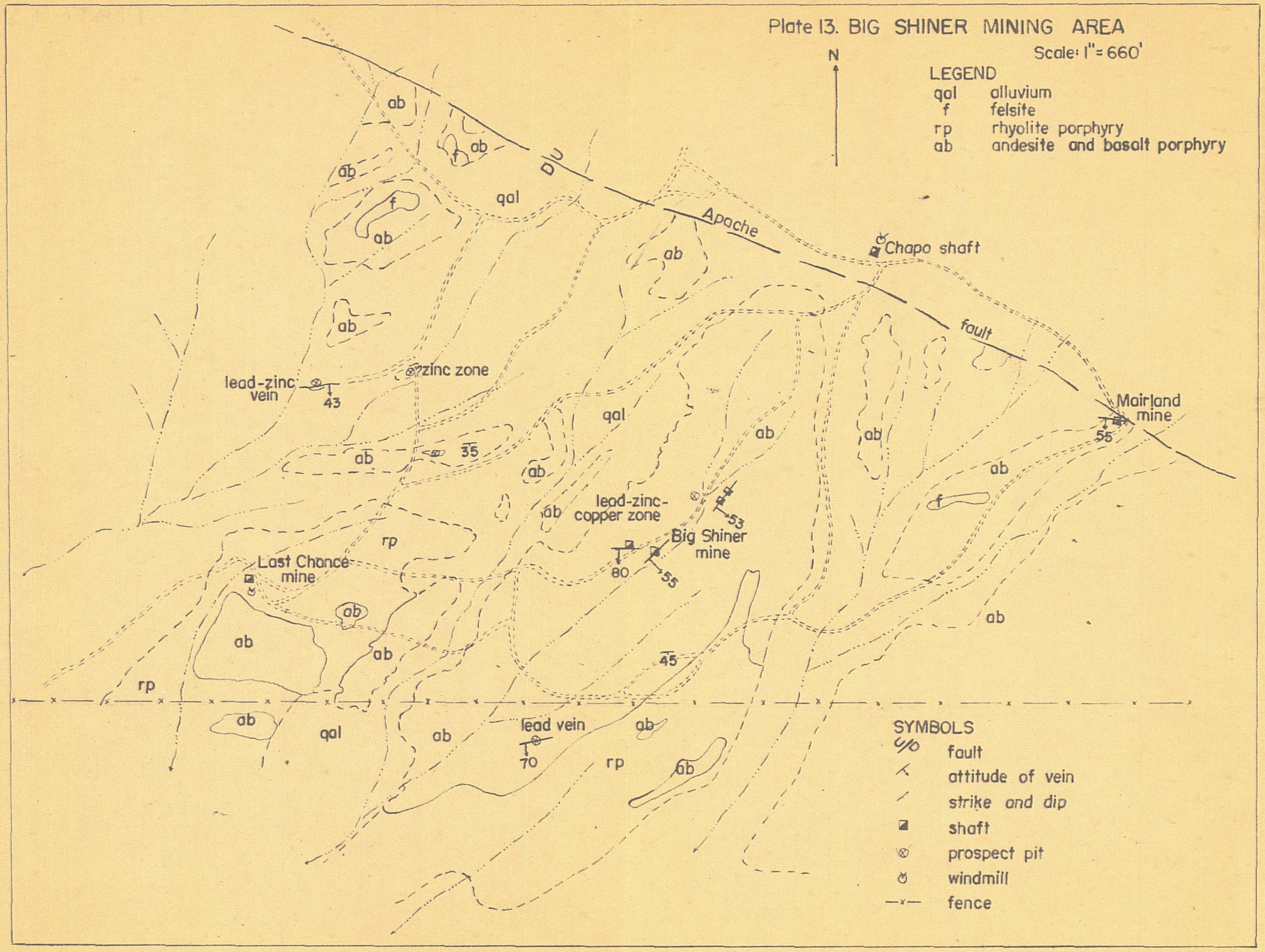


Plate 13. BIG SHINER MINING AREA
Scale: 1" = 660'
N
LEGEND
qal alluvium
f felsite
rp rhyolite porphyry
ab andesite and basalt porphyry
SYMBOLS
fault
attitude of vein
strike and dip
shaft
prospect pit
windmill
fence
Apache fault
D U
Chapo shaft
Mairland mine
55
lead-zinc vein
43
zinc zone
35
lead-zinc-copper zone
53
Big Shiner mine
80
55
Last Chance mine
45
lead vein
70
qal
ab
f
rp

Plate 14. LAST CHANCE MINE

Sca e: 1" = 100'

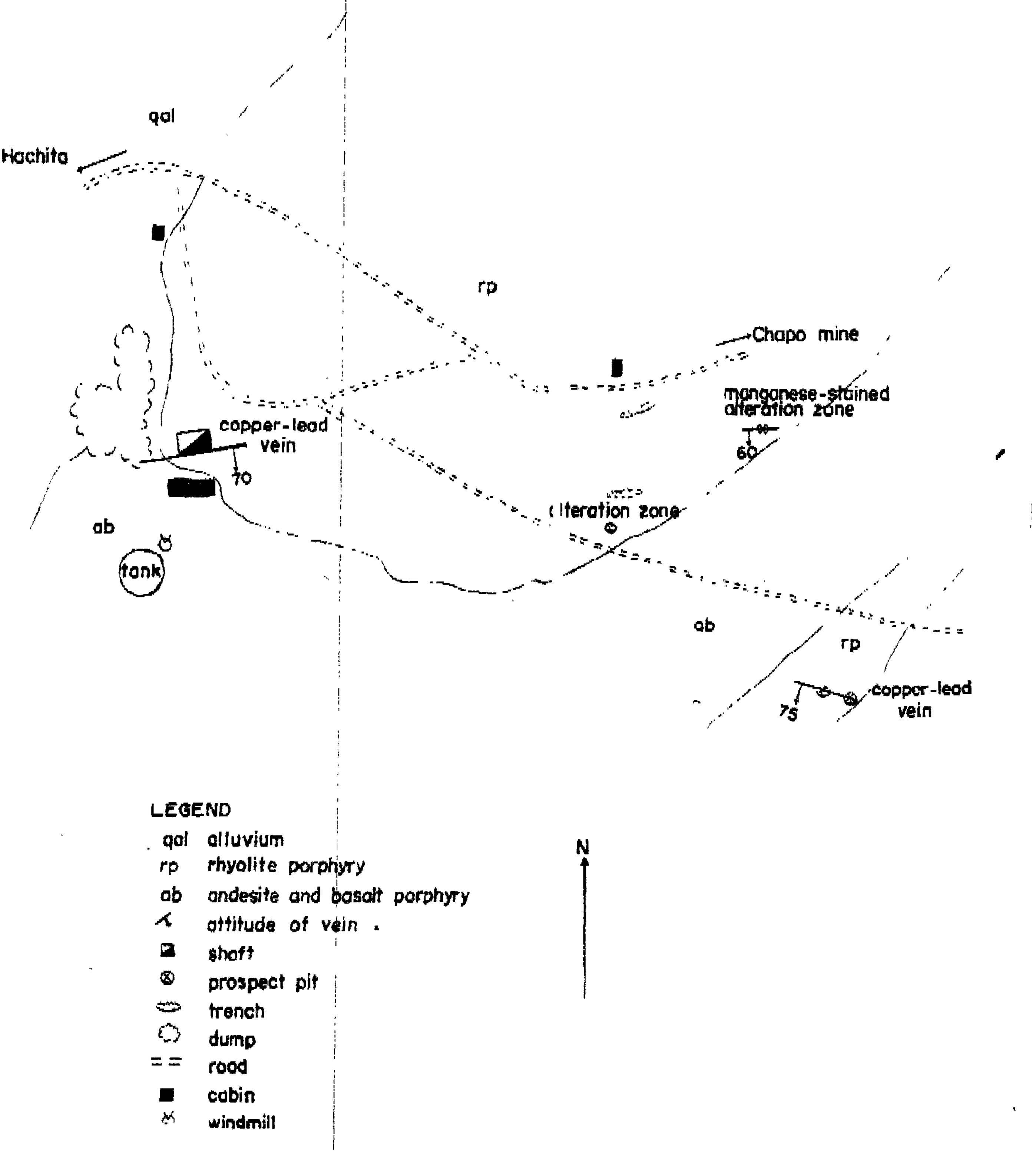


Plate 15. LUNA MINE

Scale: 1" = 100'