UNIVERSITY OF CINCINNATI

May 15 1950

I hereby recommend that the thesis prepared under my supervision by Robert Thayer Russell

entitled The Geology of the Poncha Fluorspar District, Chaffee County, Colorado

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

Approved by: John L. Rich

THE GEOLOGY OF THE PONCHA FLUORSPAR DISTRICT

CHAFFEE COUNTY, COLORADO

A dissertation submitted to the

Graduate School of Arts and Sciences

of the University of Cincinnati

in partial fulfillment of the

requirements for the degree of

DOCTOR OF PHILOSOPHY

1950

by

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CHAPTER I

INTRODUCTION

The purpose of this study is to determine to what extent the fluorspar deposits in the Poncha area, Colorado are controlled by local or regional structural features and to see if any evidence could be obtained that would give a clue to their mode of origin. The Poncha Hot Springs were investigated because their close association with the fluorspar deposits indicated that they might be genetically related.

The author believes that the study shows that a probable source of the fluorine in fluorspar deposits is a body of magma structurally connected to the deposit. Fluorine gas escapes from the magma and somehow becomes fixed as CaF_2 or SiF_4. These compounds remain fixed in solution as the acid ground water changes to an alkaline state. Upon reaching an area of low temperature and pressure the CaF_2 precipitates out or the SiF_4 breaks down and reacts to form CaF_2 and SiO_2. The author believes that in this paper lies the first attempt to apply certain new geo-chemical data on fluorspar to the origin of fluorspar deposits.

In the Poncha area a shear zone provided the channel for the fluorine-bearing solutions. The various country rock types, which contribute the character of the gouge making it permeable or impermeable, controlled the flow of the ore solutions and the location of the ore bodies. The near-by lavas and the hot springs are the surface expressions of a magmatic body which underlay the area.

The Poncha fluorspar district is in the southern part of Chaffee County, Colorado (see fig. 1). It parallels the South Fork of the Arkan-

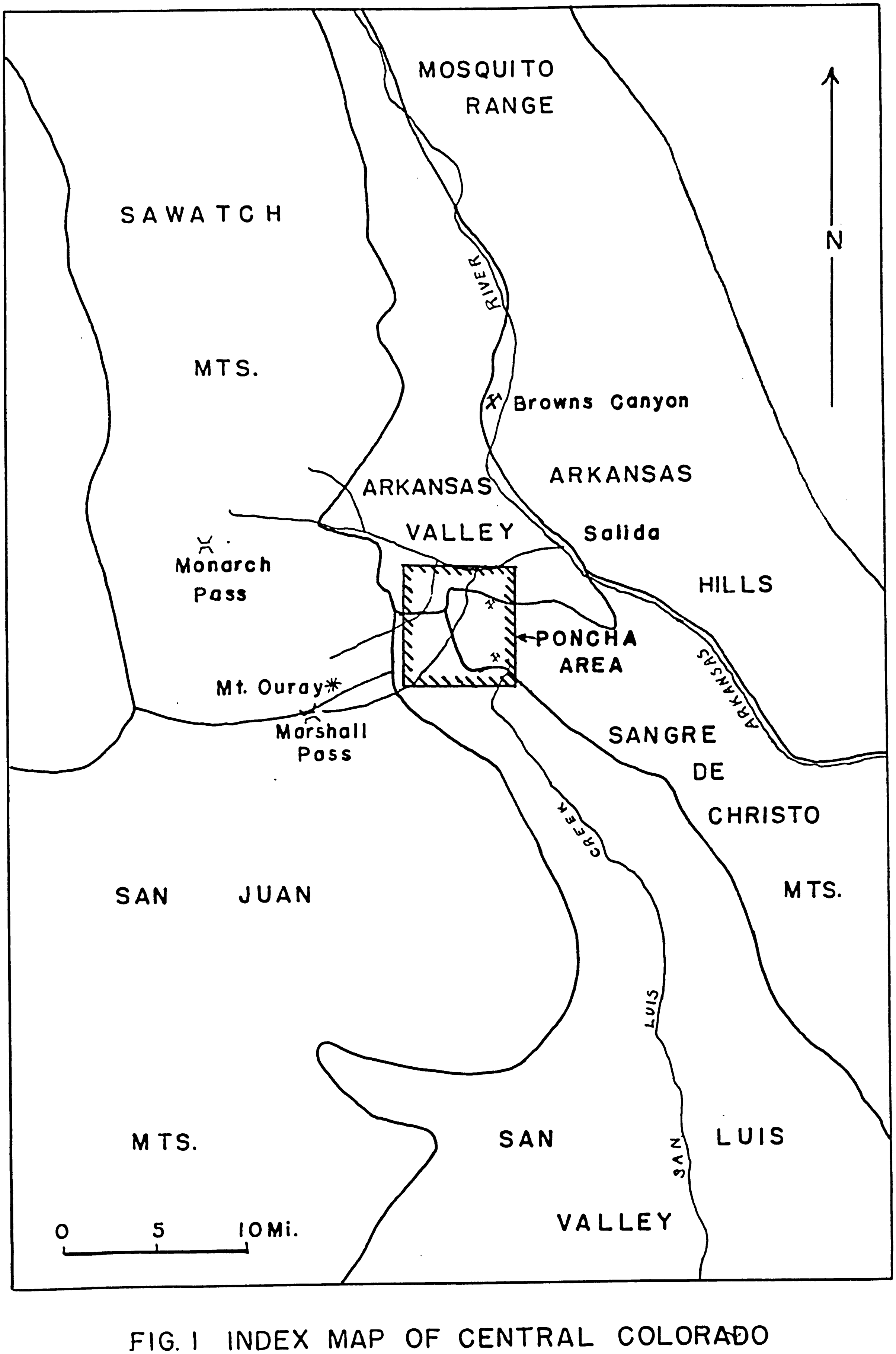

FIG. 1 INDEX MAP OF CENTRAL COLORADO

sas River for 6 miles and extends southward for 5 miles to Poncha Pass. The main habitation consists of the small town of Poncha at the northern edge of the area; there are also a few cabins clustered around the Poncha Hot Springs. Salida, 5 miles to the east, is the nearest city.

U. S. highway 50 passes along the northern edge of the area. Near the town of Poncha, U. S. highway 285 crosses Highway 50 and continues through the middle of the district to Poncha Pass and the San Luis Valley to the south. A narrow gauge branch line of the Denver and Rio Grande Western Railroad operates between Salida and points west. At Poncha Junction, a branch of the narrow gauge line turns south and, within a mile, approaches the highway and parallels it to Mear's Junction where the line branches again. One fork continues south to Alamosa; the other turns west to cross Marshall Pass.

The Poncha district lies in the southern Rocky Mountains as defined by Fenneman.[1] Figure 1 shows the relation of the Poncha district to the surrounding physiographic features.

The Poncha fluorspar district is very rugged. Altitudes range from 7300 feet at the town of Poncha to over 10,000 feet at Poncha Peak and Cleveland Peak less than 2 miles distant. Poncha Pass is 9000 feet above sea level. The area is deeply dissected, which results in many steep slopes.

The climate is semi-arid. Sage, pinon pine, and juniper grow on the lower slopes. On the higher parts of the area, which receive more mois-

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1. Fenneman, N. M., Physiography of the Western United States: Ch. II, 1931.

ture, spruce, douglas fir, and several types of pine are common. Four permanent streams cross the area. San Luis Creek flows south from the district. Poncha Creek rises on Marshall Pass and flows through the area to join the South Fork of the Arkansas River near Poncha. Little Cochetopa Creek likewise drains into the South Fork of the Arkansas River. All other streams are intermittent.

Previous to the present study, several geologists had visited the area and had submitted memoranda, none of which were published, to the U. S. Geological Survey. In 1942 T. G. Andrews visited the area. In 1943 D. C. Cox inspected the deposits. In May and June of 1944 Cox, R. D. Trace, and J. O. Fisher mapped the surface geology at the Aksarben mine. In May 1945 Cox and D. M. Henderson mapped the lower mine tunnel at this deposit. In the same year Cox[2] published a paper on Colorado fluorspar in which the Aksarben mine was mentioned.

In order to obtain the needed information for this dissertation, it was necessary to make an areal geologic map, to map the mine workings, to study the various rock types, to map the geologic structures and their physiographic expressions, and to work out the geologic history of the area. The writer studied the Poncha area in the field during the summer and fall of 1945 while employed by the U. S. Geological Survey. The field work was divided into three phases. One phase was the mapping on air photos of the area between the Arkansas River Valley and Poncha Pass. The second consisted of making a detailed topographic and surface geologic map of the Divide fluorspar mine. The third phase was underground mapping

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2. Cox, D. C., General Features of Colorado Fluorspar Deposits: Colo. Sci. Soc. Proc., Vol. 14, No. 6, 1945.

at the Aksarben and Divide mines. The areal mapping was not completed at this time except for a narrow strip along Highway 285.

The work was part of a program for the investigation of strategic and critical minerals. The Colorado Metal Mining Fund Supplied about half of the money for this work. In March, 1947 a summary report was issued covering this early study[3].

In July 1947 the author returned to Salida to spend two months making a private study of the area. The areal mapping was finished and some of the mine workings restudied. Thin sections and laboratory studies were completed during the winter of 1947-48.

The author wishes to acknowledge the help of the following groups and individuals: The U. S. Geological Survey and the Colorado Metal Mining Fund financed the early work. R. E. Van Alstine, Commodity Geologist for Fluorspar, U. S. Geological Survey, directed the work and later obtained permission from the Director of the Survey for the author to complete the study as a private project. Doak C. Cox, as party chief of Colorado Fluorspar Investigations, directed and assisted in the field work, especially the underground mapping. Tom Steven assisted in the mapping at Poncha Pass.

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3. Russell, R. T., The Poncha Fluorspar Deposits, Chaffee County, Colorado: U. S. Geological Survey Strategic Minerals Investigation, Preliminary Report 3-210, 1947.

CHAPTER II

STRATIGRAPHY

Introduction

Certain rock types played important roles in the origin and development of the Poncha fluorspar deposits. The Salida schist, which is a complex formation, is the country rock around the ore deposits. The specific rock types of this formation which exercised the most control on the ore are described in some detail. The volcanic lavas are the surface evidence for a magma chamber at depth that is thought to have been the original source of the fluorine in the ores. The calcareous tufa represents a recent deposit of the waning ore depositing solutions. The Arkansas formation furnishes the only local clue for dating the ore deposits. Other formations are described only sufficiently to indicate their lithologic character and relationship to the more critical rock types.

Rocks ranging in age from pre-Cambrian to Recent are exposed in the Poncha area. The most extensive rock type is the pre-Combrian Salida schist. Tertiary lavas and terrestrial sediments rank next in order of abundance. Fragments of Lower Paleozoic limestones and quartzites are abundant along certain of the fault zones. At Poncha Hot Springs a deposit of calcareous tufa was forming until the W. P. A. diverted the flow by putting in an underground collecting system.

Table I is a generalized geologic column for the Poncha area. The distribution of the various formations is shown on plate I.

TABLE I

Sequence and Character of Rocks in the Poncha Fluorspar District

Formation	Lithology	Age
Alluvium	Stream gravels, sands, and silts. Unconsolidated.	Recent
Hot Springs tufa	Gray to buff calcareous tufa. Porous, partly cemented, and crudely layered.	
Unconformity		
Terrace and pediment gravels	Large boulders in matrix of sand and gravel. Also gravel composed of volcanic pebbles	Pleistocene
Volcanic gravel	Gravels, predominantly of volcanic rock similar to underlying flows and containing Salida schist fragments	Pleistocene? or Pliocene
Unconformity		
Arkansas formation	Buff to brown sandstones, silts, clay, gravel. Locally gypsiferous and cemented	Pliocene and Miocene
Volcanics	Gray to purple andesite, yellow to red scoria, buff trachyte, and pink rhyolite.	
	(Lower Paleozoic rocks not exposed in place in map area).	
Unconformity		
Salida schist	Granite, schist, and amphibolite.	Pre-Cambrian

The various rock types were studied in thin section and by means of crushed fragments. Indices of refraction and other optical properties were measured whenever possible. The Results of these studies are contained within an appendix to this paper.

Pre- Cambrian

General

The oldest rocks in the area are granite, pegmatite, gneiss, and amphibolite. These rocks are probably a part of the Salida Schists as named by Cross in 1893.[4] The series as described by Cross contains quartzites, meta-sediments, granites, and metadiorite. The geologic map of Colorado, compiled in 1935, shows hornblendite and schists extending, with the exception of a narrow overlap of younger rocks, from east of Salida to Poncha and on to Mt. Ouray. The pre-Cambrian sequence of this area is referred to in this paper as the Salida schist.

Salida Schist

The Salida schist in this area includes granite, amphibolite, diorite pegmatite, schists, and gneiss. Two types of granite are present. Near the Aksarben mine biotite granite is very common. In the southern part of the area a muscovite granite, which is locally intensely sheared, outcrops over wide areas. Amphibolite, schist, and gneiss outcrop over extensive areas in the center of the district. The diorite pegmatite is

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4. Cross, C. W., On a series of peculiar schists near Salida, Colorado: Colo. Sci. Soc. Pr. 4, pp. 286-293, 1893.

invariably associated with the amphibolite.

All of these rock types are metamorphic with the possible exceptions of the diorite pegmatite and the granite. The pegmatite is a massive, coarse rock which shows no structural features. The granite appears massive on a fresh surface, but weathered outcrops exhibit a distinct foliation. The degree of metamorphism of the Salida schist series is that of the Amphibolite facies.[5] The diorite pegmatite, which is the youngest rock in the series, probably falls in the Epidote-Amphibolite facies.[6]

Granite. The most common rock in the Salida schist series at Poncha is a fine-grained granite. Exposures near the Aksarben mine are rough and angular (see plates II and XI). Steep cliffs of granite rise abruptly on either side of the mine portal. Numerous deep clefts which result from the deep weathering of schist bands or fault zones cross the granite in various directions.

In the central part of the area the granite forms rounded ridges or knobs. In sections 22 and 26 zones of brecciated granite form sharp and conspicuous ridges (see plate IV).

In hand specimen the granite from the Aksarben mine appears light gray. The rock is fine-grained. None of the mineral grains are over one

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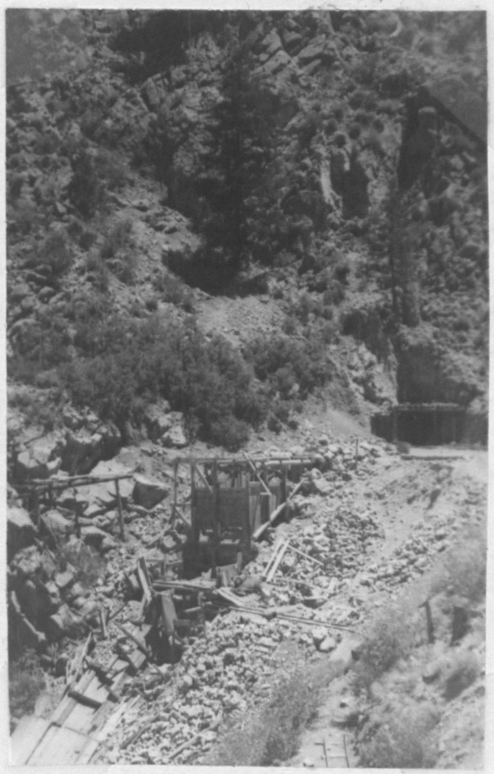
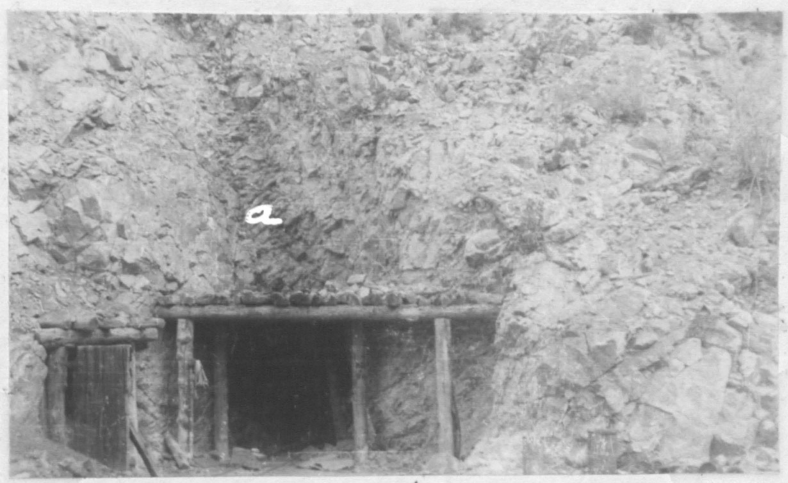
5. Turner, F. J., Mineralogical and Structural Evolution of the Metamorphic Rocks: Geological Society of America Memoir 30, pp. 76-88, 1948.

6. Turner, F. J., Mineralogical and Structural Evolution of the Metamorphic Rocks; Geological Society of America Memoir 30, pp. 88-92, 1948.



A. Aksarben Mine. Upper portal and Loading bin.



B. Aksarben Mine. Shear zone (a) at upper portal.

tenth of an inch in diameter, and the average size would be about half of that. The dark mineral, biotite, is aligned in planes giving the rock a foliated appearance. This is much more apparent in weathered outcrops than in fresh specimens. The light-colored minerals are gray to white feldspar and quartz.

The granite from the Divide mine is light gray to white. Most of the mineral grains are too small to be distinguished in a hand specimen.

Amphibolite. Amphibolite is a fairly common rock type in the central part of the area. In both the southern and northern parts of the area, large bands of amphibolite alternate with the lighter-colored granite (see plate V). In hand specimen the amphibolite is dark green. Some of it contains thin bands or scattered patches of white plagioclase.

Augen Gneiss. There is a small area of augen gneiss west of the Aksarben mine. Exposures exhibit a crude banding of light and dark layers. Large white augen 3/4 to 1 1/4 inches long are scattered along the light bands. Some of the banding bends around the augen while other bands are intersected by the augen.

Schistose Rocks. Many types of schistose rocks are found in the Poncha area. Numerous blocks of schist are exposed in the wide fault zone just north of the Aksarben mine. In the southern part of the area, several schistose rocks form prominent bands near the highway but can be traced for only a short distance along the strike. The rock types are coarse quartz-mica schist, fine-grained mica schist, and a narrow band of fuchsite-mica schist interbedded among the other schists. None persists over a large enough area to be mapped as an individual unit. Lack of

A. Aksarben Mine. Entrance to lower workings.

B. Poncha shear zone (F_1) exposed in cut on road leading to lower Aksarben adit.

exposures in critical areas plus displacement along large shear zones makes it impossible to figure out a regional pattern or structural trend for these rocks.

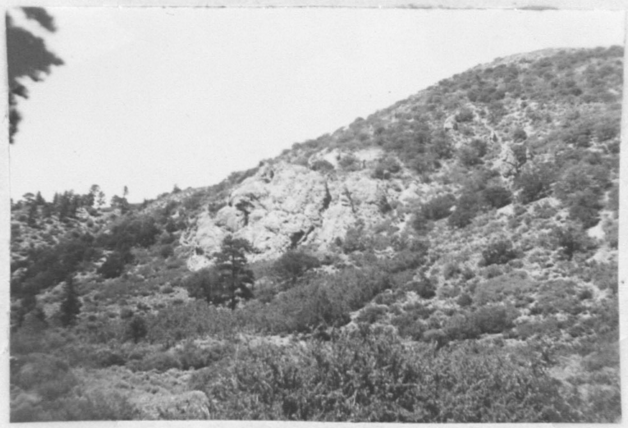
Paleozoic Rocks

There are no exposed Paleozoic rocks within the map area. A thin sequence of Lower Paleozoic rocks followed by a thick Upper Paleozoic sequence exists near-by. East of Salida such a series rests unconformably on the Salida schists. West of the area similar sediments rest on the pre-Cambrian. There is good reason to believe that Paleozoic rocks once covered the map area. Several rock types which are characteristic of the Lower Paleozoic have been identified as forming the bulk of several large fault breccias exposed along Little Cochetopa Creek. The surface rocks along this creek are late Tertiary. The pre-Tertiary rocks forming the floor of the Salida basin may be in part Paleozoic.

Tertiary

Igneous

The Tertiary igneous rocks in the Poncha area, which range in composition from porphyritic basalt through andesite and trachyte to rhyolite, consist of a series of lava flows and one dike. The trachytes are lighter colored and are more vesicular than the andesites. They are found at the northwestern end of a narrow belt of lavas, but a few are associated with the andesites in the central portion of the belt. The rhyolite is limited to one dike a short distance south of the Aksarben mine. This rhyolite



A. Outcrop of silicified breccia.

B. Detail of silicified breccia.

is about 2 miles from the nearest volcanic rocks.

A narrow belt of lava flows extends from the Arkansas Valley to Mear's Junction (see plates I and VI). South of this point the volcanic rocks are in widely scattered patches which extend south and west of the Divide mine into the San Luis Valley (see plate I). A railroad cut between Mear's Junction and Poncha Pass exposes a small area of volcanic agglomerate.

The color, texture, and internal structural features of the volcanic rocks exhibit wide variety. These rocks are generally dark gray; however, they may be purple, reddish orange, or yellowish tan. The color is closely related to the texture and structure of the rocks. The central parts are massive and the tops of the flows are typically scoriaceous or amygdaloidal and are characterized by the brighter colors mentioned above.

Sedimentary Rocks

Arkansas Formation. The belt of fine gravel, sand, and minor amounts of clay, 1 to 2 miles wide, that is exposed across the northern part of this area is called, in this paper, the Arkansas formation. Along the western edge of the area, the Arkansas formation swings south and abuts against or inter-tongues with volcanic gravels. A recent study of the Arkansas Basin by Powers[7] has dated the Arkansas formation as Pliocene. The age determination was made by Dr. Alfred Romer of Harvard University

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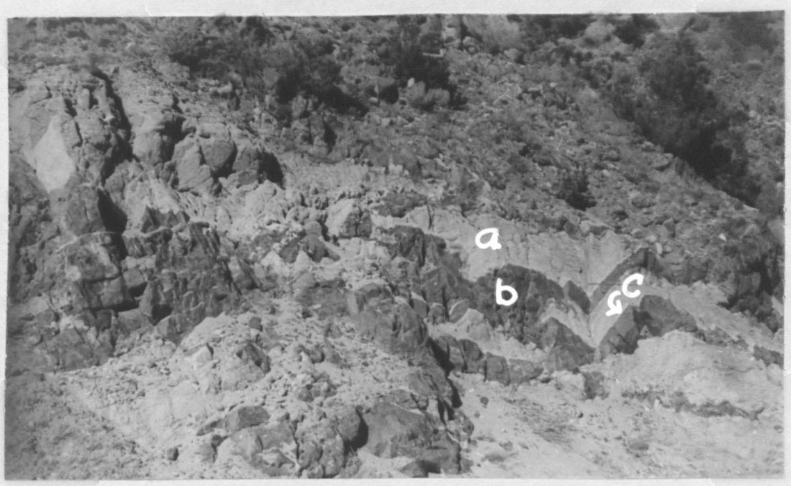
7. Powers, W. E., Physiographic history of the Upper Arkansas River Valley and the Royal Gorge, Colorado: Jour. Geol. Vol. 43, No. 2, pp. 184-199, 1935.

A. Amphibolite intruded by granite.



B. Granite (a) Amphibolite (b) and
light contact zone (c).

and was based on a molar of Pliohippus lerdyannus and an astragalus of an unidentified camel. This formation is, in the main, uncemented, but a few gravel beds are cemented with calcium carbonate.

The lithology varies from one place to another. Along Highway 287 just south of Poncha, the Arkansas formation consists of gravel, sand, and silt (see plate VII). In a roadcut a short distance north of the map area, the formation is mostly gravel, one half to two inches in diameter, with lesser amounts of sand. Northeast of Poncha Peak erosion has produced high cliffs of this formation that are predominantly silty sand (see plate VII). The reentrant just north of Cleveland Peak consists predominantly of Arkansas silts and clays which have eroded to produce several acres of badlands. Exposures of this type continue west to the mouth of Little Cochetopa Creek. A short distance up the creek, to the south, volcanic gravels cover the Arkansas formation. No volcanic pebbles were found in this formation, which indicates that the Arkansas formation is probably older than the volcanic gravels.

The great variation in lithology plus the limited area studied make it impossible to postulate a source for these sediments. They appear to be basin sediments whose source was not in the immediate vicinity.

Quaternary

Pleistocene

The Pleistocene beds in the Arkansas Valley are coarse gravels that cap the Pliocene sediments. In some instances the contact between the two is an angular unconformity (see plate VII). In the Poncha Area these

A. Outcrop of Andesite.

gravels have a maximum thickness of about thirty feet.

The areal extent of the Pleistocene is similar to but less than the Pliocene. The Pleistocene gravels were deposited on the eroded surfaces formed during the erosion of the Pliocene beds. Dissection of the basin took place in seven stages starting in the late Pliocene and continuing to the present. Each stage is represented by a pediment or a terrace. Only the higher surfaces, which are glacial and possibly pre-glacial, have a cap of coarse gravel. The lower, post-Pleistocene terraces have recent river gravels of much smaller size on their surfaces.

The material making up the Pleistocene deposits gives every indication of coming from a local source. The beds are coarse, uncemented, and unsorted, and they consist of boulders, 1 to 2 feet in diameter, which rest in a matrix of gravel, sand, and silt. The more resistant rock types form angular boulders. These angular boulders are of types of rock which are common in the near-by pre-Cambrian areas. They include amphibolite, quartzite, granite, schist, and augen gneiss. A portion of one of the surfaces of a high terrace has the shape of an alluvial fan, which indicates a local source for that deposit.

Recent

The Recent sediments are made up of alluvium along the permanent and the intermittent streams and of hot springs deposits of calcareous tufa. Most of the alluvium along the streams in this area is in bands too narrow to map. However, the South Fork of the Arkansas River has a wide flood plain of recent origin. This flood plain, which is extensively cultivated,

A. Arkansas formation overlain unconformably by coarse Pleistocene gravels.

B. Arkansas Formation.

consists of silt and loam. The alluvium along the smaller streams is coarse sand and fine gravel. The deposits of calcareous tufa will be discussed at length in the section dealing with the origin of the ores.

TABLE II ANALYSES OF HOT SPRING WATERS

	Poncha[1,2] 4714	Poncha[3] 174	Poncha[3] 175	Poncha[3] 176	Poncha[3] 177	Poncha[3] 178	Brown's Canyon[2] 4712	Brown's Canyon[2] 4713	Ojo Caliente[4]	Wagon Wheel Gap[5] 1	Wagon Wheel Gap[5] 2	Wagon Wheel Gap[5] 3
SiO_2	83.	54.1	81.2	80.3	77.1	15.4	42.0	38.0	60.2		84.	73.
Fe	0.05						0.17	0.04		3.	2.	1.
Ca	17.0	19.7	20.4	17.7	22.2	34.8	7.6	7.9	22.8	46.	66.	17.
Mg	0.9	2.7	3.3	2.3	2.7	8.7	0.7	1.8	9.5	53.	15.	15.
Na	194.0	180.5	166.0	174.5	163.7	12.8	158.0	151.0	995.7	347.	393.	360.
K	8.0	16.5	36.5	21.0	43.2	4.0	6.8	4.8	34.1	52.	133.	156.
CO_3							4.9	4.9	2153.5	582.	353.	431.
HCO_3	215.0	223.1	235.4	220.9	221.3	143.5	128.0	127.0				
SO_4	204.0	207.4	197.3	198.7	215.5	25.7	141.0	142.0	151.0	161.	457.	135.
Cl	51.0	54.7	54.7	54.7	54.7	10.3	55.0	53.0	231.4	66.	195.	210.
F	12.0						15.0	13.0	5.2			
NO_3	0.1											
BO_3	0.2						0.3	0.3				
B_4O_7									4.2			
PO_4									0.2			
Li									3.4	8.	11.	9.
Sr									1.4			
Fe_2O_3 Al_2O_3		1.7	3.5	4.2	4.2	2.6						
Total ppm.	676	760.4	7983	774.3	804.6	257.8	494	479	3671.4	1320.	1710.	1470.
Properties a	44.5	49.49	42.80	43.67	42.54	10.38	47.2	45.8	34.8	34.4	41.4	45.5
b	4.8	6.51	6.73	5.74	6.89	38.68	2.5	3.7	1.5	13.9	8.5	4.5
d	32.6	30.78	29.76	30.53	31.19	12.98	35.3	35.1	7.7	10.9	28.1	18.9
Class	I	I	I	I	I	III	I	I	I	I	I	I
Primary salinity	65.2	61.56	59.52	61.06	62.38	20.76	70.6	70.2	15.5	21.8	56.2	37.8
Secondary salinity						5.2						
Primary alkalinity	23.8	25.42	26.08	26.28	22.70		23.8	21.5	54.2	47.0	26.6	53.2
Secondary alkalinity	9.6	13.02	13.46	11.48	13.78	72.16	5.0	7.4	3.0	27.8	17.0	-- 9.0

1 References on next page

TABLE II

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3. George, R. D., and others, Mineral waters of Colorado: Colorado Geol. Survey Bull. 11, pp. 402-406, 1920.

4. Lindgren, Waldemar, The hot springs of Ojo Caliente and their deposits: Econ. Geol., Vol. 5, pp. 22-27, 1910.

5. Emmons, W. H., and Larsen, E. S., The hot springs and the mineral deposits of Wagon Wheel Gap, Colorado: Econ. Geol., Vol. 8, pp. 235-246, 1913.

CHAPTER III

AREAL GEOLOGY

General

The areal geology of the Poncha area including the structural geology, physiography, and geologic history, provides the necessary geologic setting for the fluorspar deposits. Pre-Cambrian history saw the formation of the country rock in which these deposits lie. The Tertiary to Recent history saw the formation of the ores. Faulting provided structural control. Lavas indicate a convenient magmatic source for fluorine. The Pliocene to Recent sediments provide an inadequate but the only means of dating the ores.

The relationship of the Poncha area to the surrounding physiographic divisions is shown on figure 1. Only three of these divisions extend into the area mapped. The Arkansas Valley forms the northern edge of the map, and the head of the San Luis Valley lies within the southern part of the map area. Physiographically the deeply dissected volcanic gravels which form the southwestern part of the area are a continuation of the San Luis Valley. The pre-Cambrian rocks which form the central part of the eastern half of the map area are a northwestward extention of the Sangre de Cristo Mountains.

The Poncha area contains rugged peaks and broad valleys. Poncha Peak and Cleveland Peak rise to about 10,500 feet in elevation. The elevation of the South Arkansas River, 2 miles to the north, is about 7150 feet. Both of the peaks have very steep slopes. Poncha Creek has cut a V-shaped gorge between the two peaks (see plate VIII). The Pre-

Plate A view from Poncha Peak looking southwest. A, Mt. Ouray. B, Marshall Pass. C, Surface developed on volcanic gravels northwest of Mear's Junction. D, West side of Poncha Creek gorge. E, Poncha Creek. F, Poncha Pass.

Cambrian terrain between Poncha Peak, the Divide mine, and the eastern edge of the map is deeply dissected by numerous streams. The Arkansas Valley consists of a series of pediments and terraces which descend step-like to the South Arkansas River; the higher pediment surfaces are deeply dissected. To the south the pre-Cambrian section descends rather abruptly to the broad, flat San Luis Valley.

Pre-Cambrian

The pre-Cambrian history of the area begins with the deposition of a series of sedimentary rocks. Following deposition of these sediments, the area was metamorphosed, and granitic igneous rocks were formed. Regional metamorphism converted the sediments into mica schist, augen gneiss, and amphibolite.

Following metamorphism extensive faulting broke up the area. The result is an apparently unrelated jumble of various types of metamorphic rocks. Large silicified breccia zones formed at this time and now stand out as prominent ridges. The pre-Cambrian rocks rise as a rugged, resistant mass above the surrounding areas.

Paleozoic and Mesozoic

The Paleozoic and Mesozoic record is missing near Poncha but can be pieced together from evidence gathered in near-by areas. Good Paleozoic sections are found at Monarch Pass, the area east of Salida, and along the Arkansas River southeast of Salida. Mesozoic rocks are not known in the immediate map area but are known in the Sangre de Cristo Mountains to the southeast.

Tertiary

The Tertiary record is incomplete. Subsequent to the probable deposition of Cretaceous and early Miocene sediments, the area was uplifted and deeply eroded. Most of the Mesozoic and Paleozoic rocks that were present were removed from the Poncha area. The axis of the uplift which brought about the removal of these sediments was approximately the center of the present Arkansas Valley from Poncha to Leadville. At the present time numerous patches of Paleozoic rocks may be found in the mountains on either side of this valley, but pre-Cambrian rocks crop out along the edge of the valley. It is possible that some Paleozoic and Mesozoic rocks are beneath the Tertiary sediments in the central portions of the Arkansas Valley.

Extensive faulting accompanied and/or followed the early Tertiary uplift and erosion. It continued until after the deposition of the Arkansas formation but ceased before the Pleistocene. In middle Miocene times the present Arkansas Basin was depressed relative to the surrounding country, and the Arkansas formation was deposited throughout much of Pliocene time. Faults in the Poncha area are related to the down-dropping of the Arkansas River Basin and probably to the uplift of the surrounding mountains. It is not possible to do more than give a relative age for these faults.

The Arkansas Basin joins the rugged pre-Cambrian area at the base of a very prominent scarp. This scarp is a fault zone (F_1 on plate I) which has the greatest width and perhaps the greatest displacement of any in the area. It is referred to in this paper as the Poncha shear zone. This fault trends roughly east and has been offset by several north-trending faults (F_5 and F_6). Its most important and widest exposure, over one thousand feet, is along the road from the hot springs to the Aksarben fluorspar mine (see plate III). Exposures are not continuous across the entire zone, but they are close enough together to indicate a single wide shear zone. The northernmost exposures are along roads leading from Highway 285 to the hot springs. These exposures continue intermittently along both the roads leading up the hill to the fluorspar mine. In all cases the shear zone is capped by gravels and is visible only in deep cuts. Soft, crumbly, easily weathered gouge, white to light-gray in color, is found in the shear zone. Within this gouge are patches ten to twenty feet wide either of brecciated granite or amphibolite or of highly sheared schists and augen gneisses. This results in a very incompetent mass that erodes easily. The Poncha shear zone must have a vertical displacement of several thousand feet, but it is impossible to measure the exact amount.

A fault (F_2 on plate I) follows along the west side of Little Cochetopa Creek. Another one (F_3) parallels it about one half mile to the east. These two faults are referred to as the Little Cochetopa Creek fault system. The longest of these two faults (F_2) outcrops one half mile south of the South Fork of the Arkansas River and about four hundred feet west of the road that follows Little Cochetopa Creek. This fault continues southward parallel to the creek for about 2 miles where it is lost under a cover of gravels. It outcrops as a resistant mass of breccia which projects above the more easily eroded silts, clays, and gravels which are on either side of it. The rock types which make up the breccia are Lower Paleozoic in age and include the Cambrian Sawatch quartzite; the Manitou limestone, Harding sandstone, and Fremont limestone of Ordovician age; the Parting quartzite and overlying limestones of Devonian age; and the Mississippian Leadville limestone. The breccia fragments contain no recognizable fossils, but their identity was tentatively determined on the basis of lithology. These two faults are part of the post-basin-filling deformation of the Poncha area. They indicate that Paleozoic sediments underlie the Arkansas formation at Little Cochetopa Creek.

The pre-Cambrian rocks along the northern part of Poncha Creek are sheared and fractured. The deformation becomes less intense away from the creek. As a result the exact boundary of this fault zone is doubtful, but its approximate center line is shown on plate I as F_6. This fault, at its northern end, offsets the Tertiary-pre-Cambrian contact, thus indicating that it is late Pliocene in age.

Another Tertiary shear zone (F_7) contains the ore deposits at the Aksarben mine. It is cut off by the Poncha shear zone to the north and dies out a short distance south of the mine. This shear zone will be discussed in detail in connection with the structure and origin of the ore deposits.

The physiographic development of the Arkansas Basin has been out-lined by Powers.[8] In late Pliocene time valley filling ceased and uplift and faulting initiated a series of erosion surfaces (see plate IX). These developed as unconformable gravel caps throughout the Pleistocene and into the Recent. Their age has been determined by the relationship of these surfaces to glacial moraines and outwash along the eastern edge of the Sawatch Range.

The surfaces include both terraces and pediments. The younger surfaces are terraces along the present Arkansas River and its major tributary, the South Fork of the Arkansas River. The higher and older surfaces are pediments which have a surface slope of one to four degrees toward the center of the valley. In the map area only four of the seven surfaces recognized by Powers are present.

The fourth and highest pediment surface in the Poncha area probably corresponds to Powers' number 6. This surface consists of coarse boulders of pre-Cambrian gneiss which rest unconformably on Pliocene sediments. Along most of the northern edge of the map, this pediment laps up against the pre-Cambrian rocks. The Aksarben fluorspar mine is just south of the contact of this pediment with the pre-Cambrian, and the Poncha Hot Springs are just within the northern edge of this pediment.

In surrounding areas, which include the San Juan Mountains to the south and Brown's Canyon to the north, igneous activity took place and probably continued throughout the Tertiary. At Poncha Pass and north to

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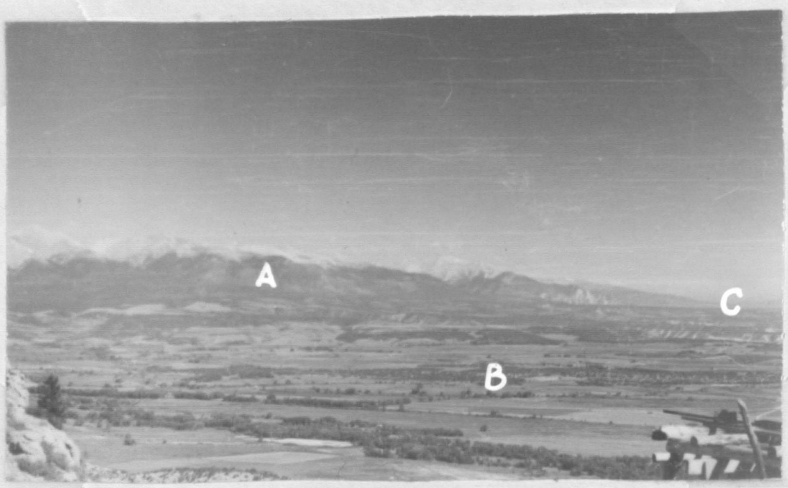
8. Powers, W. E., Physiographic history of the Upper Arkansas River Valley and the Royal Gorge, Colorado, Jour. Geology, Vol. 43, No. 2, pp. 184-199, 1935

Mear's Junction, andesite rests horizontally on the pre-Cambrian gneiss. North of Mear's Junction a belt of volcanic rocks cuts across the map area separating the pre-Cambrian rocks from the Tertiary sediments. These volcanics are dated as early Miocene or older; this is the same age as is given to the volcanic rocks of the San Juan Mountains 10 miles to the southwest. The northernmost outcrop of the lavas appears to dip under the Arkansas formation, so that the lavas of this area are all pre-Arkansas Basin filling.

The contact of the northern andesite mass with the Salida schist is approximately vertical. This steepening of the schist-andesite contact was probably accompanied by faulting. Although no fault planes were discovered here during the field work, an inferred fault (F_4) is mapped, as it gives the most satisfactory explanation of this contact.

The southern end of the map area lies within the extreme northern section of the San Luis Valley (see plate X). Here San Luis Creek enters the valley from the pre-Cambrian hills to the northeast. Everything south of the Divide mine and Poncha Pass plus much of the area of volcanic gravels that is west of Mear's Junction is included in the San Luis Valley. This wide, broad valley rises rather steeply at its northeastern end. The edge of the valley, in the vicinity of the Divide mine, is an escarpment that rises steeply to the rugged pre-Cambrian area to the north. However, at its northwestern edge, the floor of the San Luis Valley continues to rise to the north from Poncha Pass on a bench consisting of the surface of the volcanic gravels, and it is also identified on shoulders which rise northward on either side of the Poncha Creek gorge (see plate VIII). The

A. Eroded volcanic gravels west of Mear's Junction



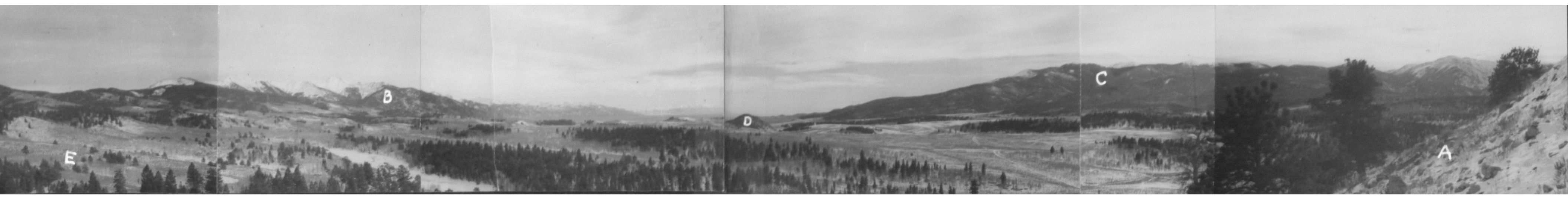
B. View looking north from the Aksarben mine.
A, Sawatch Mts., B, Arkansas Basin, C,
North extention of basin toward Leadville
and Mosquite Range on right.

Plate X

Panoramic view of the San Luis Valley looking southward from the Divide Mine.

A. Hillside at Divide mine, B Sangre De Christo Mts.

C. San Juan Mts., D Round Hill, a patch of volcanic rock in the center of the San Luis Valley, E. Pre-Cambrian floor of the northern end of the valley



E
B
D
C
A

small patch of volcanic gravel in the northwest corner of section 33 lies on this bench. West of Cleveland Peak the volcanic gravels are too highly dissected to trace the further continuation of this valley surface (see plate IX). At this point the San Luis Valley surface has been extended northward to within 3 miles of the Arkansas Basin and to a point about 2500 feet above the present floor of that basin.

The volcanic gravels, which locally contain large amounts of Salida schist boulders, are probably late Pliocene or Pleistocene in age. They overlap the Arkansas formation west of Cleveland Peak and appear to have been derived from the southwest.

CHAPTER IV

DESCRIPTION OF FLUORSPAR DEPOSITS

Aksarben Mine

The Aksarben mine is on the north slope of Poncha Peak just above the highest pediment surface. A dirt road connects both the upper and lower mine workings with the Poncha Hot Springs (see plates I, II & III). Part way up the hillside the road forks. Each fork leads to a part of the mine workings.

The hillside above the mine workings is dotted with prospect pits (see plate XI). Some of the pits were dug as discovery holes for the claims which were located south of the Aksarben property. None of the pits had a good enough showing of ore to encourage further work on the surface. These pits are along a swarm of small fluorspar veins which trends S.40°E. to S.60°E. up the hillside from the mine workings. They follow the northeast side of a deep gully. The individual fluorspar veins are very narrow and do not persist for any great length. The gully may indicate the center of a crushed zone along which the fluorspar deposits are localized. The area has an extensive covering of talus, especially along the lower side of the gully, which obscures much of the geology.

The underground workings of the Aksarben mine can be divided into two groups. The upper workings are the oldest and the most extensive. Ore was mined from one level of the upper workings, and exploratory work was undertaken on two other levels. The lower working is more recent and, when the field examination was completed, it consisted only of development work.

Upper Workings

The upper workings of the Aksarben mine consist of three levels (see plate XII). All three levels are reached by an adit at elevation 8395 feet. There are two entrances separated by a few feet of rock. At one time two sets of leasors operated the mine, and each group drove its adit. The southwestern drift (see plate XII) continues in a southeasterly direction for a distance of about 150 feet. Caving ground was encountered at the southeast end of the drift causing it to be abandoned. According to reports of several miners, the workings did not continue very far beyond the face of the cave-in. Several side workings have caved. About mid-way along the adit, an incline on the southwest side goes down to a lower level.

The northeast drift has a cave-in about one hundred feet from the entrance that conceals about sixty feet of the drift. Just beyond this cave-in is a stope about one hundred feet long. Halfway along the stope a two-compartment internal shaft extends down from the adit level to two lower levels. Two hundred feet beyond a crosscut from the southwest adit (see plate XII), the northeast drift is again caved. The workings are reported to extend about 180 feet beyond this cave-in. In this caved portion of the drift several ore bodies 2 to 4 feet wide were reported, but no large stopes were developed. One hundred feet southeast of the crosscut there is another large stope developed above this level.

The second or incline level may be reached by crosscut from the bottom of the incline from the internal shaft. This level is only 27 feet below the adit level. The drift at this level follows the ore zone for about 250 feet. Ore was obtained here from the vein as it was exposed in the drift and in two small stopes. Between the crosscut from the incline and the internal shaft, another crosscut was extended 35 feet to the northeast to explore more fully the complete width of the shear zone at this depth.

The third or shaft level, at the bottom of the shaft, is about fifty feet below the adit level. A drift was driven toward the south at this depth for a distance of about seventy feet. This exploratory level is about 22 feet below the second level. It has no stopes, and any ore produced came from the drift.

Lower Working

The lower working is reached by a branch of the access road. This adit is about two hundred feet lower than the lowest of the upper workings. It is driven, for about 350 feet, entirely in granite parallel to the ore vein which is northeast of it. Two crosscuts were driven east from the adit until they intersected the vein. Both crosscuts were caved when the mine was first visited.

In 1947 a new group of operators took over the property and began operation on the lower adit level. They backfilled the adit between the two crosscuts with muck. They extended the first crosscut across the full width of the vein, a distance of approximately 12 feet. A rise was started in the granite on the northeast side of the vein. The walls and back are heavily timbered, so that it is impossible to determine the dip or strike of the vein at this point.

Divide Mine

The Divide Property is reached by a dirt road that leaves the main highway about a mile north of Poncha Pass (see plates I, XIII, and XIV). The mine workings include an open cut, two small adits with caved shafts, and several small pits. The open cut produced most of the ore from the Divide mine. This cut has three branching trenches (see fig. 2) from 6-10 feet deep. Surrounding these trenches is an area from which all the overburden has been stripped.

Adit number 1 has a simple plan (see fig. 3). A short distance from the portal, it splits into two branches. There are no stopes or other evidences of extensive mining.

Adit number 2 is more extensive (see fig. 4). A short distance in from the portal, a small room was started on the south side. At the west end of the adit there is a small room and a stope. A northward extension of the workings encountered at least one pocket of ore. West from this extension, a caved portion of the tunnel continues for at least another 25 feet. No information could be obtained as to whether it encountered any ore.

During 1945 several bulldozer trenches were cut diagonally down the hillside immediately below the mine workings. In most cases the trenches just got to the bottom of the talus and soil. Very little bed rock was exposed, and almost no fluorspar was found that could be proved to be in place.

A. Divide Mine. General vein.

B. Divide Mine. Open cut.

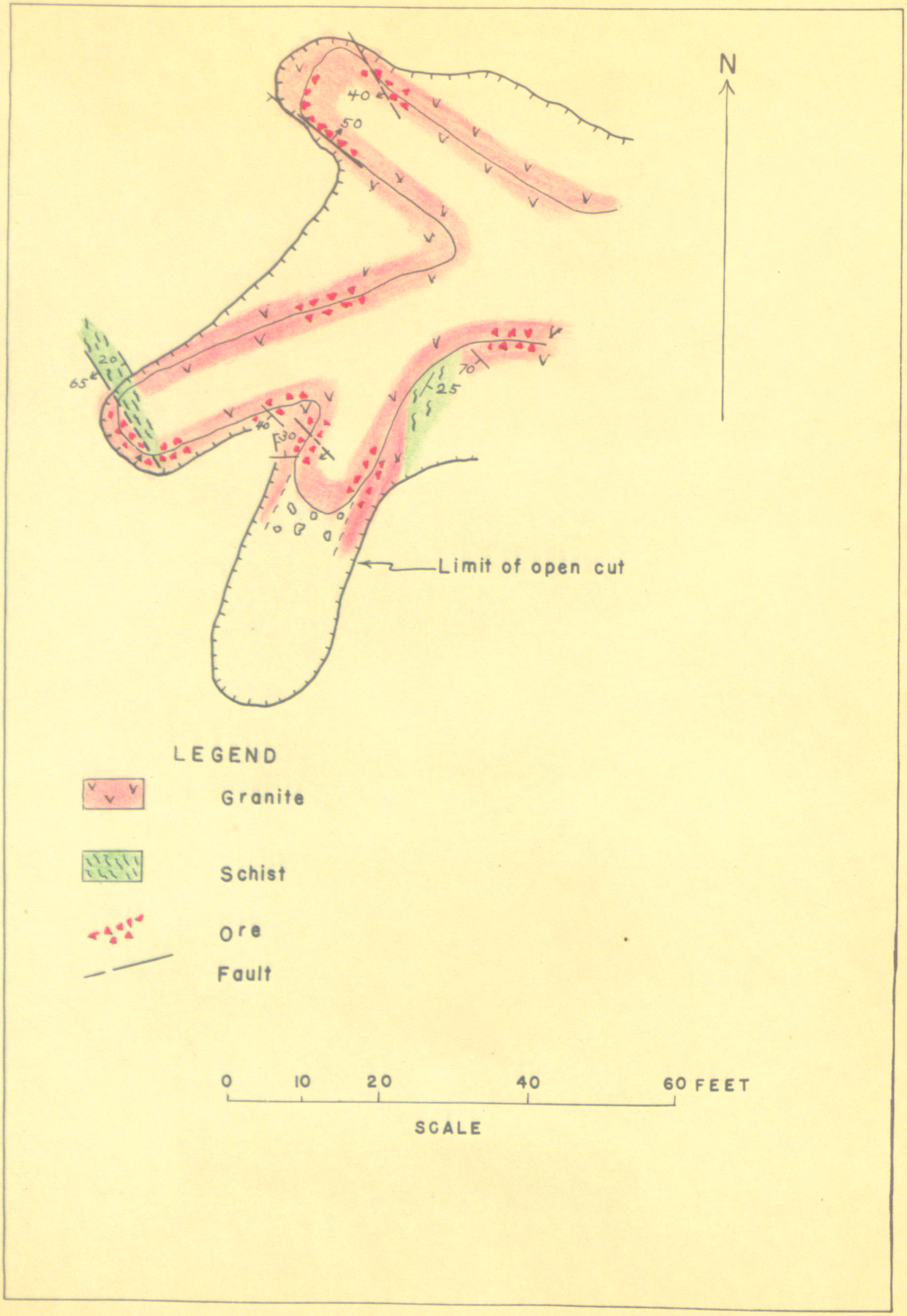


FIG. 2 DIVIDE MINE, OPEN CUT

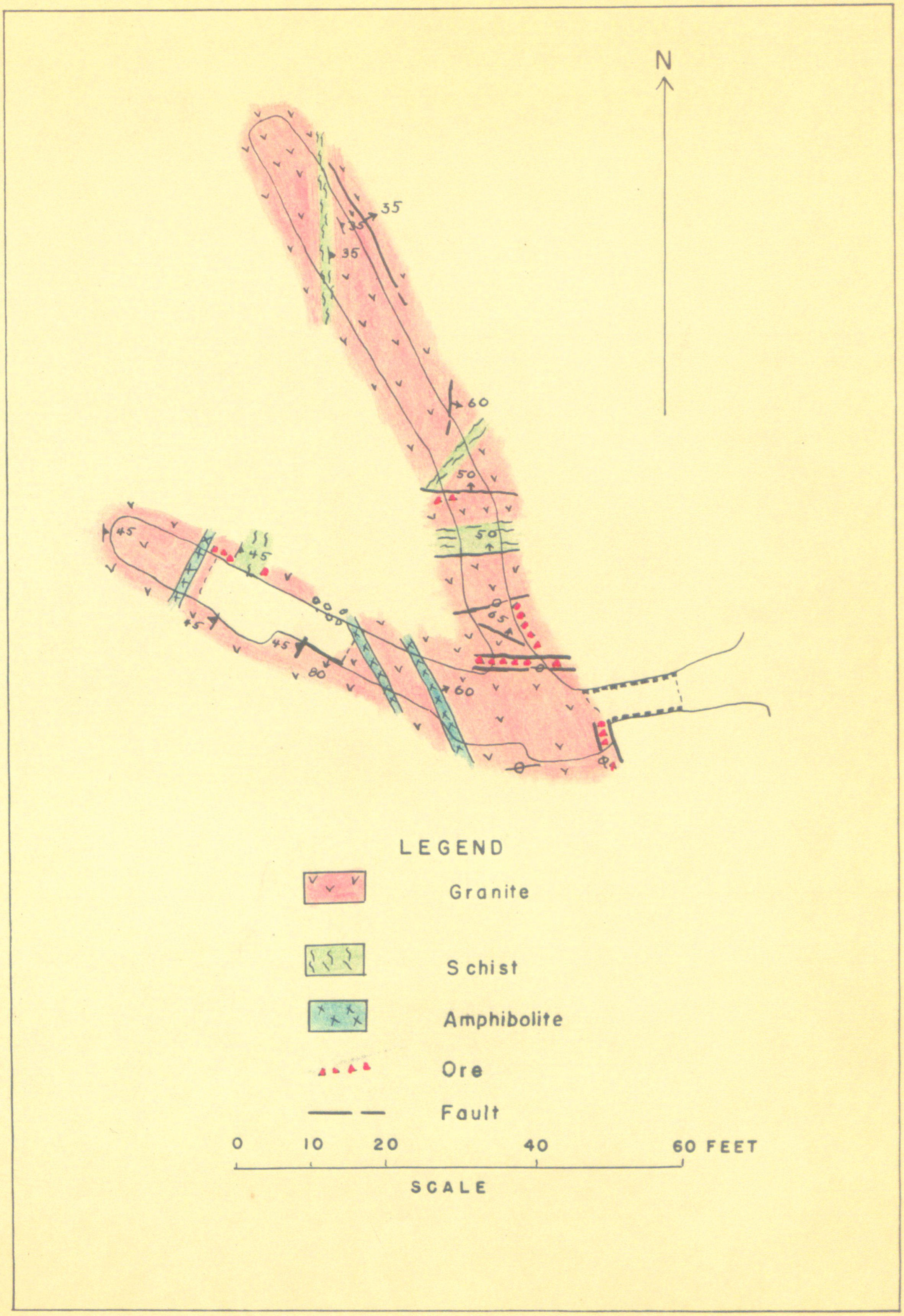


FIG. 3 DIVIDE MINE, ADIT NO. 1

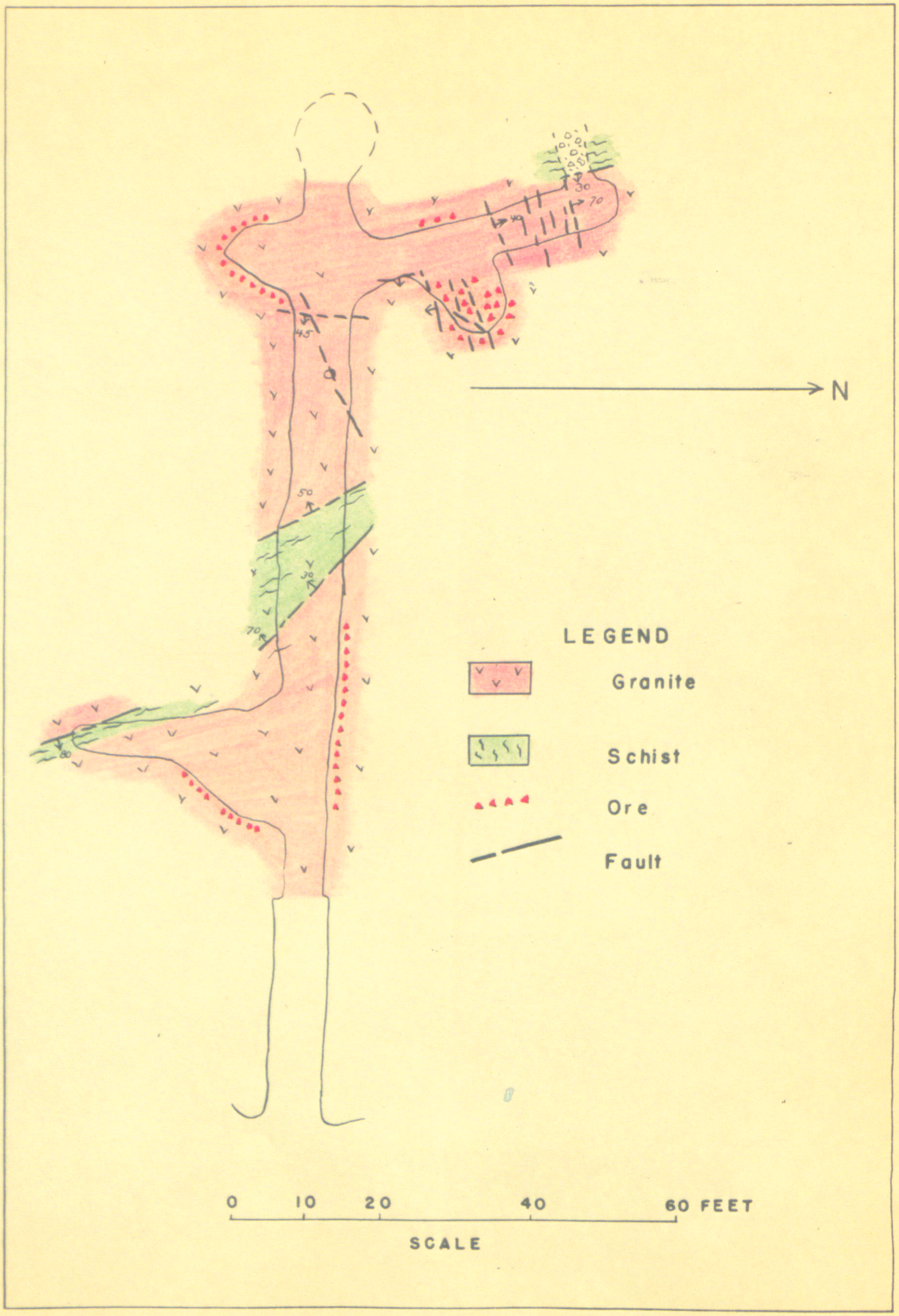


FIG. 4 DIVIDE MINE, ADIT NO. 2

CHAPTER V

MINERALOGY

General

The terms fluorite, fluorspar, and fluorspar ore need to be defined to prevent confusion. Fluorite is a mineralogical term that designates naturally-formed calcium fluoride, which has the chemical composition CaF_2 and definite physical, chemical, and optical properties. In this paper the term fluorite will be used whenever the various properties mentioned above are discussed.

The term fluorspar, a general term, will be used to designate the ore mined or the mill concentrates which contain the mineral fluorite. The term also includes the mineral aggregate which is mined or could be mined for its fluorite content.

Fluorspar ore is fluorite-bearing material that can be mined with profit. The term ore is used because fluorspar is a natural product which is extracted at a profit. The policy of using the word ore only for metallic products is rejected, because there is no good equivalent term for non-metallic substances. Therefore the meaning of ore is expanded to include non-metallic substances that are mined at a profit. In order to be mined at a profit in the Poncha area, fluorspar ore must contain at least 30 per cent CaF_2, and the vein should be at least 30 inches wide and have considerable vertical and lateral extent.

Fluorite, calcium fluoride (CaF_2), is a non-metallic, glassy mineral composed of 51.1 percent of calcium and 48.9 percent of fluorine. It crystallizes in the isometric system, generally in cubes, but octahedra are not uncommon. Good crystals are not common, and the usual mode of occurence is as massive or fibrous fluorite.

Well crystallized fluorite has perfect octahedral cleavage. The mineral is brittle and fractures across cleavage planes on uneven, splintery, or conchoidal surfaces. Its characteristic colors are white, blue, purple, and aquamarine. Massive fluorite is commonly white or a pale color, while the deeper colors are generally limited to the better developed crystals. Transparent or translucent varieties have a vitreous luster; opaque varieties have a glistening to dull luster.

Fluorite has a hardness of 4.0. It is one of the heavier nonmetallic minerals, having a specific gravity of 3.017 to 3.357 with an average of about 3.183. The mineral weighs about 198.5 pounds per cubic foot and has a volume of about 10 cubic feet per ton. Fluorspar ore has a lower specific gravity, owing to its inclusion of lighter rock-forming minerals and to the common presence of voids. Its volume usually ranges from 11 to 12 cubic feet per ton.

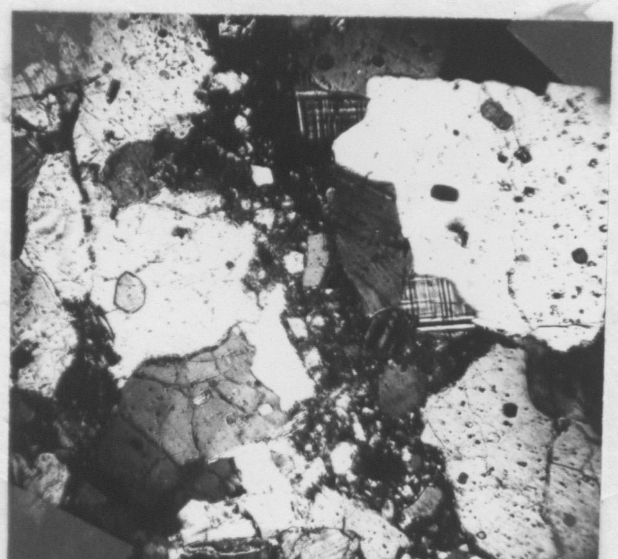
Most fluorite is luminescent when heated and glows with a blue or green light, but this luminescent color is not related to the color of the original specimen. On heating it also decrepitates or bursts into small pieces with a crackling noise. Before the blowpipe fluorite colors the flame reddish yellow, and when heated to 1387°C it fuses to an enamel that has an alkaline reaction with turmeric paper. Fluorite has a low index of refraction which ranges from 1.4339 to 1.4342 for sodium light. Fluorite is a nonconductor of electricity. It is highly insoluble in pure water but is attacked by strong acids and alkaline waters.

Fluorspar Ore

The descriptions of the fluorspar ore and its paragenesis are taken mainly from the Divide mine. The same relations, but on a larger scale, exist at the Aksarben mine. The Aksarben ore is too loose and friable to study in thin section. The Aksarben ore fills small and large fractures in the granite in a manner similar to that exhibited in the thin sections of the Divide ore.

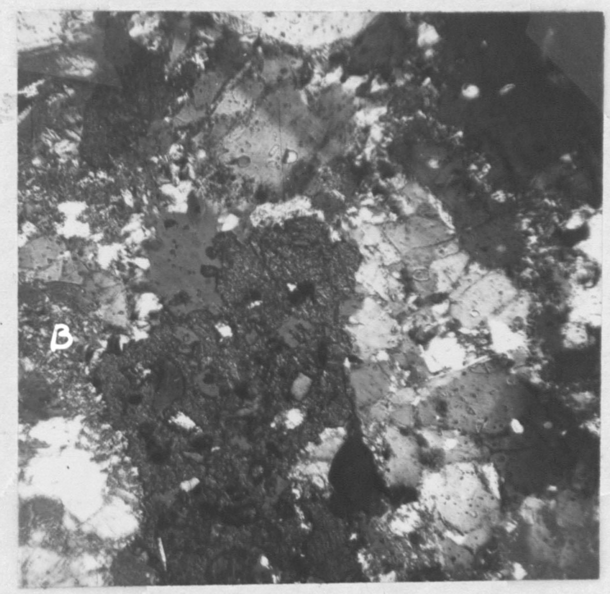
The country rock, in which the ore formed, is a fine-grained granite (see plate XV). Shortly before and during fluorspar mineralization, this rock was brecciated. The megascopic aspects of this are described elsewhere. The brecciation was also microscopic (see plate XV). This micro-brecciation crossed the granite in various directions and provided channels for the ore solutions. Fluorite was deposited in these cracks. In some instances the fluorite filled open spaces; elsewhere it replaced the gouge. This process is well illustrated in plates XVI, XVII, and XVIII. When large areas of fluorite are present, the unreplaced rock fragments are angular. The fluorite has replaced the gouge but only slightly attacked the larger rock fragments. Gouge replacement can explain how some fragments of rock are completely surrounded by a band of radiating fluorite. The fluorite, in this latter instance, is fibrous and oriented perpendicular to the rock core. It is uniform in thickness and appears to have developed uniformly and simultaneously. The enclosing gouge, which supported and separated numerous rock fragments, was porous enough to allow solutions to completely surround its fragments. The fluorspar crust grew outward replacing the breccia as it grew. The end product is a lot of rock separated by one quarter to one half inch

A. Slide No. 62. Breccia veinlet in granite.
x nicols. x 46.5 .



B. Slide No. 60. Brecia veinlet in granite.
x nicols. x 46.5 .

A. Slide No. 60. Fluorite (F) replacing gouge along a breccia veinlet. Large breccia fragments (B) have not been replaced. Plain light. x 46.5 .



B. Slide No. 60. Same as A. x nicols. Note fine gouge (B) along edge of fluorite. x 46.5 .

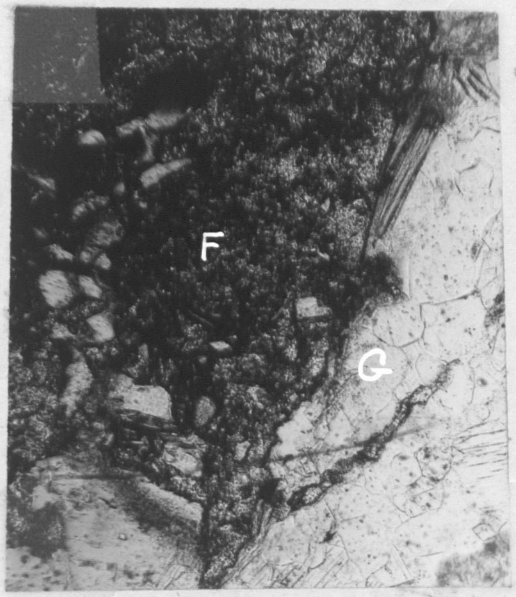
of fluorite. A good example of the results of this process is found in one of the veins on the Divide property.

Chalcedony is associated with some of the fluorspar but is very erratic in its distribution. Most of the chalcedony forms bands parallel to the surface it is coating. Most of the chalcedony lines cavities (see plate XIX).

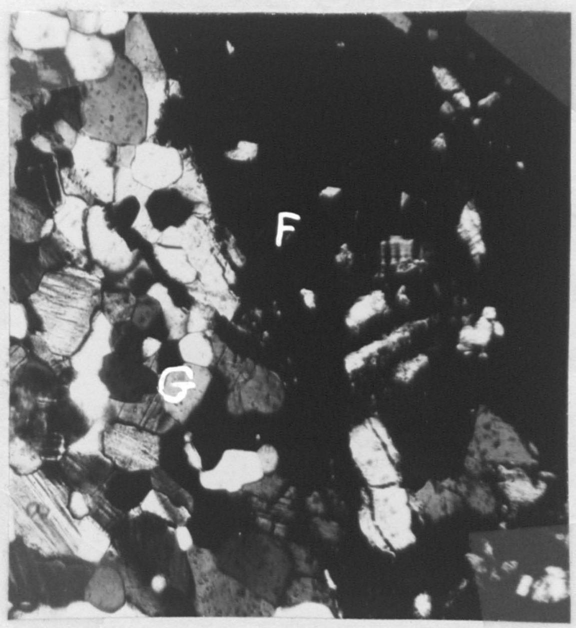
Solutions carrying iron circulated through some of the breccia immediately after its formation. These solutions deposited thin film on the rock fragments which is now hematite or limonite. Subsequent mineralization replaced the gouge with fluorite but did not remove the thin film of iron minerals.

Paragenesis

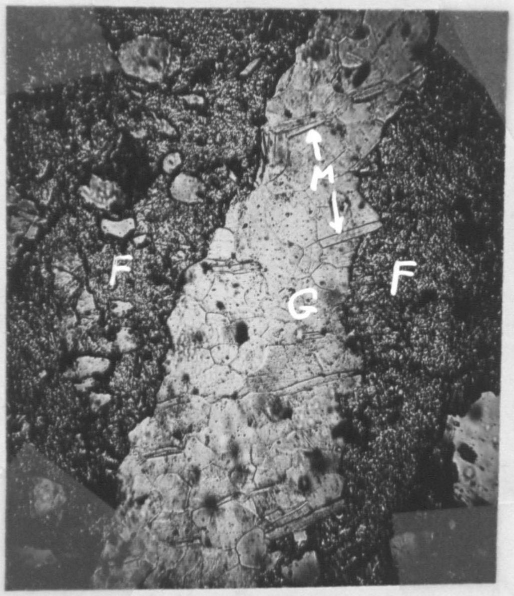
The sequence of events during mineralization is quite simple. First the country rock was brecciated, and faulting and shearing continued during and after mineralization. Next solutions deposited thin coats of limonite and/or hematite on certain of the breccia fragments. The continuing faulting broke up these fragments in some instances. Next fluorite and chalcedony were deposited. Both are found on rock fragments, and each is found following the other. The ore solutions may have changed character several times during deposition and in so doing shifted between depositing fluorite and chalcedony. In places small patches of gouge were left unreplaced, and small cavities were left unfilled.



A. Slide No. 61. Fluorite (F) in contact with granite (G) and surrounding large breccia fragments. Plain light. x 46.5 .

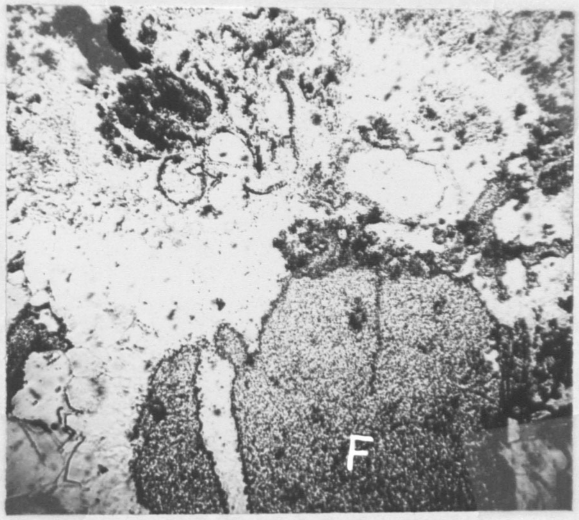


B. Slide No. 61. Same as A. x nicols. Note how edge of fluorite tends to follow the boundaries of some of the larger grains. x 46.5 .

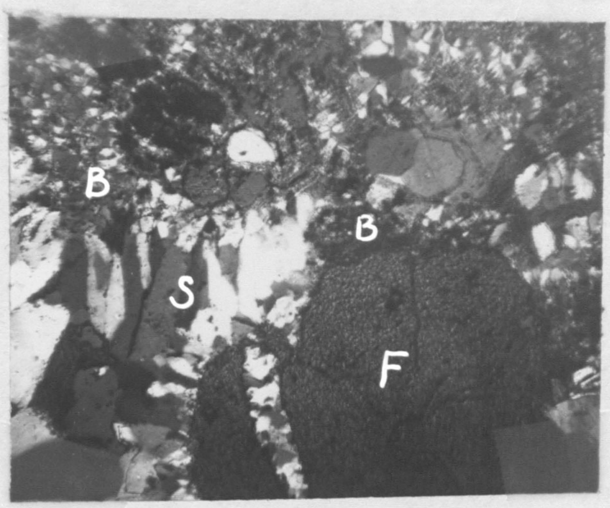


A. Slide No. 57. Fluorite (F) surrounding granite (G) and large individual mineral grains. Note alignment of muscovite (M) in granite. Plain light. x 46.5 .

B. Slide No. 57. Same as A. x nicols. Note sharp contact of Fluorite and other minerals. In some cases contact follows grain boundaries. x 46.5.



A. Slide No. 59. Fluorite (F) associated with granite breccia and secondary silica. Plain light. x 46.5.



B. Slide No. 59. Same as A. x nicols. Fluorspar (F) Breccia (B) and secondary silica (S) x 46.5 .

CHAPTER VI

STRUCTURAL CONTROL OF ORE

General

Structure was the controlling factor in localizing the ore deposits. Within structurally favorable zones, rock type was the major determining factor. The fluorspar ore is found along the fractures of shear zones. There are both wide and narrow zones, and any individual zone may vary greatly in width. The intensity of the shattering within them varies. The best grade ore was produced from the most highly shattered zones at their places of greatest width. This accounts for the difference in the two mines. The Aksarben mine is along a wide, intensely shattered shear zone and has produced good-grade ore from several large ore bodies. The Divide mine has no well-defined shear zone; its ore, which is low-grade, is along small and irregular fractures, small pockets, and stringers.

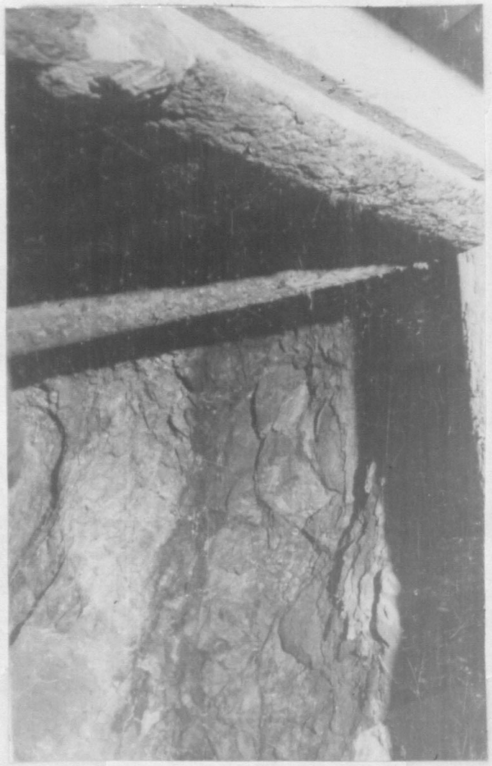
Aksarben Mine

At the Aksarben mine a shear zone (F_7) trends northwest in country rock that is mainly granite (see plate XI). Exposed at the surface of the surrounding area is a minor amount of schist. Talus and soil cover much of the area. This shear zone is the channel along which the fluorite-bearing solutions rose to the surface. At the present time solutions still rise along the northwest extension of this shear zone, but they now reach the surface at a lower elevation at the Poncha Hot Springs.

Impermeable gouge, formed from extensive schists in the Poncha shear zone (F_1), which cuts across the northwest-trending shear, prevents any further migration or lowering of the present outlet of the springs.

Inside the mine, structure and rock type exercise control of the ore on a smaller scale. During the shearing the granite broke into blocks that were separated by breccia or by open spaces. The breccia was porous, containing only a small amount of gouge, and, along with the open spaces, was easily penetrated by the ore-depositing solutions. The schist, as exposed in the underground workings, is a brown, limonite-stained rock which has preserved its schistose structure but has altered to the consistency of stiff clay. It occurs in irregular shaped masses called "mud seams" by the miners (see plates XX and XXI). When the faults crossed the schist or "mud seams" the resulting clay-like gouge proved to be an impenetrable barrier to the ore solutions. A vein of ore that is several feet wide along a fault in the granite either pinches out completely or narrows down to a fraction of an inch upon encountering the schist. The low strength of the altered schist-rock made mining difficult, and cave-ins were common. As a result mining ceased when schist bands became frequent or very wide.

The full width of the Aksarben shear zone is not known. The mining operations have explored a width of about one hundred feet. On the surface, fluorspar veinlets are scattered over a width of at least 150 feet. Southwest of the mine and across a gully is a ridge of brecciated granite that contains a few stringers of fluorspar. The area underlying the gully, which may represent the zone of greatest shearing, has never been tested for ore. Both the gully and the brecciated granite ridge are



A. Aksarben Mine. Schist (dark) and granite (light) along fault on incline level.

B. Aksarben Mine. Schist (dark) and granite (light) on incline level.

roughly parallel to the mine workings. It is possible, therefore, that the shear zone may be much wider than shown in the present mine workings and include the gully and brecciated ridge. However, short crosscuts have been extended twenty to fifty feet either side of the main workings, and in all cases they have ended in granite or schist that had little or no mineralization.

The structural details of the Aksarben mine are shown on plate XII. Several generalizations concerning structural control can be made. The shear zone persists for a considerable distance, but the individual fractures which localize the ore can be traced for short distances only. The ore follows a fracture zone that is often offset and very irregular. In many instances a series of closely spaced fractures have localized the ore. Within a short distance these ore-bearing fractures may fan out and disappear or be cut off by a cross fault or schist. Bands of altered schist tend to make the occurrence of the ore more spotty. Faults which strike across the general trend of the shear zone seem to be detrimental to the development of the ore. Most of the faults dip steeply, over 45°. This lack of a persistent ore trend exists in both the vertical and the horizontal direction.

The map of the underground workings (see plate XII) illustrates the lack of horizontal persistence of ore or ore structure. Only two large stopes are present, and both of these are on the incline level. A third possible ore body is located at the far end of the lower adit level. The mine workings between these ore bodies contain narrow veins of fluorspar in barren granite.

A. Aksarben Mine. Adit level. Entrance to large stope showing fault surface (a) and fractured granite veined with fluorspar (b).

B. Aksarben Mine. Cave-in where tunnel enters schist zone. Granite along walls in foreground.

The lack of persistence of structural control in the vertical direction is well shown in figures 5-11. The strike of the shear zone remains fairly constant between the adit and incline levels. However, on the shaft level, the strike has shifted to a northerly direction. Down the hill at the lower adit level the strike is again in a northwest direction.

These sections, figures 5-11, cover a vertical distance of only 55 feet, yet it is difficult to correlate from one level to another. Faults cannot be projected and rock types change in the short distance between levels. Ore zones, if they can be projected, change greatly in character within a few feet.

The most important structural feature in the Aksarben mine is the irregular trend of the ore. The drifts have followed the most promising ore streaks. In some instances a particular set of fractures may be followed for over one hundred feet, for example, at the northwest end of the incline level and at the large stope at the internal shaft on the adit level. At the southeast end of both of these straight ore-bearing areas, the zone of richest ore shifts slightly to the southwest to another set of fractures (see plate XII). In the case of the adit level, the first set of fractures appears to continue but for some reason becomes unfavorable for ore development. The ore trend on the incline level was offset by cross fractures. The best example of a fracture zone containing many different trends can be seen on the shaft level (see plate XII). Here, no individual trend continues for more than 40 feet. The fractures are narrow. Cross fractures diverted the ore solutions and produced

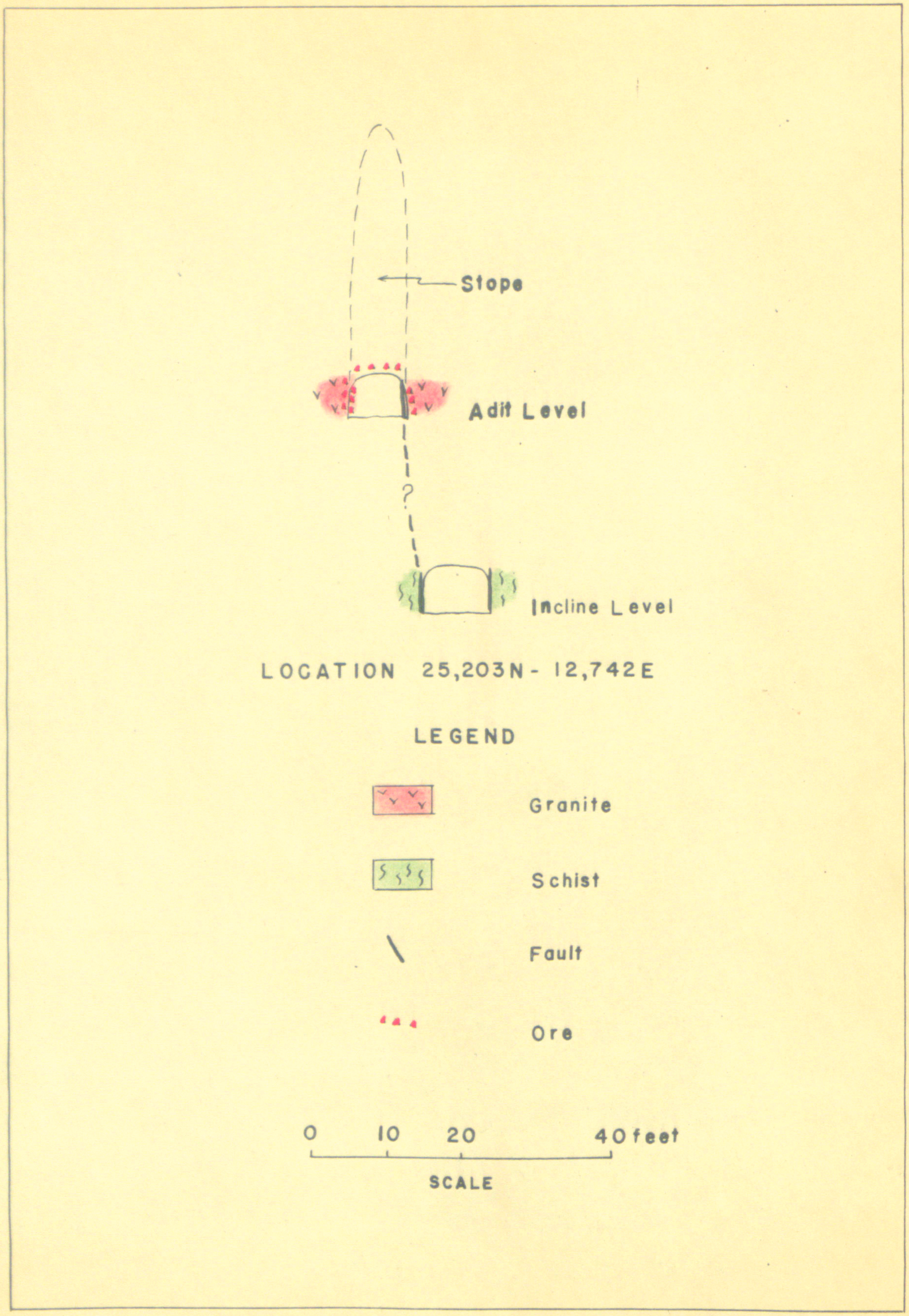


FIG. 5 AKSARBEN MINE, SECTION C-C'

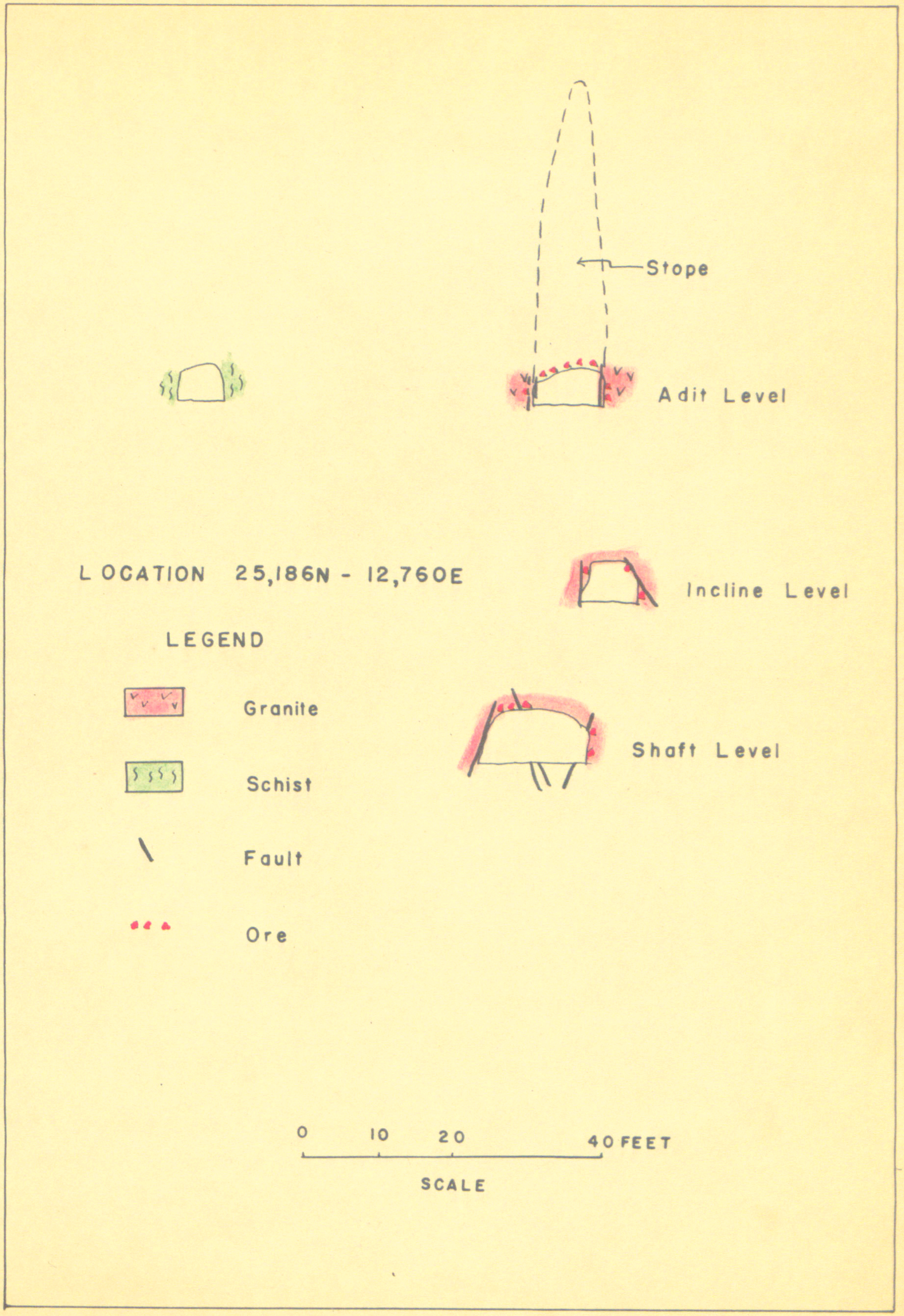


FIG. 6 AKSARBEN MINE, SECTION D-D'

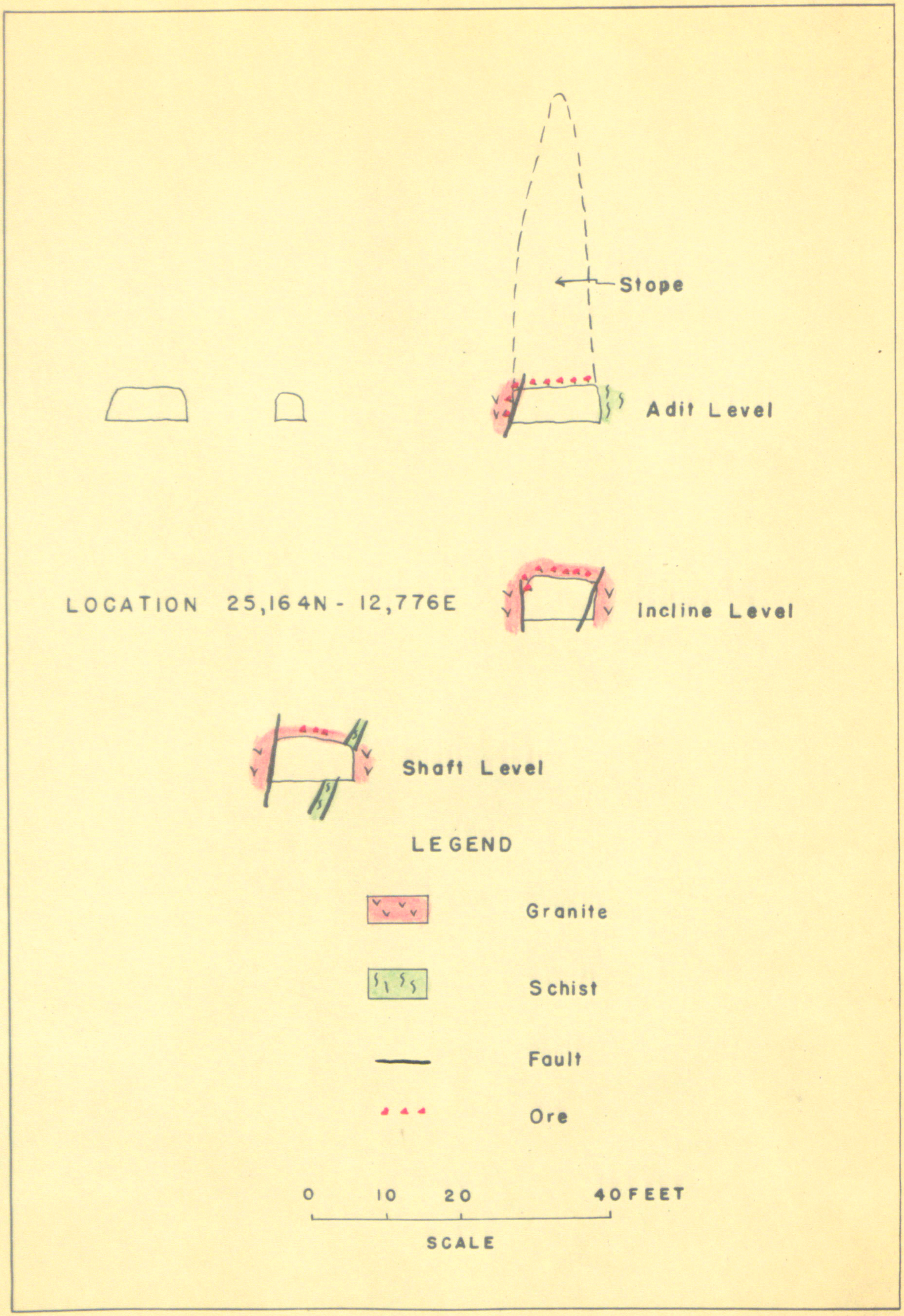


FIG. 7 AKSARBEN MINE, SECTION E-E'

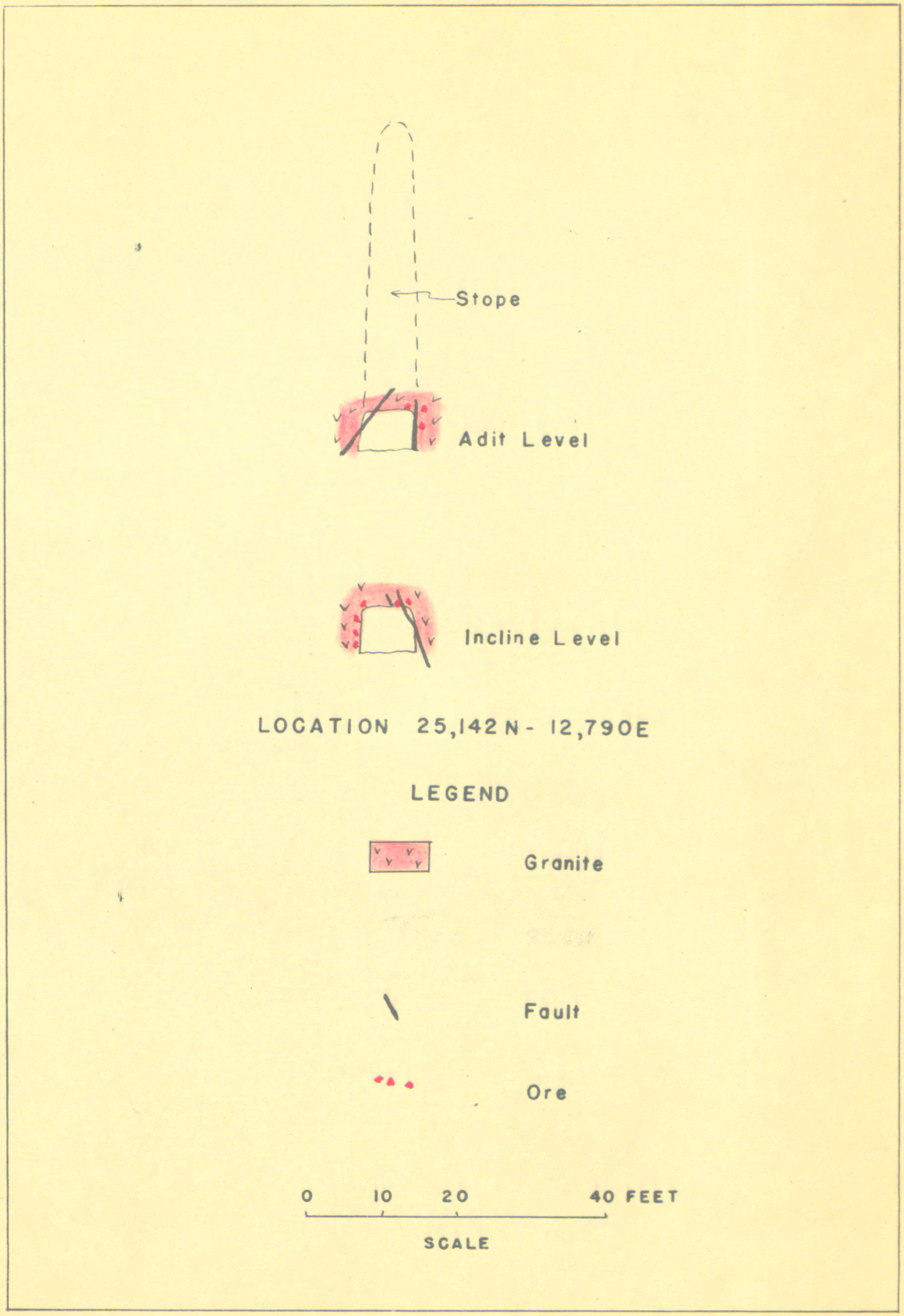


FIG. 8 AKSARBEN MINE, SECTION F-F'

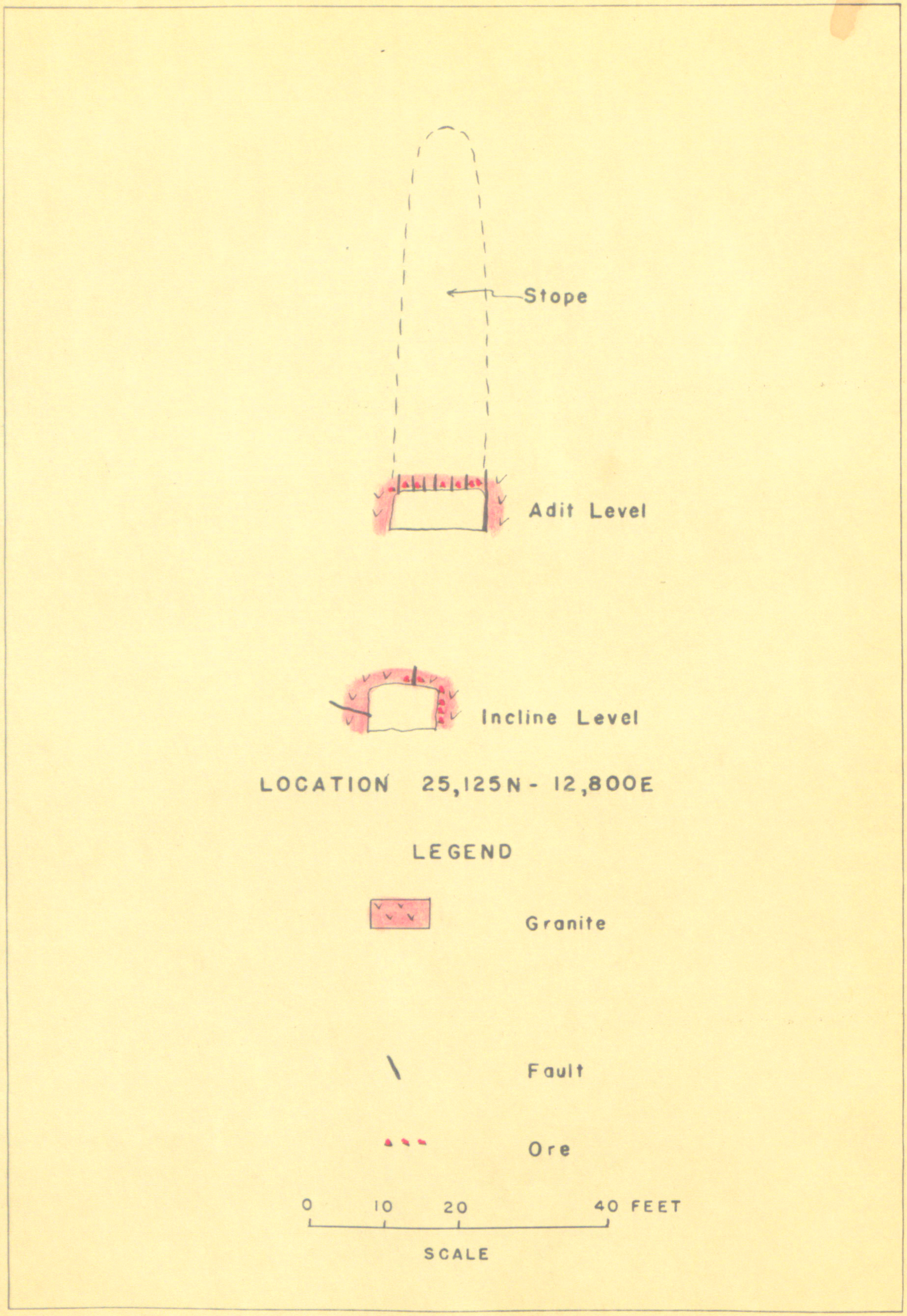


FIG. 9 AKSARBEN MINE, SECTION G-G'

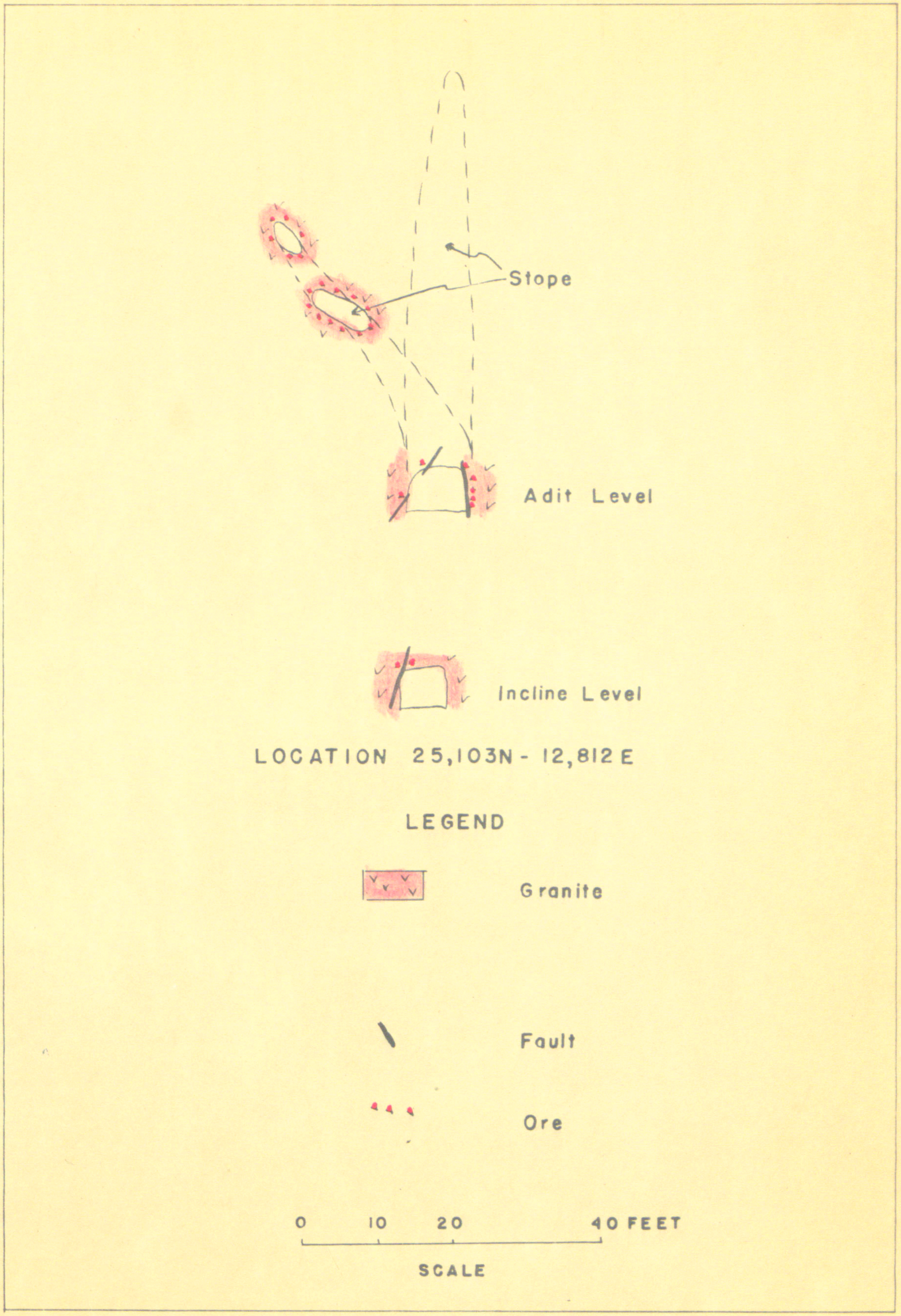


FIG. 10 AKSARBEN MINE, SECTION H-H'

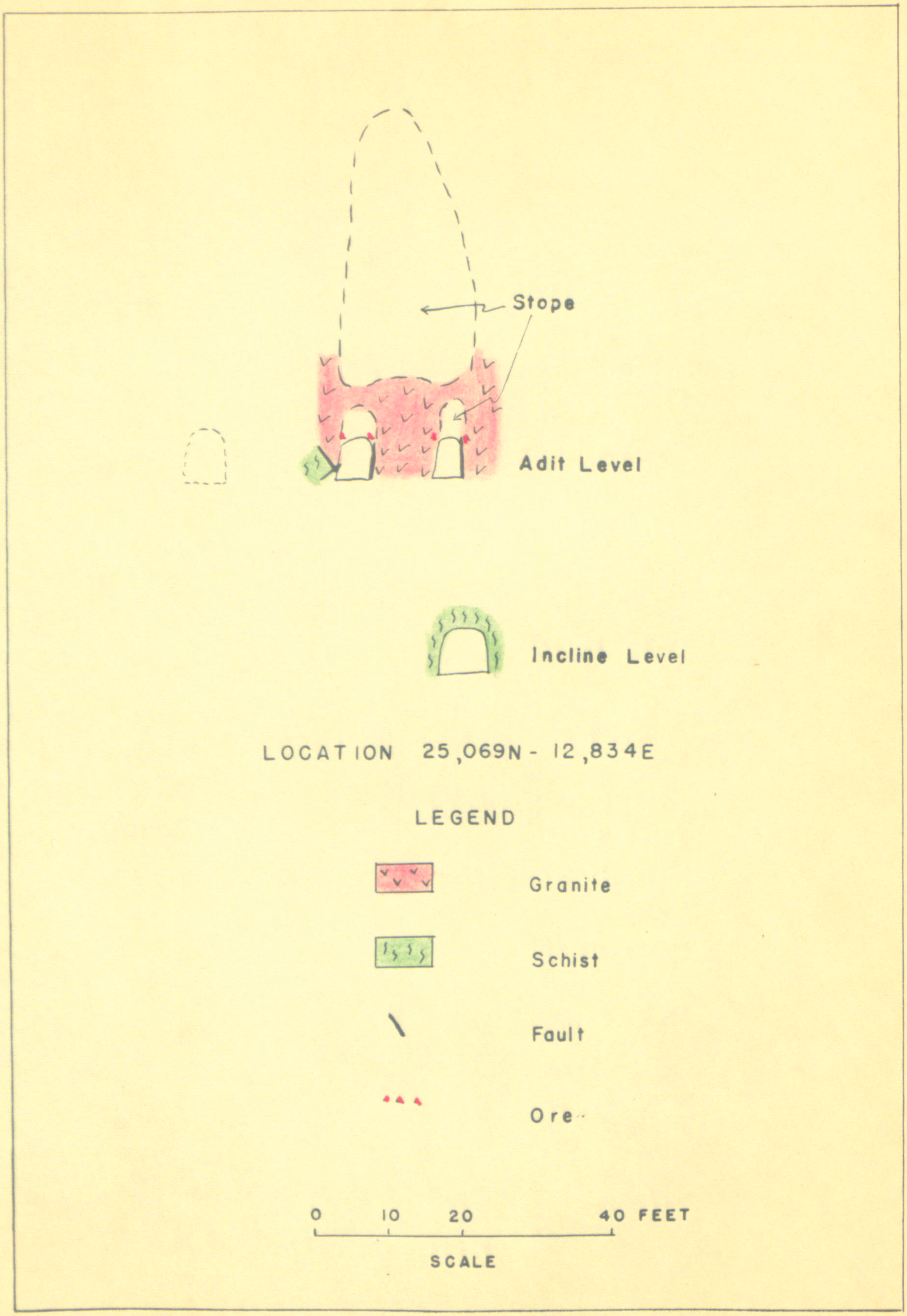


FIG. 11 AKSARBEN MINE, SECTION J - J'

large blocks of barren granite in the center of the zone. This situation makes it difficult to find and to follow a definite trend in the ore at this level.

An interesting irregularity is the occurrence of small pockets of ore that have formed at the side of the main ore trends. Twice on the incline level and once near the far end of the adit level, mining was extended twenty to fifty feet into such pockets and away from the main trend. These small pockets of ore represent blocks of brecciated granite, bounded by faults or schist, which were close enough to the main ore channels to be mineralized.

Altered schist bands interrupt the ore streaks at many places. They are of major importance in that they directed, i.e. blocked, the ore solutions from going in certain directions. The structural pattern of the shear zone is so irregular that one cannot predict the occurrence of these large barren areas caused by the schist. A small schist band at the south-east end of the incline level effectively prevented ore solutions from reaching the following 10 feet of granite. Also an area of schist at 25,160 N. and 12,720 E. discouraged the miners from trying to continue working that portion of the adit level. The large stope at the internal shaft on the incline level strikes into schist; a strong fault carries through the schist, but only a narrow stringer of fluorspar follows this fracture.

Faulting and ore deposition proceeded simultaneously. In many places the ore shows well-developed slickensides which indicates that the movement was very close to vertical. The process repeated several times. This repetition developed a thick fracture filling consisting of bands of ore separated by slickensided surfaces. The faulting was accompanied by horizontal tension in many places. Each movement tended to increase the width of the fracture. In some cases subsequent deposition of fluorspar was not sufficient to fill the opened space, and small flat vugs resulted. These openings are not lined with crystals.

At places where compression developed during faulting, the fluorspar was brecciated. Some of the banded ore may contain small patches of brecciated ore. The two large stopes were filled almost entirely with brecciated ore. The ore in the stopes was so thoroughly broken up that it was impossible to tell how many periods of faulting and deposition was represented. This ore was so loose that it presented a serious mining problem. After the stopes were started the ore simply ran out. It was so loose that no one dared enter the stopes, and they have been caving intermittently ever since mining operations ceased.

Divide Mine

At the Divide mine, structure also controls the amount and distribution of ore. Most of the fractures here are narrow and widely spaced. Movement along the fractures was not recurrent as at the Aksarben mine. There is a lack of structural trend. No wide shear zone is exposed in or around the mine workings. The individual faults strike in many different directions. These are shown on figs. 2-4. East and northwest strikes are most common. None of the breaks is known to extend for any great distance.

Rock type also plays an important role in localizing the ore here. The country rock is granite. Schist masses, both altered and unaltered, are present. They have cut off ore solutions along any fractures that they intersect. Ore has formed in open fractures and has replaced gouge. However, the simple fractures at this mine did not form large amounts of gouge and thus limited the size of ore veins.

The main open cut (see fig. 2) produced most of the ore from the Divide mine. The country rock is mostly granite, but two small schist bands are present. The remaining ore is largely confined to several fractures which are shown on the map. Fractures probably extended along the three arms of the cut where mining was concentrated.

Adit No. 1 (see fig. 3) does not follow any structure. It crosses numerous schist bands or "mud seams." Only a few faults cut the country rock which is granite. With two exceptions the mineralization along the faults is not persistent. The two veins just inside the entrance strike about at right angles to each other and though well mineralized are too narrow to mine. The north-striking vein is very interesting mineralogically. Its ore is unlike that which is found in the Poncha area but very similar to the Brown's Canyon ore. This vein represents the only fault on the Divide property which developed large chunks of breccia supported in gouge. Some present open spaces may have existed then or may have been later developed by the action of fluorite-bearing solutions which replaced the gouge. The vein filling consists of granite fragments surrounded by pale-violet fluorite. The fluorite is fibrous. The fibers are short, about one quarter of an inch in length, and are perpendicular to the surface they coat. Between the fluorite-coated pebbles most of the space is filled with massive, white fluorite. A few open cavities have small quartz crystals projecting in toward the center of the opening. The large cores of country rock beneath the fluorspar coating cut down the total fluorspar content to below the point where this narrow vein could be classified as ore.

Adit number 2 (see fig.4) contains the most extensive underground workings at the Divide property. The adit was driven in a westerly direction for about 140 feet apparently with no regard for structure. Two small rooms on the south side of the adit and a small stope at the end produced some low grade ore. The country rock contained many closely spaced, narrow fractures that were filled with fluorspar. The northwest extension of the workings encountered a band of ore-bearing faults and, subsequently, much schist. A caved portion extended perhaps another one hundred feet in schist. Had the band of mineralization not encountered schist, an important ore body might have been developed in this adit.

Numerous pits and bulldozer trenches have caved and, therefore, expose very little geology.

CHAPTER VII

Ore Reserves

Aksarben Mine

The Aksarben mine could be developed into a good, small mine. On the basis of text results and of estimated ore reserves, and if the operators did not try to overexpand, it shoud be possible to operate this property at a profit. Exploration in this mine would have to be by means of drifts. Diamond core drilling in similar rock types at other fluorspar deposits in Colorado has not proved very satisfactory. With exploratory drifts any new ore body could be worked almost immediately.

The Aksarben ore was tested by the Bureau of Mines.[9] These tests indicated that the ore could be treated successfully by either of two methods, sink-float or flotation. A portion of the fluorite occurs as fine as 150-mesh, and in many cases the individual fluorite grains have a surface coating of calcium corbonate and iron oxide. However, about half of the fluorite is present as particles ranging from one quarter inch to about 8-mesh.

The tests were run as follows:[10]

> Since a portion of the fluorite is free at comparatively coarse sizes, sink-float treatment was employed. Ore was crushed to minus 1-inch and screened on 8-mesh. The oversize was treated by sink-float

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9. Batty, J. V., Havens, R., and Wells, R. R., Concentration of Colorado fluorite ores: U. S. Bureau of Mines, R. I. 4139, p. 12, 1947.

10. Idem. pp. 15-16.

> methods at media gravities of 2.83 and 2.70. The minus 8-mesh material was ground to minus 65-mesh and the fluorite floated using an emulsion of oleic acid stabilized with Emulson X-1 as collector and frother. The flotation concentrate was cleaned three times....
>
> Sink-float treatment of Aksarben ore crushed to minus 1-inch recovered over 89 percent of the fluorite in the fraction treated or 46.7 percent of the total fluorite in a metallurgical-grade product assaying 87.3 percent CaF_2. Flotation of minus 8-mesh material recovered an additional 31.9 percent of the fluorite in a plus 98-percent CaF_2, acid grade concentrate.
>
> Additional flotation tests were run on the original ore, and finer grinding proved to be beneficial.----
>
> Flotation of minus 150-mesh Aksarben ore recovered 82.7 percent of the fluorite in a concentrate that assayed 98.15 and met specifications for acid-grade spar. Over 90 percent of the fluorite could be obtained in a plus 97 percent CaF_2 product.

The ore at the Aksarben mine ran 40 to 90 percent fluorite. Analyses of several ore samples are given in table III. The estimated production figures are given in table IV. The ore reserves of this mine are shown on plate XXII and table V.

Divide Mine

At the Divide property the grade of ore was poor to begin with and got progressively worse as mining continued. Early ore ran about 35 percent CaF_2. When operations ceased the ore grade had fallen off to about 20 percent CaF_2. All ore was milled at Brown's Canyon north of Salida. The estimated production of the Divide property is tabulated in table VI.

No ore reserves are calculated for the Divide property. The fluorspar present is distributed too sparcely to be considered ore. Unless a

TABLE III

Analyses of Aksarben Ore

	1.	2.	2.	4.	5.	6.	7.
CaF_2	59.75%	36.76%	41.25%	27.37%	41.83%	40.67%	59.26%
SiO_2	22.2						
$CaCO_3$	.45						
Fe	1.8						
MgO	.4						
Al_2O_3	4.6						
R_2O_3	7.1						
Total	96.30%						

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1. Batty, J. V., Havens, R., and Wells, R. R., Concentration of Colorado fluorite ores: U. S. Bureau of Mines, R. I. 4139, p. 12, 1947.

2-7. Partial analysis by Colorado Fluorspar chemist. Representative samples of vein on adit and incline level. No location of samples available.

TABLE IV

Fluorspar Production   Aksarben Mine.

	Metallurgical Ore		Milling Ore
1933	50 tons		
1934	300 tons		
1935		Idle	
1936		"	
1937		"	
1938		"	
1939	200 tons		
1940	40 tons		
1941		"	
1942	3450 tons (?)		
1943	6264 tons		8,358 tons
1944			11,994 tons
1945		"	
1946		"	
1947	Development work		

new and promising discovery is made, the property must be considered as exhausted. Only war-time conditions prompted the working of the property in the first place, and it is doubtful if the operation was profitable.

TABLE V

Estimated Ore Reserves - Aksarben Mine

Block Number		Tons
Indicated Ore		
1		204
2		491
3		1,020
4		238
5		1,635
6		136
7		455
8		239
9		545
10		750
11		341
	Total	6,054
Inferred ore in developed areas.		
12		545
13		545
14		1,635
15		365
	Total	3,090
Inferred ore in undeveloped area.		
16		70,000

(Based on ore averaging 8 feet wide in productive area and 60 percent of the tunnels in productive ore).

Total ore reserves 79,144 Tons

TABLE VI

Fluorspar Production	Divide Property 1943
Tons of ore:	% CaF_2:
76*	38.84
119	31.37
97	46.43
295	36.76
112	37.25
192	36.65
382	34.41
357	33.56
240	35.60
48	38.02
260	34.45
49	38.95
210	30.98
31	47.03
414	28.73
12	38.91
255	23.99
40	23.46
466	24.37
46	39.70
461	18.77
91	23.38
152	18.77
55	14.19
391	26.64
34	22.73
73	34.02

* Tonnage figures are for a week's production. If two or more parts of the property were being worked simultaneously separate figures were reported.

CHAPTER X

ORIGIN OF THE ORE

Summary of Theories of Origin of Fluorspar Deposits

The origin of fluorspar ore is not well understood. Most publications that deal with fluorspar-producing areas are largely descriptive and devote little or no space to origin or source. The same is true about the fluorspar that constitutes a gangue mineral in certain ore deposits. Most statements about the source of the fluorspar-depositing solutions can be summed up in a statement like: they came from depth and probably were produced by the cooling of an igneous magma relatively rich in fluorine. A review of the literature reveals that most detailed work on fluorspar in this country has been in the Illinois-Kentucky field where conditions are different from those in western United States. Several people have discussed the origin of the eastern ores, but such work is just beginning for the western areas. Only recently have the western deposits had any economic importance. These deposits are scattered over a vast area and probably represent many different conditions of deposition and origin of which the Poncha deposits are only one.

A discussion of the theories of the origin of fluorspar must first consider briefly the work done in, and the theories developed for, the Illinois-Kentucky field. In doing this it should be kept in mind that, there, the geologic conditions differ considerably from those described earlier in this paper. The eastern ores are in open fault-fissure veins in flat-lying country rock composed of limestone, sandstone, and shale. There the common gangue mineral in the veins is calcite with minor amounts of barite. Calena, sphalerite, and pyrite are common in some of the ores. Peridotite dikes of post-Pennsylvanian age, which intruded the area before the formation of the fluorspar deposits, are scattered throughout the district.

By contrast, the Poncha deposits occupy shear zones in igneous and metamorphic rocks. The ore contains no vein gangue mineral. Evidence of Tertiary volcanism is abundant in the area.

One of the earlier workers in the Illinois-Kentucky district was Julius Fohs. His views on the origin of the deposits are contained in the following statement.[11]

> Fluorspar consists of calcium and fluorine. The wall rocks form a ready source of calcium, but contain little or no fluorine. Igneous dikes of mica-peridotite, a dark green rock consisting of more than a dozen minerals, two of which, biotite and apatite, usually contain more or less fluorine, traverse the district. Upon analysis, this rock, none of which is very fresh, now shows very little fluorine content, yet it, together with the underlying mass from which it was given off, or the underlying mass alone, seems the most probable source of the fluorine. The compounds, ultimately to form the deposits, were transported by means of ascending thermal or heated solutions, coming as an aftermath of the eruption resulting in dikes.

This is one of the earlier statements to postulate an igneous source for the fluorine. Subsequent work in this district has tended to expand these views.

More recently L. W. Currier has studied the Cave-in-Rock bedded ore which, although the result of different structural controls, is undoubtedly from the same source as the fissure deposits described by Fohs. Currier's views on the origin of this ore are as follows:[12]

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11. Fohs, F. Julius, Fluorspar deposits of Kentucky: Kentucky Geol. Survey, Bull. 9, p. 61, 1907.

12. Currier, L. W., Geological and Geophysical Survey of Fluorspar areas in Hardin County, Illinois, Part I. Geology of the Cave-in-Rock Distruct: U. S. Geol. Survey Bull. 942, pp. 47-49, 1944.

> In origin and geologic history, the bedding-replacement deposits of the Cave-in-Rock district are, in their general aspects, similar to the vein deposits that characterize the rest of the Illinois-Kentucky field. The source and character of fluoriferous solutions and the time of deposition are believed to be the same for both types of deposits....
>
> The source of mineralizing solutions for the entire fluorspar field is believed to have been a deep-lying mass of molten rock material, or magma, that existed at considerable depth, doubtless several thousands of feet below the present surface....
>
> Late hydrothermal emanations from the deeper part of the magma basin ascended along major fault fissures, which must have cut through the congealed upper part of the deep-seated magma as well as through the overlying strata. These emanations were especially rich in fluorine, so that hydrofluoric acid, formed by hydrolysis, was relatively abundant in the ascending solutions. Wherever calcium carbonate (as limestone or as vein calcite) was encountered along the paths of circulation, chemical reactions resulted in the formation of fluorspar. So long as the upward flow of the solutions was relatively unimpeded, by virtue of the more or less open character of the fissures, a considerable excess of hydrofluoric acid probably remained in the solutions and was carried upward until it gradually became used up by reaction with calcium carbonate encountered along the fissures. It is a natural result of such action that some of the fault fissures contain fluorspar through a large vertical range. For long distances and in many places along faults, also, smooth, compact, slickensided walls gave little chance for replacement of the wall rock, even where it was composed of limestone, except at intersections with other fissures. But even where the wall rocks could not be replaced vein fluorspar was probably deposited directly from solution wherever the progressively decreasing pressure and temperature of the solution made it unable to carry the calcium fluoride obtained at lower horizons. Wherever crystalline calcite was encountered as fissure filling, as, for example, between walls of the thick Ste. Genevieve limestone and lower formations, fluorspar was deposited both by reaction of the hydrofluoric acid of the solutions with calcite, and through volume-for-volume replacement of calcite by the calcium fluoride carried in the solutions.

Several articles have been published recently on fluorspar deposits in areas of igneous and metamorphic rocks. Most of these are concerned with recently developed areas which have a small amount of underground workings which results in limited exposure in three dimensions. Most early examinations are confined largely to structural control, size and grade of ore bodies, and possibilities of economic development.

War-time considerations imposed certain time limitations and placed economic considerations foremost in these studies. The investigations at Poncha were started under such circumstances.

The most extensive recent work on western fluorspar deposits is that compiled by Rothrock on the fluorspar deposits of New Mexico. This report covers several years of pre-war and war work by the U. S. Geological Survey in New Mexico. After mapping numerous deposits in many mining districts, Rothrock comes to the conclusion that:[13]

> All the fluorspar deposits that have been mined in New Mexico are believed to have a genetic relation to igneous intrusions. The deposits are epigenetic; that is, they were formed later than the rocks in which they occur. Judging from the presence of such gangue minerals as quartz, barite, and calcite, the deposits crystallized from ascending aqueous solutions, acidic in composition, that were derived from the crystallization of deep-seated cooling magmas.
>
> In places these ascending or hypogene solutions had little reacting power, as is indicated by the absence of wall-rock alteration. The resulting deposits, which must have been formed by simple crystallization of the vein minerals in open spaces such as fissures, interstices of fault breccias, and solution cavities, are herein called void-filling bodies. In other places the solutions were more reactive, possibly because of higher temperatures or differences in chemical composition or in the stability of the wall rock. As a result, the rocks with which the solutions came into contact were extensively altered. Finely comminuted rock, such as that in brecciated zones, and chemically unstable minerals such as calcite, the micas, and the feldspars, were replaced by more stable vein minerals, which thus formed replacement bodies. Both replacement and void-filling commonly took place in recurrent stages, and both may have contributed to the formation of a single deposit.

Ralph E. Van Alstine[14] made a study of certain Newfoundland

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13. Rothrock, Howard E., Johnson, C. H., and Hahn, A. D., Fluorspar Resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 21, pp. 21-22, 1946.

14. Van Alstine, R. E., The fluorspar deposits of St. Laurence, Newfoundland: Econ. Geol., Vol. 39, No. 2, pp. 124-125, 1944.

fluorspar deposits. These were associated with granite and, concerning their origin, he says:

> The source of the fluorite is believed to have been the same magma reservoir that supplied material to form the granite and associated bodies of rhyolite prophyry and lamprophre. The close spattial relation of the fluorite veins and these rocks is considered to be genetic and not merely structural control of the mineralizing solutions. Fluorite is abundant as an accessory mineral of the granite and is common in the miarolitic cavities.

Concerning Colorado fluorspar deposits specifically, Aurand[15] states:

> Throughout Colorado the main source of the fluorine appears to be deep seated rocks of igneous origin. From this source, hydrofluoric acid or other fluorine compounds in which silica formed a part, were transported, with other elements in solution, by means of ascending thermal solutions. These solutions in ascending through various fissures, faults, and dikes came into contact with lime or with other solutions, and fluorspar was deposited.

Another Colorado deposit, the Wagon Wheel Gap area, was described by Emmons and Larsen. The fluorite was mined from a fissure that also contained a hot spring. In central and southern Colorado, especially the San Juan region, fluorite is a common gangue mineral in some of the ore deposits. At Cripple Creek, Telluride, and Bonanza, fluorite has been a conspicuous gangue mineral. Geologists who have worked in these districts attribute the ore to a deep source and, specifically, to one of the magmas that must have been present at the time of ore formation.

From the foregoing quotations, it is easy to summarize the present state of knowledge of the origin of fluorspar deposits. All agree that the ore-bearing solutions came from below and were probably supplied by

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15. Aurand, H. A., Fluorspar deposits of Colorado: Colarado Geol. Survey Bull. 18, p. 25, 1920.

the cooling of a magma. The author has purposely not included some old writings that attribute the Illinois deposits to circulating groundwater, as these views are no longer seriously considered by geologists. The type of associated igeneous rocks which may represent the fluorine-containing magma varies from one district to another. It is peridotite in Illinois and Kentucky; granite in Newfoundland; granite or phonolite at Cripple Creek; granodiorite, quartz monsonite, and various types of lavas throughout New Mexico; and andesite and trachyte at Poncha. The nature of the fluorite-depositing solutions and the state in which the fluorine is transported are left vague.

Poncha Hot Springs Deposits

The Poncha Hot Springs appear to be genetically related to the Aksarben fluorspar ores. A knowledge of these hot springs is part of the basis on which any theory of origin for these ores must be built. The springs issue from the north slope of Poncha Peak about five hundred feet above the Arkansas Valley (see plates I and XXIII). These hot springs have been used for a long time as a spa where people come to drink the mineral water and to take hot mineral baths. In 1920 R. D. George published analyses of five of the springs.[16] In the late 1930's the W.P.A. installed a collecting system, which gathered the water from most of the springs and piped it to a newly built public swimming pool in Salida. As a result practically all surface flow

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16. George, R. D. and others, Mineral waters of Colorado: Colorado Geol. Survey Bull. 11, 1920.

A. Hot spring terrace (a). North slope of Cleveland Peak and South Arkansas valley in background.

B. Calcareous tufa terrace deposited by hot springs.

stopped. The natural surface flow, at present, is limited to one small spring and several seeps. Before the central collecting system was installed, there were forty individual springs having a combined flow of about one hundred gallons a minute. In 1945 the U. S. Geological Survey obtained and analyzed a sample of the spring waters from the central collecting sump (see table II).

The springs are located at what is probably the intersection of two shear zones. The Poncha shear zone which trends east forms the southern boundary of the Arkansas Basin and passes just north of the hot springs. A fracture system (F7), trending east of south, about at right angles to the Poncha shear zone includes the hot springs on two terraces, a near-by ridge of brecciated granite, and the Aksarben fluorspar mine. The former shear zone, having a width of several hundred feet of alternating gouge, brecciated rock fragments, and schist, is permeable to solutions (see plate III).

The mine-hot spring fracture system is largely in granite. As a result an insufficient amount of impermeable gouge formed to block the passage of solutions through this fault system. Similar solutions to those which now find surface expression at the Poncha Hot Springs once ascended the fracture system to the Aksarben mine. Erosion has made possible lower outlets for the solutions until the present site of the springs developed. The impermeable Ponsha shear zone makes it impossible for the hot springs to migrate to a lower elevation along the floor of the Arkansas Valley.

The hot springs formerly flowed over two calcareous tufa deposits which cap two stream terraces along the west side of a gully tributary to Poncha Creek. The thickness of the tufa cap is not known, but it probably does not exceed 10 feet. The surfaces of the tufa deposits are approximately sixty and one hundred feet above the gully. Each surface has a pronounced slope away from the gully back toward the hillside which forced the spring waters to flow back along the surface of the deposit before descending sidewise to the gully. There are two possible origins for the slope of the tufa surfaces. The fissures along which the solutions rise are located longitudinally in about the middle of the stream terraces, so that the sag in the tufa surfaces may have resulted from vigorous spring action which washed out sand, silt, and clay from the unconsolidated sediments beneath the cap of calcareous tufa. Another possible explanation is that minor faulting took place along the fissures from which the springs issue causing the slope of the former surface to be reversed.

The tufa is medium gray to buff in color. Locally, manganese oxides have produced a black stain on small areas. In places the tufa exhibits a crude bedding, but most of it appears homogenous. The texture is very porous; openings up to one quarter of an inch in diameter are quite common. As a result a natural surface or a broken surface of the tufa is very rough.

Insoluble residue studies reveal that the tufa is approximately 95 percent calcium carbonate. The insoluble constituents are, in order of their importance, chalcedony, opal, quartz, chlorite, muscovite, and fluorite. These grains are small; all of them pass a 100-mesh screen. The quartz, chlorite, and muscovite probably washed in from the Arkansas formation which underlies the tufa and forms the adjacent bank that rises to the west of the deposit, but they also could have been windblown. The chalcedony, opal, fluorite, and calcite were deposited by the waters of the hot springs. There is no local source from which surface wash could pick up opal or chalcedony. The calcite is in the form of a typical spring-deposited calcareous tufa. If fluorite grains washed down from the mine up on the hillside, they would concentrate in the gully at least sixty feet below the level of the terraces. The high specific gravity, 3.1, would exclude the possibility of fluorite grains being washed up along fissures because there is not a high concentration of other types of lighter, fragmental grains. Therefore, the fluorite in the tufa must be deposited by the hot spring waters.

The fluorite grains are not common. There are never more than four or five in any of the slides studied. These grains are clear and colorless, having square or triangular outlines.

The chalcedony grains are cloudy and roughly equidimentional. The opal is present in the skeletons of diatoms. These diatoms are very numerous and make up a large percentage of any minus 200-mesh screen sample. The opal has an index of refraction of 1.415. Several types of diatoms are present, but most appear to belong to the genus NAVICULA. These plants must have lived in the water that spread out over the terrace which had cooled slightly, because the temperature of the issuing springs, 153°F, would have killed these plants.

Analyses of hot springs which either contain fluorine in solution or are closely associated with fluorspar deposits are listed in Table II.

It will be noted that all these waters have certain properties in common. Based on their mineral content, they would be classified as sodium carbonate waters. This is best brought out by computing the properties by the Palmer method.[16] These properties are listed below the individual analyses. They include seven parts. The first three properties, "a", "b", and "d", are based on the percentages of certain mineral combinations multiplied by their reacting values. Of these "a" includes combined sodium and potassium, "b" consists of combined calcium and magnesium, and "d" contains the strong acids with the Cl and SO_4 radicals. All these waters are class I which is defined as the situation where "d" is less than "a". Primary salinity is 2 times "d". Primary alkalinity is 2 times "a" minus "d" and secondary alkalinity is 2 times "b". It will be noted that the properties of the various springs listed are very similar.

The method of analysis used on the various samples was not uniform. In some cases no tests were made for certain radicals; in others radicals were reported in a different form, for example, CO_3 and HCO_3. The table lists total parts per million, which is not the same as the total dissolved solids. These two totals are obtained in different ways. The former includes a small amount of CO_2 which is lost as a gas in the latter. The five analyses, numbers 174-178, quoted from R. D. George do

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17. Palmer, Chase, The Geochemical Interpretation of Water Analyses: U. S. Geol. Survey Bull. 479, 31, pp. 1911.

not show any fluorine. The early part of George's bulletin gives a rather complete discussion of the method of analysis used and, from that, it is evident that no test was made for fluorine. The same situation holds true for Wagon Wheel Gap, Colorado, where spring waters associated with fluorspar deposits were not analyzed for fluorine. The three samples analyzed by the U. S. Geological Survey and the waters from Ojo Caliente, New Mexico were tested for fluorine.

The springs at Poncha and those at Brown's Canyon (see fig. 1) have certain characteristics which distinguish them from the others in the table. The amount of fluorine present in these spring waters is very significant when compared to the amount reported from other springs. The relatively few analyses for fluorine in spring waters makes this comparison rather poor. Two springs at Brown's Canyon fluorspar district in Colorado, analyses numbers 4712 and 4713, showed 15 and 13 parts per million, respectively, of fluorine. These two springs are cooler than those at Poncha, but their composition is very similar. The total dissolved solids in the Poncha Springs is low when compared to the hot springs from other localities. The most commonly cited example of a fluorine hot spring is Ojo Caliente, New Mexico.[18] Lindgren studied this spring and published analyses of the spring water and of the calcareous tufa that had been deposited by the spring. The spring waters carry 5.2 parts per million of fluorine, less than half the amount present at Poncha. The analysis of the tufa showed 89.60 percent calcite and 0.9 percent fluorite.

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18. Lindgren, Waldemar, The Hot Springs of Ojo Caliente and their deposits: Econ. Geol., Vol. 5, pp. 22-27, 1910.

The springs at Wagon Wheel Gap, Colorado, issue from a fissure from which fluorspar has been mined. Emmons and Larsen,[19] after a study of the area, concluded that the spring waters previously flowed through the vein further up the hill where they deposited barite, fluorite, pyrite, and small amounts of gold and silver. Subsequent erosion lowered the outlet of the springs to their present position. Unfortunately the analysis of these spring waters did not include a test for fluorine.

Clarke[20] cites two foreign springs which contain fluorine. The springs at Vichy, France have 1.8 to 7.6 parts per million of fluorine. This was the largest amount of fluorine in a spring that was reported in the literature on hot springs. The springs at Bourbon l'Archambault have 2.68 parts per million of fluorine. Daubr'ee[21] states that the springs at Carlsbad, Bohemia and Plombie'res are currently depositing fluorite.

The origin of the Poncha Hot Springs appears to be closely tied in with the geology of the region. Lindgren[22] in his discussion of sodium carbonate waters says, "The characteristic sodium carbonate waters are,

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19. Emmons, W. H., and Larsen, E. S., The Hot Springs and the Mineral Deposits of Wagon Wheel Gap, Colorado: Econ. Geol., Vol. 8, pp. 235-246, 1913.

20. Clarke, F. W., The Data of Geochemistry: U. S. Geol. Survey Bull. No. 330, pp. 149, 1908.

21. Daubr'ee, Les'eaux Souterraines a'l'epogue actuelle: Pt. II, pp. 19-20, 1887.

22. Lindgren, Waldemar, Mineral Deposits: 4th ed., p. 53, 1933.

however, of deep-seated origin and usually break through the older igneous or metamorphic rocks underlying the lavas in regions where the active volcanism has ceased; the prevailing opinion is that these waters with their charge are in whole or in part of magmatic origin." As typical examples Lindgren lists Ojo Caliente, New Mexico; Poncha Springs, Colorado; and Carlsbad, Bohemia.

Evidence for magmatic origin of the Poncha Hot Springs is found in the following statements: The springs at Poncha ascend through pre-Cambrian granite and schist until they are very close to the surface where they pass through short sections of stream terrace and tufa deposits. Tertiary volcanic rocks are found near-by. There is a rhyolite dike about two thousand feet southeast of the springs. There is a belt of volcanic rocks 2 miles to the west. The lavas at Salida and Brown's Canyon are Pliocene or Pleistocene in age. The San Juan volcanics of Miocene and Pliocene age outcrop within 10 miles southwest of the springs. Hot springs are found at scattered intervals throughout the central part of Colorado and the San Juan Mountains. These springs, of which the Poncha Hot Springs is one example, represent the closing phase of igneous activity from the magma mass below.

Origin of the Poncha Ores

In attempting to formulate a theory to explain the formation and source of the Poncha fluorspar deposits, the author has drawn on many sources outside the Poncha area including a year's field work in the Kentucky fluorspar field. A local symposium, held while the author was in Kentucky, on the Kentucky ores helped to point out many of the problems involved.

Several problems must be solved before a satisfactory theory can be constructed. The most important problem is the ultimate source of the fluorine and the other elements that may be present in the ore deposits. At Poncha this includes only calcium and fluorine, but at other districts this would include the elements of many common ore and gangue minerals. Secondly, there is the problem of transportation. Was the fluorine carried as an ion or as a compound? If the latter, what compound? Were the solutions acid or basic, and what caused the deposition of the fluorite? It is very doubtful that the ore solutions at Poncha carried only one mineral, fluorite. This poses the problem of the non-deposition of the other elements that may have been present. Finally, it would be interesting to know at what depth the ores were formed and, if possible, over what depth range they could form. This last question is too difficult to consider with the information that is available in the Poncha area.

The ultimate source of the fluorine will be considered first. As a result of many new analyses, Barth[23] has concluded that fluorine is more abundant in the earth's crust than formerly suspected. The new figure is 800 grams per ton as compared to the former estimate of 300 grams per ton. The fluorine is present in the apatite of basalts and gabbros. In granite or the intermediate igneous rocks and metamorphic rocks, the fluorine is present in the micas, hornblende, and as fluorite.

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23. Barth , T. F. W., On the Geochemical Cycle of Fluorine: Jour. Geol., Vol. 55, pp. 420-426, 1947.

Thus any of the magmas which form igneous rocks might serve equally well as a source of fluorine.

Magmas are known to give off fluorine when they cool. The gases in volcanic areas contain fluorine. The actual percentage of this element present in the gases may be very small, but the total volume of fluorine gas thrown into the atmosphere is very large at places such as the Valley of Ten Thousand Smokes in Alaska and in Iceland. If this fluorine gas can be diverted into favorable channels, it may furnish the fluorine for a fluorspar deposit.

Barth's studies in Iceland indicate that it is very difficult to get fluorine into solutions that might form an ore deposit. The three important types of thermal activity associated with recent volcanic activity are alkaline hot springs, acid hot springs, and fumaroles. There is almost no fluorine present in the alkaline hot springs, but significant amounts are found in the acid springs before they become diluted with ground water and become alkaline as they flow away from their igneous source. Before this dilution has a chance to take place, the fluorine in the acid spring has reacted with the wall rock along its channel and so is lost. Therefore, in those relatively few instances where fluorite deposits have formed during the crystallization of a magma, some special situation must have prevailed which "fixed" the fluorine in such a way that it remained in solution in the alkaline waters.

The next element to consider is the calcium which combines with fluorine to form fluorite. Most alkaline springs carry calcium. The springs at Poncha and Wagon Wheel Gap are depositing calcareous tufa.

Probably most of this calcium came from admixed ground water and was originally derived from the solution of rocks containing calcium minerals. It is also possible that a small amount of the calcium may have been given off with the fluorine from the cooling magma. Analyses of acid hot springs associated with igneous activity show about 1 percent calcium present. This amount may be too small to be significant.

The chemistry of the transportation of fluorine in ore-forming solutions is very poorly understood. However, certain misconceptions can be cleared up which may lead to a better understanding of the problem. Certain authors have postulated the presence of fluorine, fluorine ions, or hydrofluoric acid in the ore solutions. This is impossible because:

> Fluorine is the most active of all elements and cannot exist or emanate as such in nature. Hydrofluoric acid gas or solution further does not exist as such in the presence of silica of known magma and water. Because of these facts, the fluorine of fluorspar did not arise in either the element or hydrofluoric acid. Again, we find no fluosilicates in practical amounts in nature and none whatever in this fluorspar field (western Kentucky but also applies to Poncha). We can however logically believe that fluorspar was formed from silicon tetrafluoride gases which are readily formed and go into solution or which readily exists as a vapor. This compound would form if hydrofluoric acid gas or solution were in contact with the silica of the magma and water. When SiF_4 comes in contact with calcium-bearing material, say calcite or $CaCo_3$, Calcium fluoride is formed as well as a soluble silica in solution. This takes place at temperatures below 175° C. Calcium fluosilicate may be formed by this reaction but this latter compound very readily breaks down into calcium fluoride and SiF_4 gas or solution---[24]

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24. Gaydos, A. E., Personal Communication. Al Gaydos represented an eastern chemical manufacturing company that was doing a lot of fluorine research at the time, probably in connection with the atom bomb. He released only limited information.

It seems probable that the fluorine was carried as fluorite or silicon tetrafluoride. Transportation as dissolved fluorite is more logical for the Poncha ores because no quartz minerals were formed at the same time as the fluorite. (The chalcedony at the Divide property is later than the fluorite). Also there is no local source of calcite to react with the silicon tetrafluoride. It is possible that during the deposition of fluorite the alkaline solutions were able to keep the silica in solution and carry it away. Other fluorspar deposits in the Rocky Mountains contain large amounts of chalcedony. These were probably formed by a breakdown of the silicon compound. At Poncha, the solutions containing fluorine probably reacted with a calcium compound at depth. The solutions then carried both fluorite and silica in solution. By the time the fluorite was deposited, the solutions were so alkaline that the silica remained in solution. Note that the present hot springs at Poncha carry 83 parts per million of silica in solution (see table 2).

Fluorspar deposits are formed fairly close to the surface and, therefore, should be classified as epithermal. Temperatures between 80° and 175° C. prevailed at the time of deposition. In Kentucky, fluorite crystals contain liquid inclusions of petroleum. Tests on liquid inclusions in crystals from other areas agree with these figures. These low temperatures probably indicate near surface conditions and, therefore, low pressures. It is impossible to say which factor, temperature or pressure, had more influence on the deposition of the fluorite. The solubility of fluorite increases as much as 33 percent at high pressures.[25] Little is known about the solubility of fluorite in the presence of other compounds or ions.

The origin of the Poncha deposits may be summed up as follows: The original source of the fluorine was an igneous magma. The lava flows near the mines are probably the surface expression of the magma. The fluorine left the magma as a gas in the form of SiF_4 or a similar compound. As it left the magma, or shortly thereafter, the fluorine gas reacted with calcium-containing solutions to form fluorite. This prevented the very active fluorine from being absorbed by reaction with the wall rock of the solution channel. The solutions ascended and at the same time became more alkaline with the admixture of groundwater. The original solutions had been acid. Near the surface, where the temperatures had dropped to around 175° C. and where pressures were greatly reduced, fluorite deposition commenced. The fluorite filled open cavities and replaced gouge and fine-grained breccia. Faulting continued intermittently in the shear zones while deposition was taking place.

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25. Gaydos, A. E., Personal Communication.

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APPENDIX

Petrographic Descriptions

The detailed petrographic descriptions, which are not essential for an understanding of this thesis, are included here as additional valuable information on the area. The reader is referred back to Plate I and Chapter II for the areal distribution and megascopic description of these rock types.

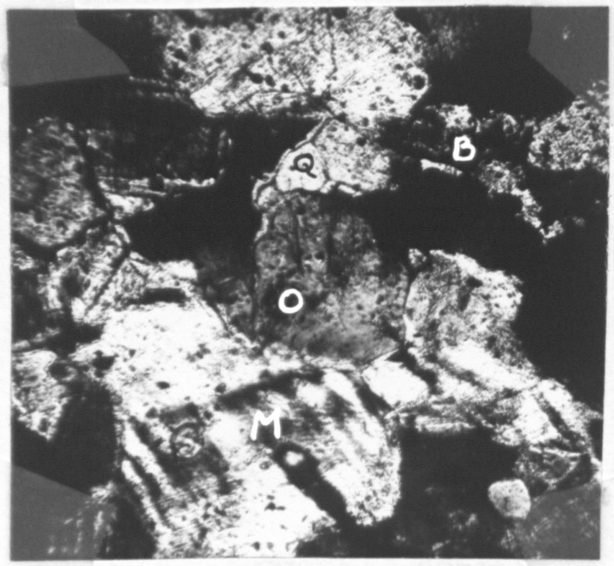
Granite. In thin section the granite from the Aksarben mine shows interlocking grains of uniform size (see plate XXIV). The percentage mineral composition of this granite was determined by making several traverses across the slide using an Hurlbut Electric Counter. The results are listed below:

Quartz	10.6%
Microcline	17.0
Orthoclase	48.8
Albite	11.0
Biotite	12.5
Total	99.9%

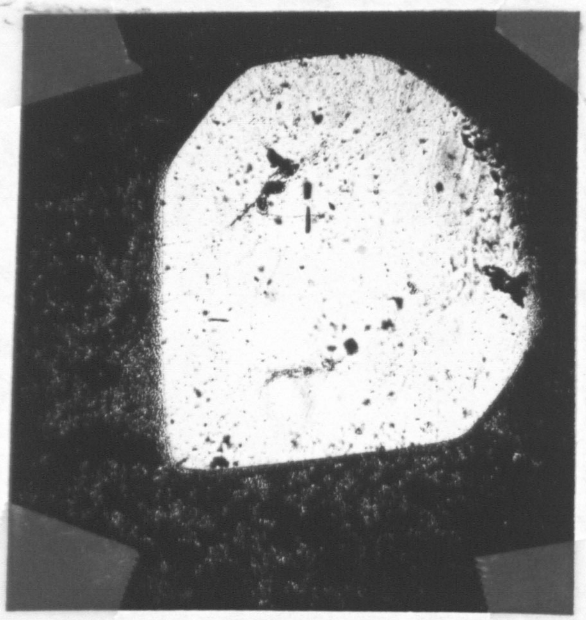
The rock, a biotite granite, contains a small amount of accessory apatite that was not included in the mineral count.

The quartz grains, some of which show strain, are clear and roughly equi-dimentional. Some small rounded quartz grains form poikilitic inclusions in orthoclase or microcline.

Microcline was distinguished in the thin section by its characteristic twining. The orthoclase grains are about the same size and shape as both the quartz and microcline grains. In plain light the



A. Slide No. 16. Granite. Aksarben Mine. Quartz (Q) Microcline (M) Orthoclase (O) and Biotite (B). X nicols. x 46.5



B. Slide No. 50. Rhyolite. Phenocryst of quartz surrounded by dense cryptocrystalline groundmass. Plain light. x 46.5 .

orthoclase grains show incipient kaolinization. This is most promounced around the edges but occasionally extends to the center.

The plagioclase, albite, grains are a bit larger than the potassium feldspars or quartz. The plagioclase twining bands stand out clearly in plain light because kaolinization has often attached one set of lamellae leaving the alternate set clear and unaffected.

The biotite flakes are elongate and roughly parallel. However they are not numerous enough to give the thin section a gneissic structure. Their color is a dull, olive green.

The apatite grains are small and clear. Most of them are inclusions in feldspar, but some are separate grains.

Thin sections of granite from the Divide mine vary greatly (see plates XVIII & XV). The average grain size, about 3/16 inches, is much smaller than the granite at the Aksarben mine. Narrow bands of micro-breccia appear on most of the slides. The mineral grains are interlocking. Some contain many poikilitic inclusions indicative of replacement.

Orthoclase is the predominent mineral in some of these slides. The grains are clear and variable in size. Its grains are commonly much larger than those of the microcline. The quartz grains have numerous poikilitic inclusions of microcline and muscovite.

Microcline is the next most common mineral. Its grains are generally smaller than those of the quartz, but a few as large as the quartz are found in the slide. Many of the small microcline grains are inclusions in large quartz grains. Other microcline grains appear to be replacing the quartz. All the microcline is clear and free from inclusions or kaolinization.

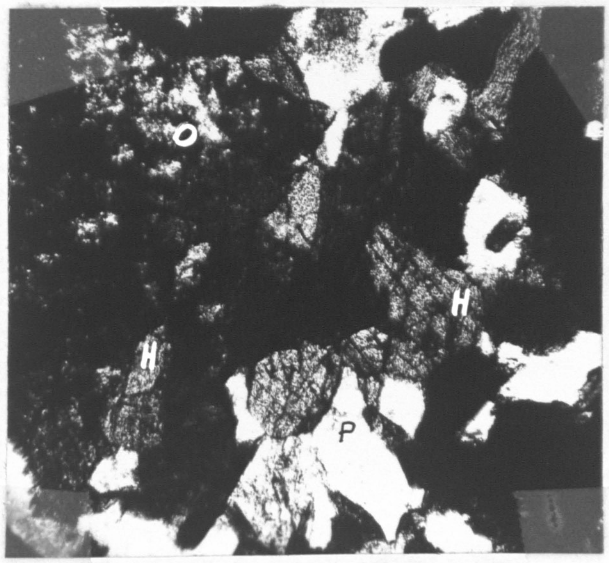
Muscovite is the only mica mineral present. Most of the muscovite grains are small and oriented parallel to each other. This rock is essentially an orthoclase-muscovite granite in contrast to the Aksarben granite which contains biotite and albite.

Amphibolite. In thin section, this rock is mostly hornblende and altered feldspars. Mineral compositions are determined in two thin sections are as follows:

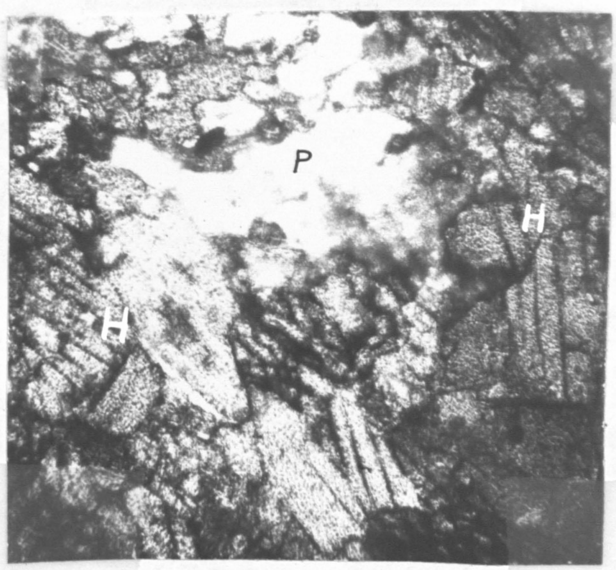
Slide	8	18
Hornblende	60.2	87.7
Plagioclase (An. 42%)	36.5	4.7
Sericite		7.5
Lucoxene	3.3	
Augite		.1
	100.0	100.0

The hornblende crystals form an unoriented interlocking mesh (see plate XXV). A few of the grains wholly or partly surround small grains of augite. The index of refraction of the hornblende grains ranges from 1.655 for α to 1.676 for $\gamma \pm .003$. These figures are very constant for the several rocks tested.

The plagioclase grains are clustered in small groups. Small grains of hornblende often project into the center of the clustered plagioclase grains. Most of the plagioclase is clear. In a few instances, kaolin has replaced certain of the twinning lamellae. Optical properties for the plagioclase are $N\beta 1.555 \pm .003$ and $2V - 90^{\circ} \pm 3^{\circ}$. This corresponds to an anorthite content of 42%.



A. Slide No. 8. Amphibolite. Hornblende (H) and plagioclase (P) grains of about equal size. Large porphroblast of orthoclase replaced by kaolin and lucoxene (O). Plain light. x 46.5



B. Slide No. 18. Amphibolite. Hornblende (H) surrounding a porphroblast of plagioclase (P). Plain light. x 46.5

One of the amphibolite specimens studied contains lucoxene and the other contains sericite. Both of these minerals replace large porphyroblasts. This replacement was almost complete, but in some cases a small central portion is unreplaced orthoclase.

Basic Pegmatite. In thin section the hornblende in this rock forms long fibrous aggregates. Some of these contain small rounded inclusions of feldspar. The outer edges of some of the hornblende grains cut part way across altered feldspar crystals. The hornblende has from pale or brownish green to black, deep green, or blue green pleochroism. The maximum extinction angle is 23°. The index of refraction varies from α 1.650 to γ 1.676. Good cleavage is common only in a few smaller crystals that do not have a fibrous habit.

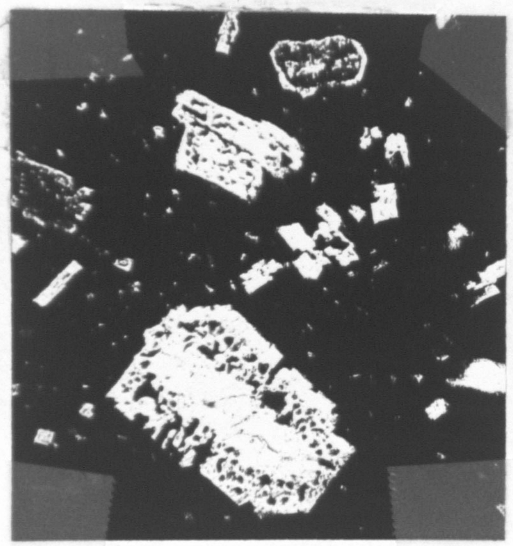
The feldspar is almost completely altered to sericite. Only a few small areas in the centers of the large crystals are unchanged. Some of the altered grains have vague banding which represents the plagioclase twinning of the former unaltered state.

Yellow-green epidote has replaced the feldspar, especially along the feldspar-hornblende contact. The epidote fingers out into the feldspar and surrounds small areas of it. The index for γ is 1.752 indicating the presence of about 16% of the $H\ Ca_2\ Fe_3\ Si_3\ O_{13}$ molecule of the epidote series as shown on Winchell's diagrams.

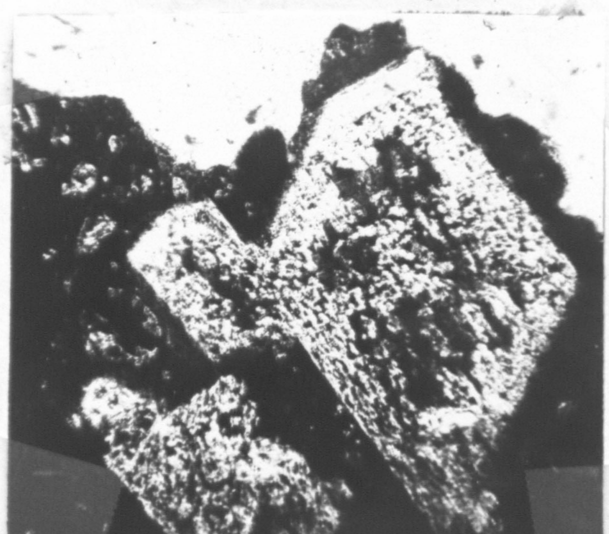
Fuchsite Mica Schist. This rock consists of about 1/3 mica flakes which rather effectively mask the quartz and andesine feldspar which make up the rest of the rock. The optical properties of the Fuchsite are α 1.578, β 1.592, and γ 1.594. 2V is approximately 30° and the mineral is biaxial negative. The pleochroic formula is x blue green y green and z pale green. There is no apparent dispersion of the optic axes. Some of the flakes are pale green to colorless but these have the same optical characters as the green grains. The well-oriented mica flakes produce a good schistosity.

Basalt and Andesite. In thin section phenocrysts of plagioclase, biotite, magnetite, augito, and apatite make up 30-40 percent of the rock (see plate XXVI). The groundmass is cryptocrystalline with some glass. In the basalt the groundmass contains small feldspar phenocrysts in a dark brown glass. The andesite has small feldspars in a crypto-crystalline material.

The plagioclase feldspar phenocrysts are larger and more numerous than any other type. The composition of the plagioclase ranges from andesine to bytownite. The phenocrysts started to crystalize fairly early and in many cases had not attained a complete crystal outline when the rock solidified. During their growth numerous feldspar grains developed by engulfing areas of the groundmass and occasional apatite grains. All stages of this process are present. A few grains having poorly developed crystal outline, are no more than alternate blebs of feldspar and intervening channels of groundmass. Other crystals with good outlines contain a scattering of groundmass. Crystallization took place by eliminating the groundmass material from the cores and rims of the grains so that many grains exhibit groundmass inclusions between clear centers and clear rims. Finally normal, clear feldspar crystals developed. In some cases crystallization was a rythmic



A. Slide No. 25. Andesite porphyry. Note zoned inclusions of groundmass in feldspars. Plain light. x 46.5 .



B. Slide No. 23. Basalt porphyry. Feldspar crystals inclosing a large amount of groundmass. Plain light. x 46.5 .

alternation of fine bands of clear plagioclase with bands of groundmass inclusions. Similar feldspars have been described by Stobbe.[26]

Biotite flakes are fairly abundant and have good crystal outline. Absorption is very strong, from yellow brown to black. Numerous inclusions of fine-grained magnetite tend to obscure the biotite.

Magnetite phenocrysts are small and rather uniformly distributed. Augite is found sparingly. Apatite grains are small and widely scattered.

Trachyte. In thin section, these rocks have certain characteristics which separate them from the andesites (see plate XXVII). The trachytes have a larger percentage of groundmass. One section contained 81% groundmass and 19% phenocrysts. Other sections generally have an even larger percentage of groundmass. The fine-grained, dense groundmass has the appearance of a devitrified glass.

About 90% of the phenocrysts are feldspar. The two types present are orthoclase and oligoclase. Some of the feldspar phenocrysts are very glassy suggesting sanidine, but optical tests eliminated it. The oligoclase is not commonly twinned, and many of the phenocrysts are not oriented in such a way that quick, conclusive optical tests could be made. The determination of the presence of, and the distinction between these two minerals rests largely on tests made on crushed fragments of phenocrysts obtained from hand specimens.

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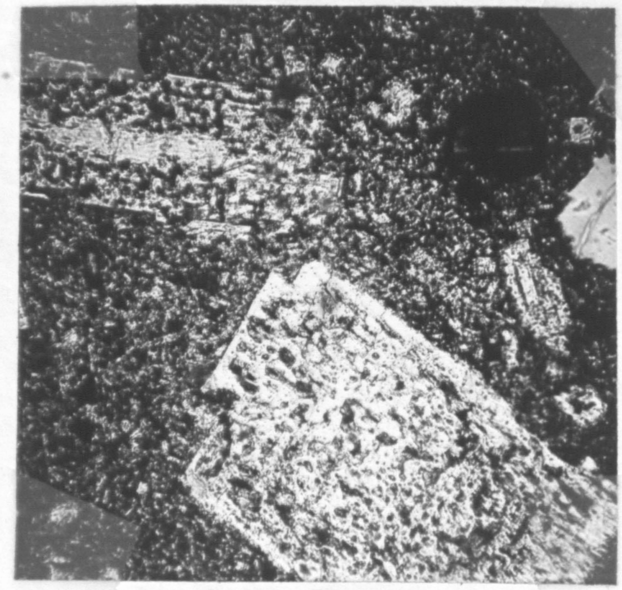
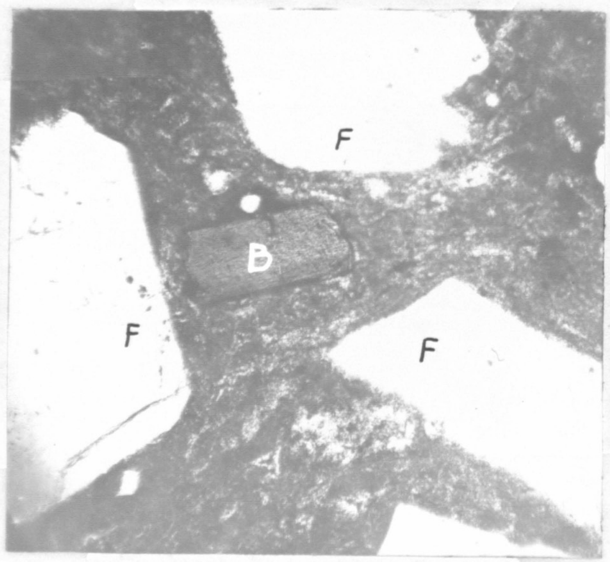


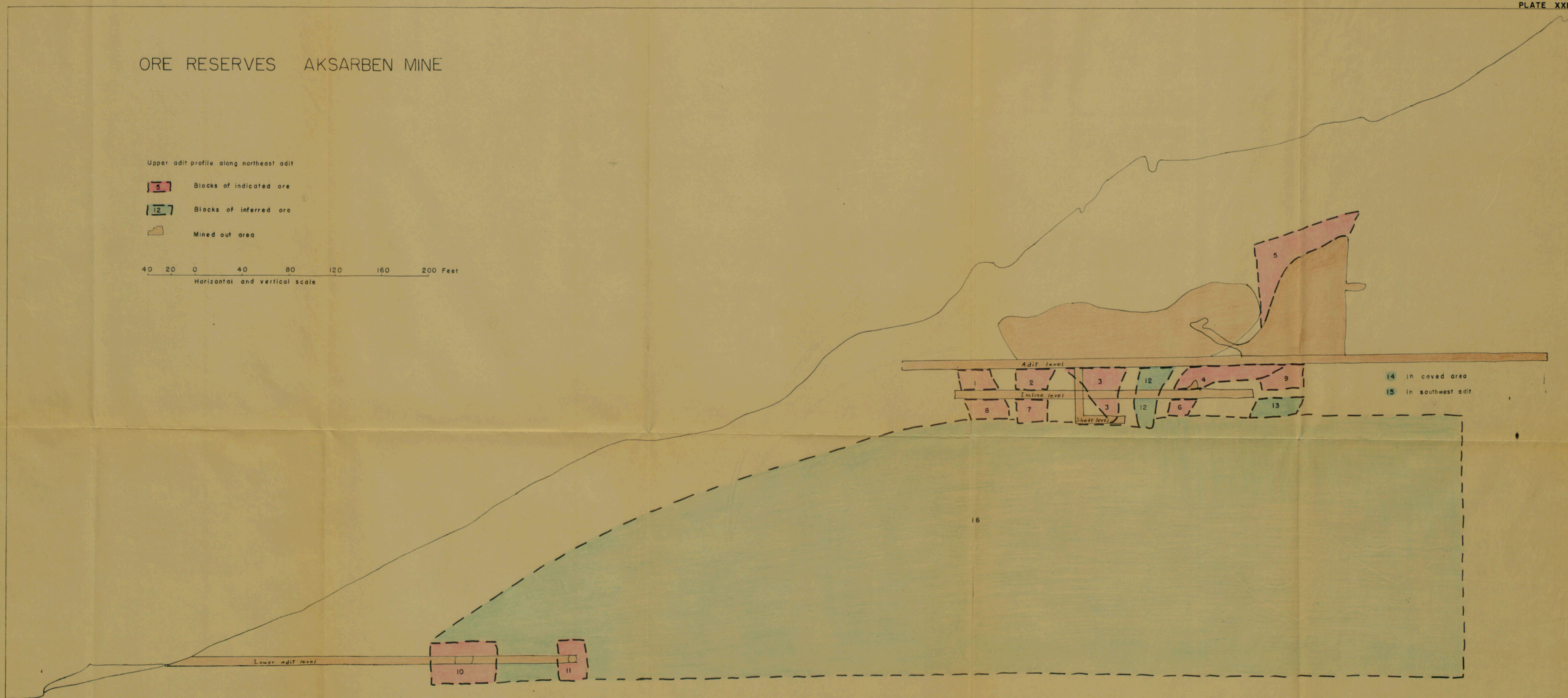
A. Slide No. 20. Trachyte porpytry. Feldspar crystals inclosing a large amount of groundmass. Plain light. x 46.5.

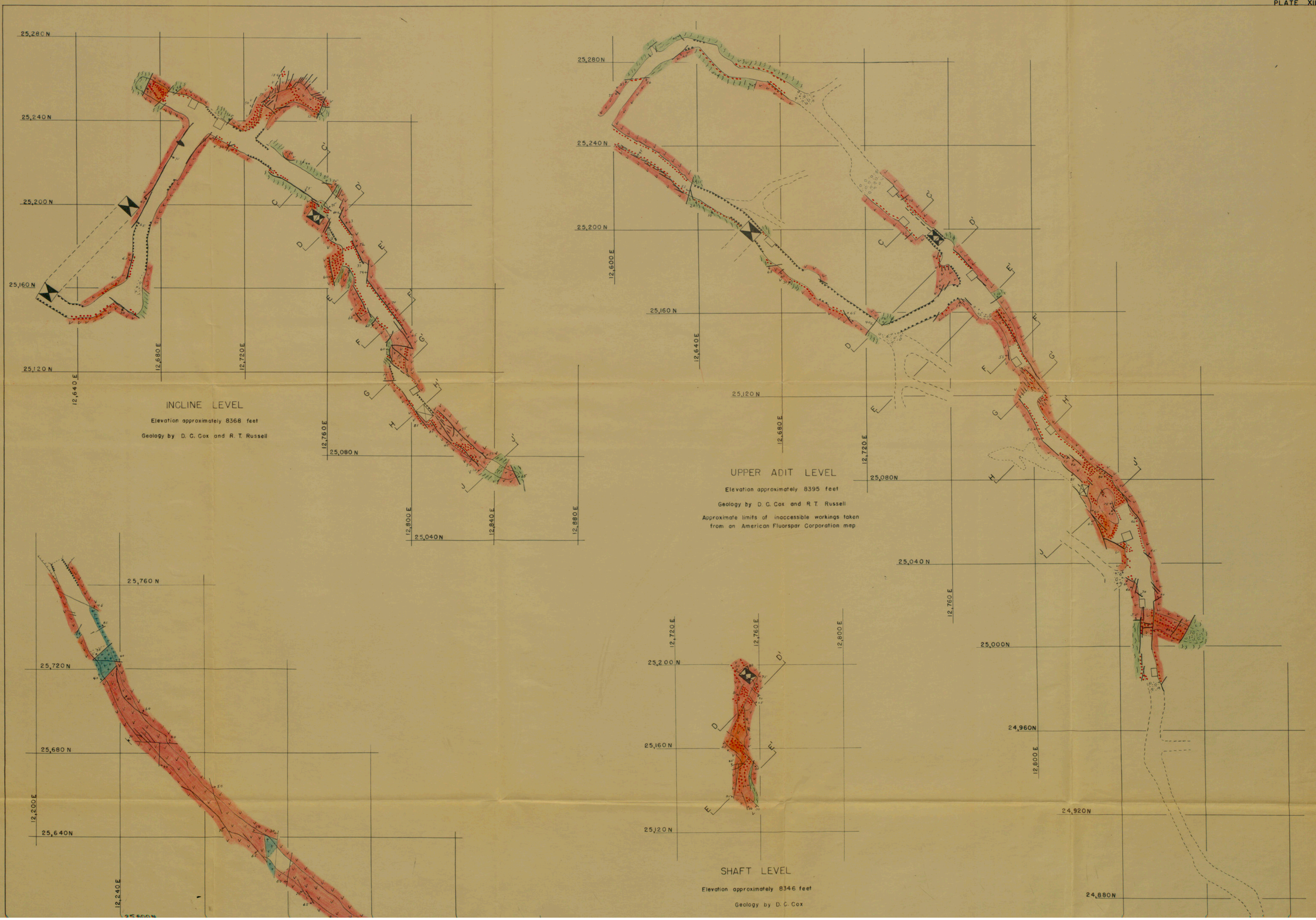


B. Slide No. 432. Trachyte porphyry. Feldspars (F) and biotite (B) in a groundmass which has distinct flow structure. Plain light. x 46.5 .

Other minerals make up a minor amount of the total phenocrysts. Their distribution is erratic. The most common and persistent one is magnetite. Its individual grains are small. Often a large amount of magnetite dust is scattered through the groundmass. Biotite is the only other primary mineral. Its flakes are small, dark brown, and have very strong absorption. Kaolin is formed from the alteration of some of the feldspars.

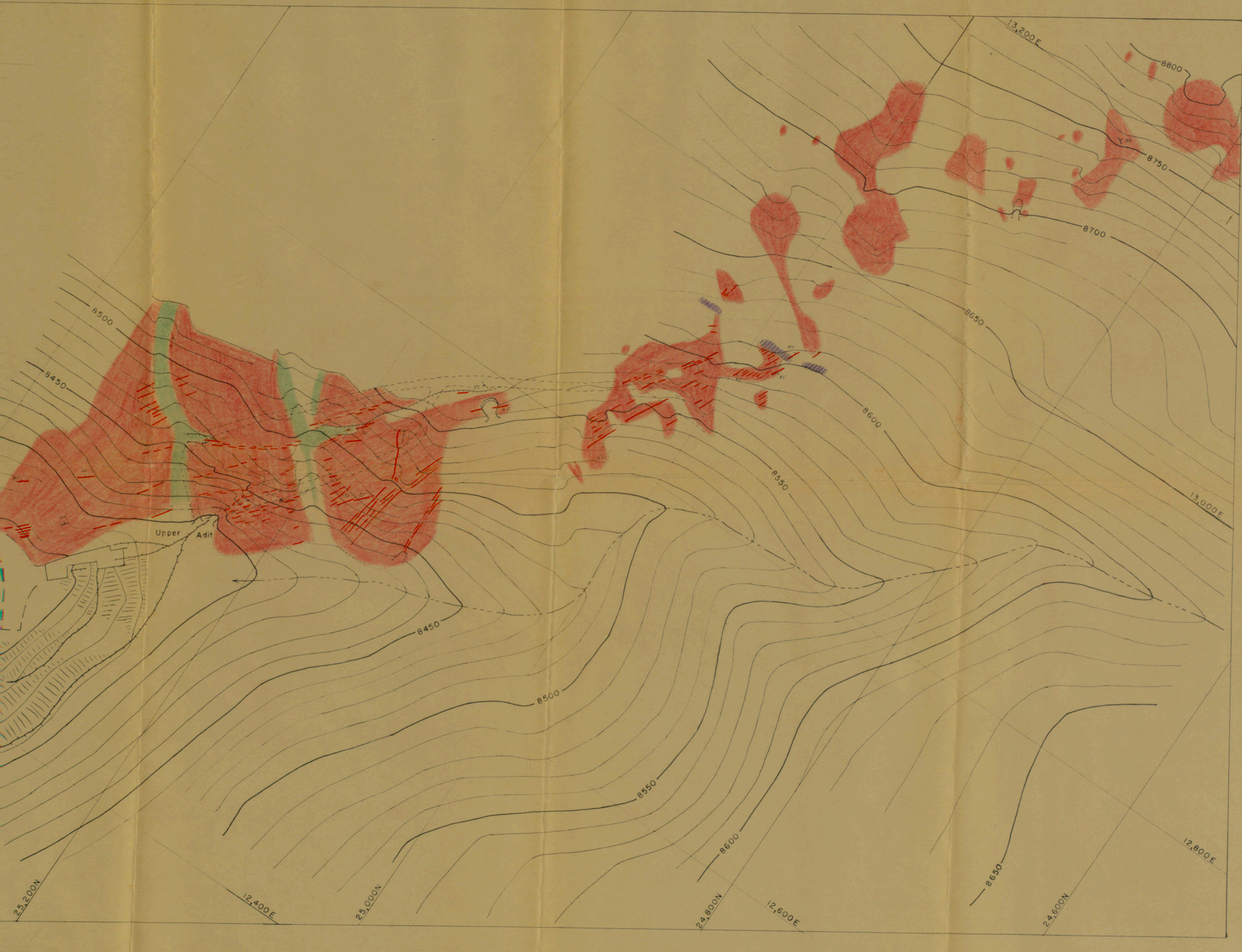
Rhyolite. The rhyolite is from a dike a short distance up the hill from the Aksarben mine. No rhyolite is associated with the belt of volcanic lavas west of the mine. This rock is felsitic and has a grayish orange pink color. Small quartz phenocrysts are sparcely distributed throughout the rock (see plate XXIV). The feldspar phenocrysts are few in number and are completely altered to sericite.


ORE RESERVES AKSARBEN MINE
Upper adit profile along northeast adit
5 Blocks of indicated ore
12 Blocks of inferred ore
Mined out area
40 20 0 40 80 120 160 200 Feet
Horizontal and vertical scale
Adit level
Incline level
Shaft level
Lower adit level
14 in caved area
15 in southwest adit
1
2
3
4
5
6
7
8
9
10
11
12
13
16


INCLINE LEVEL
Elevation approximately 8368 feet
Geology by D. C. Cox and R. T. Russell
UPPER ADIT LEVEL
Elevation approximately 8395 feet
Geology by D. C. Cox and R. T. Russell
Approximate limits of inaccessible workings taken from an American Fluorspar Corporation map
SHAFT LEVEL
Elevation approximately 8346 feet
Geology by D. C. Cox
25,280 N
25,240 N
25,200 N
25,160 N
25,120 N
25,080 N
25,040 N
25,000 N
24,960 N
24,920 N
24,880 N
25,760 N
25,720 N
25,680 N
25,640 N
12,600 E
12,640 E
12,680 E
12,720 E
12,760 E
12,800 E
12,840 E
12,880 E
12,200 E
12,240 E

GEOLOGIC MAPS OF THE MINE WORKINGS
AT THE AKSARBEN FLUORSPAR MINE
CHAFFEE COUNTY, COLORADO
INCLINE LEVEL
Elevation approximately 8368 feet
Geology by D. C. Cox and R. T. Russell
UPPER ADIT LEVEL
Elevation approximately 8395 feet
Geology by D. C. Cox and R. T. Russell
Approximate limits of inaccessible workings taken from an American Fluorspar Corporation map
SHAFT LEVEL
Elevation approximately 8346 feet
Geology by D. C. Cox
LOWER ADIT LEVEL
Elevation approximately 8140 feet
Geology by D. C. Cox and D. M. Henderson
EXPLANATION
Granite
Schist
Amphibolite
PRE-CAMBRIAN
Fluorspar in veins or breccia
Caved rubble
Fault, vertical and showing dip
Strike and dip of foliation
Raise
Winze
Incline
Ore chute
Walls lagged
Back lagged
20 0 20 40 60 80 100 Feet

8300
8250
8200
8150
8350
8400
8450
8500
Lower Adit
Upper Adit
8250
8300
8350
8400
26,000N
25,800N
12,000E
25,600N
25,400N
12,200E
25,200N
GEOLOGIC MAP OF THE AKSARBEN FLUORSPAR MINE, C
EXPLANATION
Rhyolite
Granite
Schist
TERTIARY
PRE-CAMBRIAN
Fluorspar vein showing dip
Fault
Strike and dip of foliation
Limit of outcrop
40
0
40
80
120



FLUORSPAR MINE, CHAFFEE COUNTY, COLORADO

EXPLANATION

Fluorspar vein showing dip

Fault

Strike and dip of foliation

Limit of outcrop

Adit

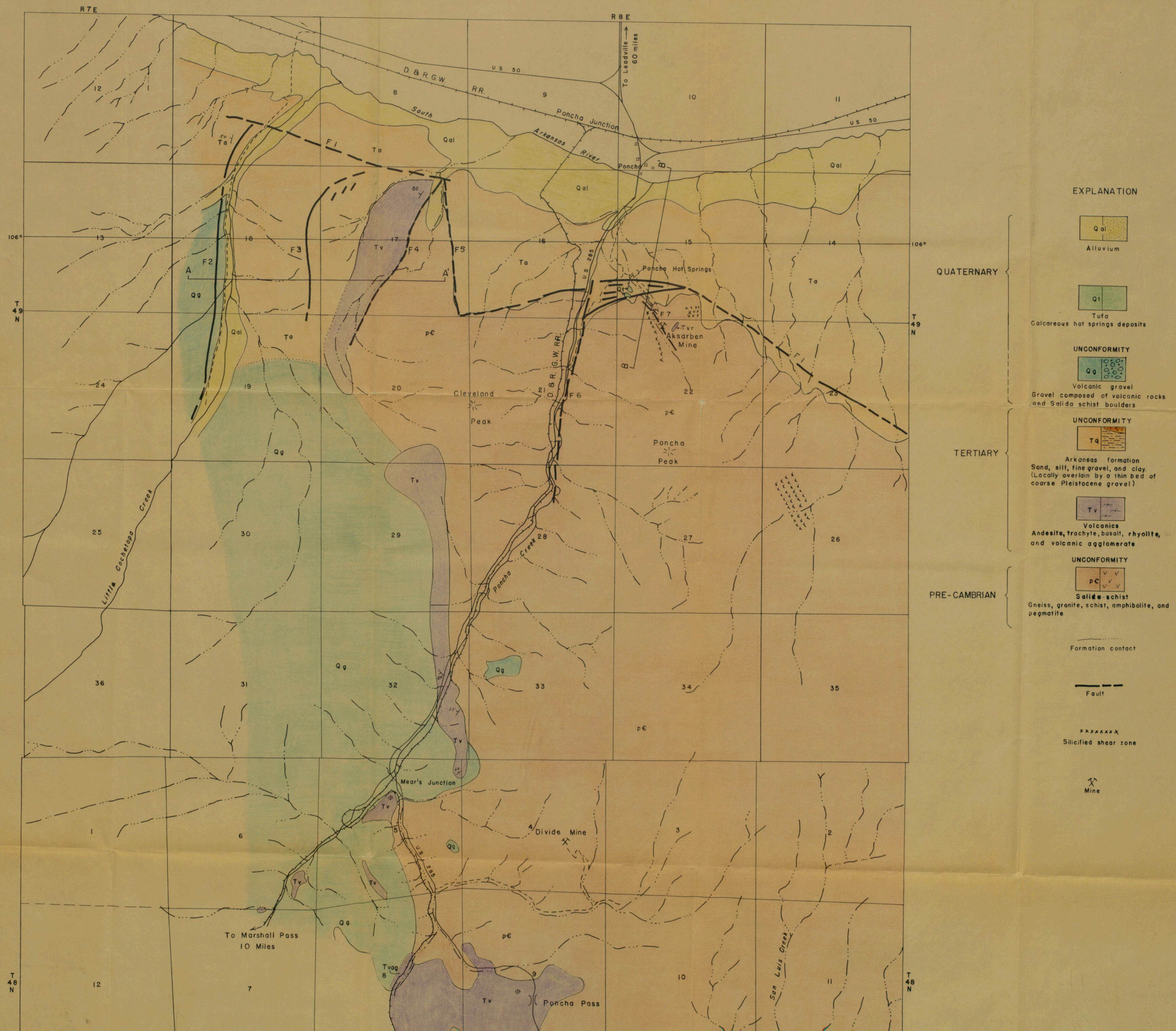
Edge of open cut

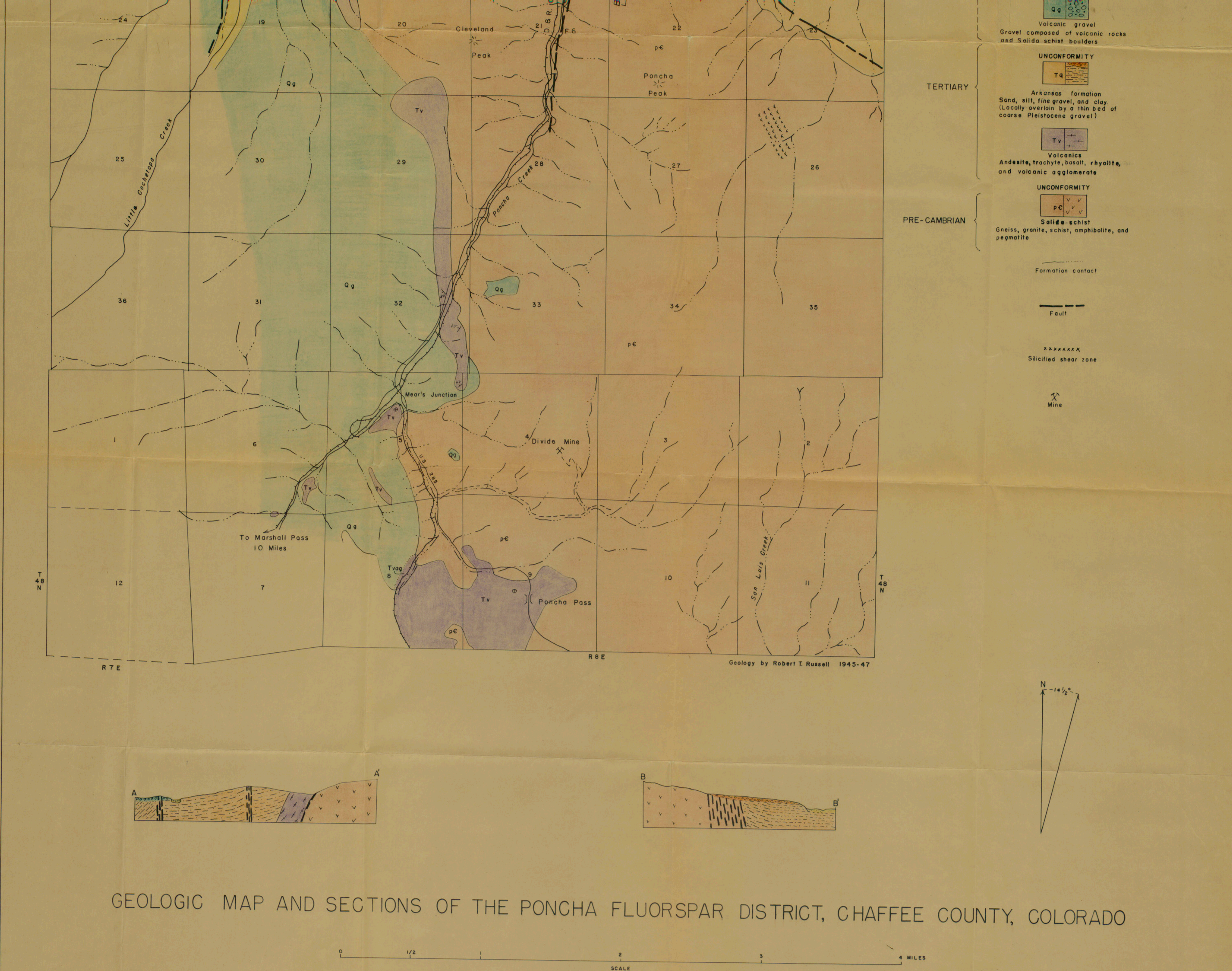
Dump

Building

40 80 120 160 200 Feet

PLATE I


R7E
R8E
To Leadville 60 miles
US 50
D & R.G.W. RR.
South Arkansas River
Poncha Junction
Poncha
Poncha Hot Springs
Tvr
Aksarben Mine
F1
F2
F3
F4
F5
F6
F7
A
A'
B
B'
Cleveland Peak
Poncha Peak
Poncha Creek
Little Cochetopa Creek
US 285
D & R.G.W. RR.
Mear's Junction
Divide Mine
To Marshall Pass 10 Miles
Tvag
Poncha Pass
San Luis Creek
106°
T 49 N
T 48 N
Qal
Ta
Tv
Qg
pЄ
EXPLANATION
QUATERNARY
Alluvium
Tufa
Calcareous hot springs deposits
UNCONFORMITY
Volcanic gravel
Gravel composed of volcanic rocks and Salida schist boulders
TERTIARY
UNCONFORMITY
Arkansas formation
Sand, silt, fine gravel, and clay. (Locally overlain by a thin bed of coarse Pleistocene gravel)
Volcanics
Andesite, trachyte, basalt, rhyolite, and volcanic agglomerate
PRE-CAMBRIAN
UNCONFORMITY
Salida schist
Gneiss, granite, schist, amphibolite, and pegmatite
Formation contact
Fault
Silicified shear zone
Mine



GEOLOGIC MAP AND SECTIONS OF THE PONCHA FLUORSPAR DISTRICT, CHAFFEE COUNTY, COLORADO

PLATE XIV


MAP OF
DIVIDE FLUORSPAR MINE
CHAFFEE COUNTY, COLO.
N
9500
9450
9400
9350
9300
9250
9200
9150
9100
9050
Adit No.1
Adit No.2
Main open cut
EXPLANATION
Foliation of granite
Adit
Open cut
Mine dump
100 50 0 100 200 300 Feet