GEOLOGY AND ORE DEPOSITS

OF THE

DARWIN SILVER-LEAD MINING DISTRICT

INYO COUNTY, CALIFORNIA

Thesis by

Vincent C. Kelley

In Partial Fulfillment of the

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MAPS
(in pocket)

ABSTRACT

The survey of the geology and ore deposits of the Darwin Hills presents two major problems. The first is the origin of the stratified silicate aureole about the Darwin stock. Such silication may be accomplished by pure thermal metamorphism or by additive processes. Field relations, supported by petrographic and chemical evidence, indicate that metasomatism played the dominant role. Considerable silica and other materials were introduced into the limestones by the magmatic emanations.

The second major problem involves the origin and classification of the ore deposits. The deposition of all the ore bodies took place at a distinctly later time that the development of the silicate aureole. A period of tectonic fracturing in which most of the fissures of the district were developed intervened between the early silication period and the later metallization period. Three structural controls, igneous contacts, bedding planes, and fractures, dominated the location of the deposits. Genetically all three structural types are the same.

The ore mineralization is not of the high temperature type and hence is not pyrometasomatic as classed by Knopf. Because of certain structural and textural features and the presence of such gangue minerals as fluorite and barite, the deposits are classed as upper mesothermal.

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INTRODUCTION

LOCATION

The Darwin district is located within the desert basin and range province of eastern California about 20 miles east of Owens Lake (Plate I). Darwin is 230 miles from Los Angeles and 24 miles from Keeler, the branch terminus of the Southern Pacific railroad. The Death Valley highway which passes through Darwin has been steadily improved since the establishment of the Death Valley National Monument in 1933. Eastward from Darwin for many miles the road follows the wash which drains a large upland area subject to summer cloudbursts. Because of the repeated destruction of the section of the highway in the wash a new road has been proposed and surveyed which will pass six or eight miles to the north of Darwin.

The area described herein as the Darwin silver-lead district is coextensive with the Darwin Hills which in turn fall within the legal confines of the New Coso mining district. The town of Darwin lies at an altitude of 4750 feet along the western

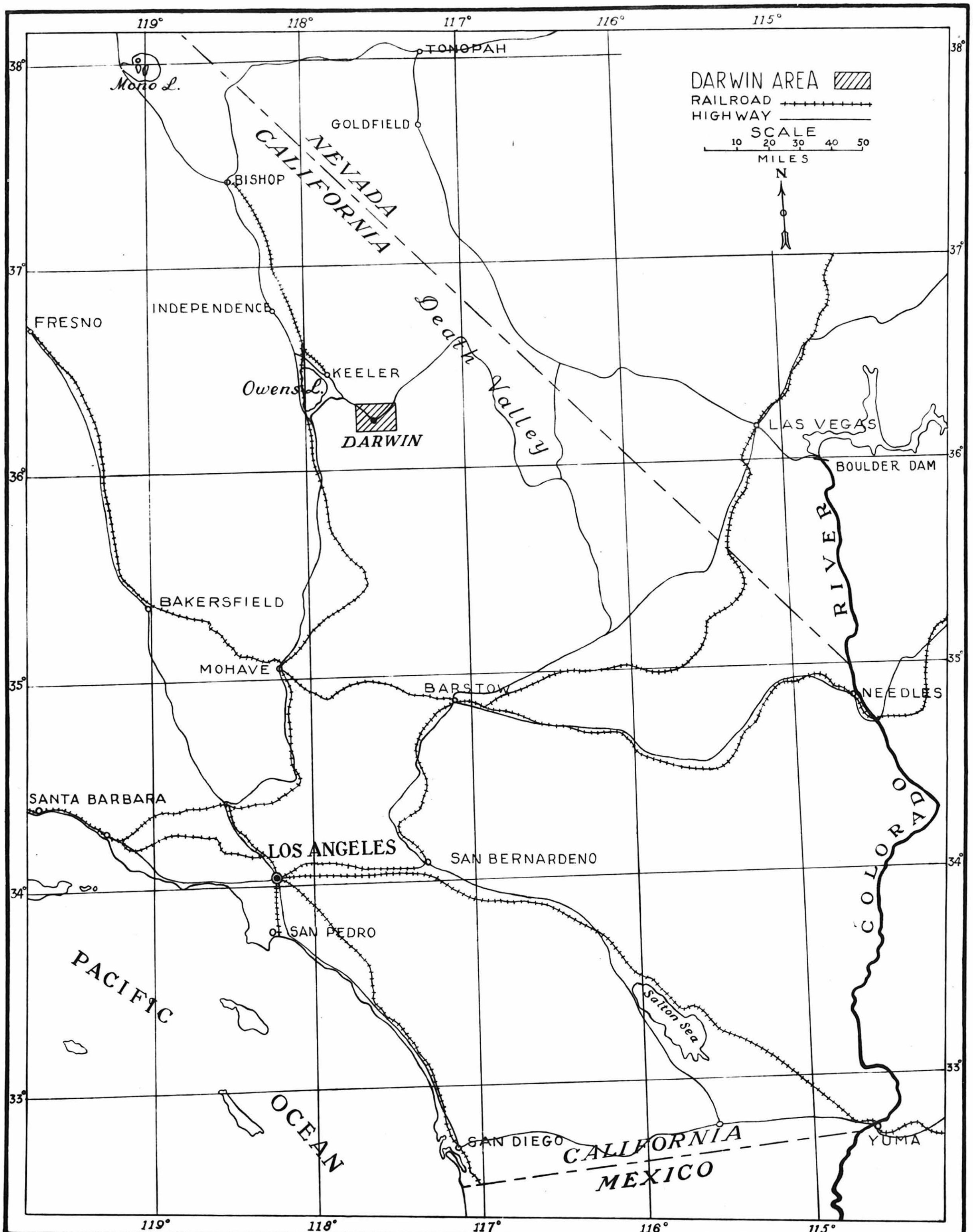

DARWIN AREA
RAILROAD
HIGHWAY
SCALE
10 20 30 40 50
MILES
N
119°
118°
117°
116°
115°
38°
37°
36°
35°
34°
33°
TONOPAH
Mono L.
GOLDFIELD
NEVADA
CALIFORNIA
BISHOP
Death Valley
FRESNO
INDEPENDENCE
KEELER
Owens L.
DARWIN
LAS VEGAS
BOULDER DAM
RIVER
BAKERSFIELD
MOHAVE
BARSTOW
NEEDLES
SANTA BARBARA
LOS ANGELES
SAN BERNARDENO
COLORADO
SAN PEDRO
PACIFIC
OCEAN
Salton Sea
SAN DIEGO
CALIFORNIA
MEXICO
YUMA

Plate I

edge of the Darwin Hills. The population of Darwin and the adjacent camps in 1937 was about three or four hundred.

HISTORY

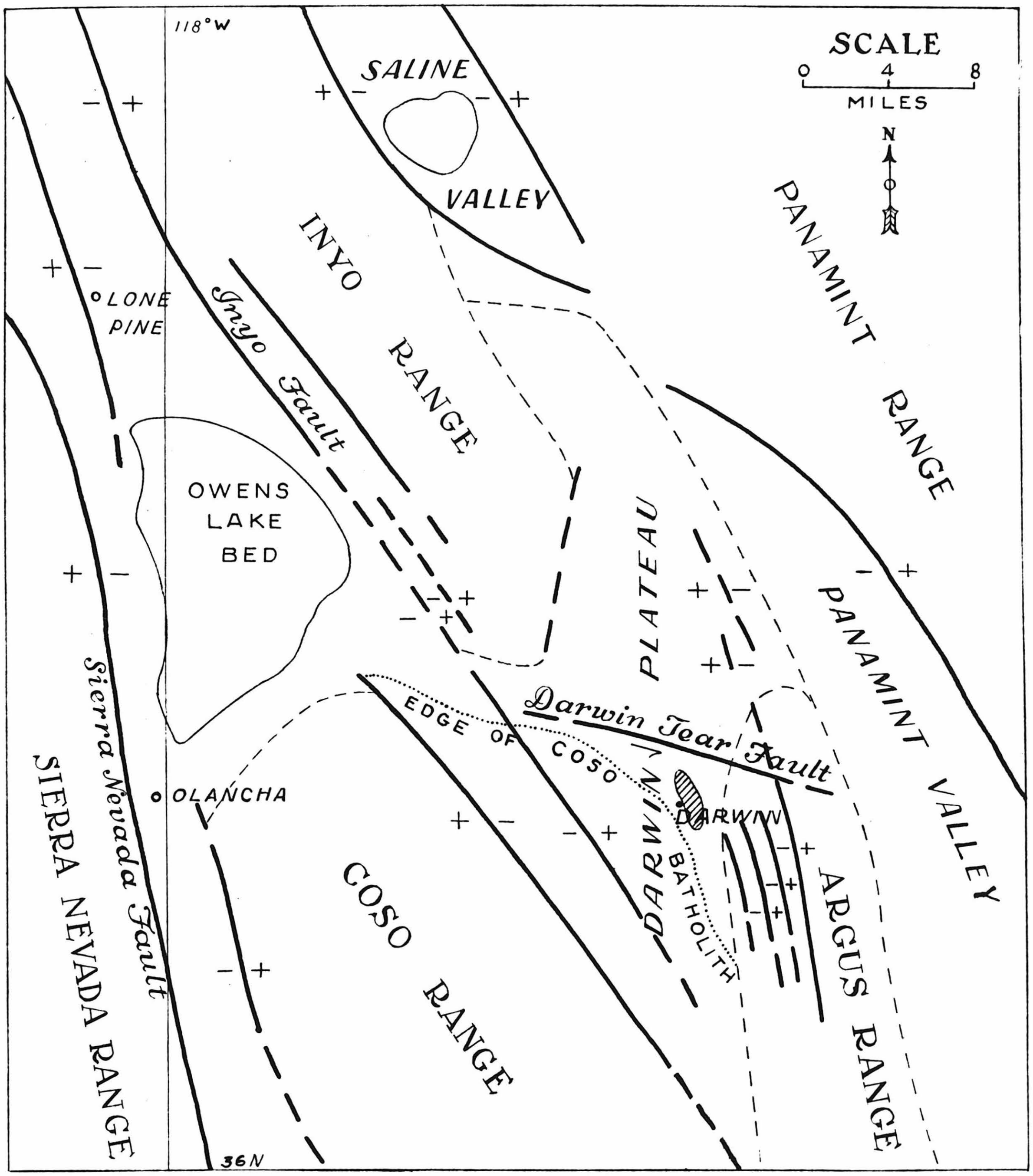
The Darwin deposits were discovered in the early seventies and the district flourished during the first two decades largely from the rich surface ores. Before 1880 several smelters had been built near Darwin with capacities from 20 to 100 tons. In 1875 water was piped down from the Coso Mountains, a distance of eight miles. During those early days Darwin is said to have spread eight blocks in either direction and to have had a population of 5000.

Only the slag dumps mark the former presence of the smelters. Due to poor transportation facilities and exhaustion of the rich near surface ores the district lay dormant or only sporadically active until the World War gave impetus to mining. About that time many of the larger properties were consolidated and development began anew with modern methods and equipment. In the early twenties a new camp and mill were erected and additional water was obtained from the Darwin wash. Although shut down during the depression, plans for reopening were formulated in 1936 and mining began again early in 1937. The district is estimated to have produced about $5,000,000 in lead, silver and zinc. About half of this was gained before 1900.

PHYSIOGRAPHY

The Darwin Hills lie near the center of a large mountain block or broken arch some 30 miles in width trending in a north-northwesterly direction in common with other ranges in this region. More often this large horst is considered in three smaller and separate physiographic units, namely, the Inyo Range, Coso Range, and Argus Range. However, the Darwin region is a separate unit or central plateau above which these adjacent ranges have been elevated by faults (Plate II). On the Darwin Plateau is still well preserved the general character of the oldland surface which existed prior to the basin and range faulting of Quaternary time.

The Darwin Hills rise only slightly above the general level of the Plateau and trend in a northwesterly direction. The hills proper are six miles in length and rise from 500 to 1000 feet above the broad Darwin Wash which borders the hills on the west, south, and east. One is first impressed with the idea that the smaller physiographic features on the plateau such as the Darwin Hills are erosional remnants on the oldland surface. However, obscure structural evidence in the form of remnants of dis-



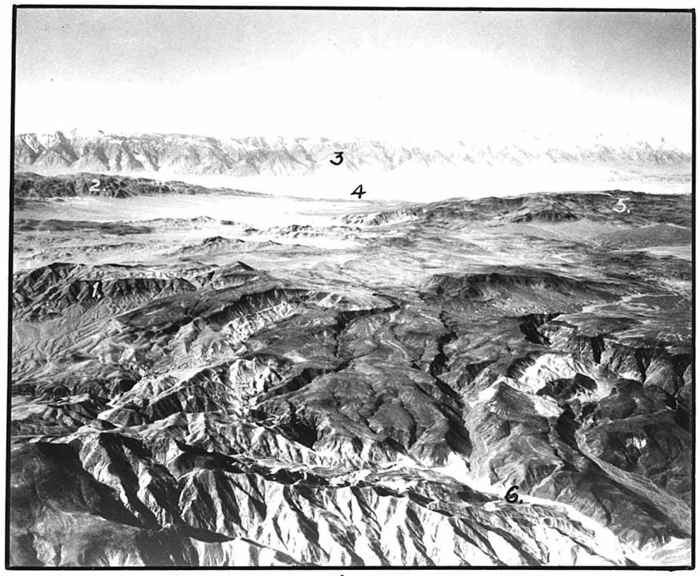
118°W
36N
SCALE
0 4 8
MILES
N
SALINE
VALLEY
INYO RANGE
Inyo Fault
PANAMINT RANGE
PANAMINT VALLEY
LONE PINE
OWENS LAKE BED
PLATEAU
Darwin Tear Fault
EDGE OF COSO BATHOLITH
DARWIN
OLANCHA
Sierra Nevada Fault
SIERRA NEVADA RANGE
COSO RANGE
ARGUS RANGE

Plate II

Plate III

A. View across the Darwin Plateau from the east over Panamint Valley. Note (1) the north end of the Darwin Hills, (2) the north end of the Coso Range, (3) the Sierra Nevada, (4) Owens Lake, (5) the south end of the Inyo Range, and (6) Darwin Wash. In the foreground is the north end of the Argus Range.

B. North end of the Argus Range and Darwin Wash from over Panamint Valley. Note (1) the sauth end of the Darwin Hills, (2) the Coso Mountains, (3) the Sierra Nevada. The lava sheets capping the Argus Range on the left are equivalent to those in Darwin Wash at the right.



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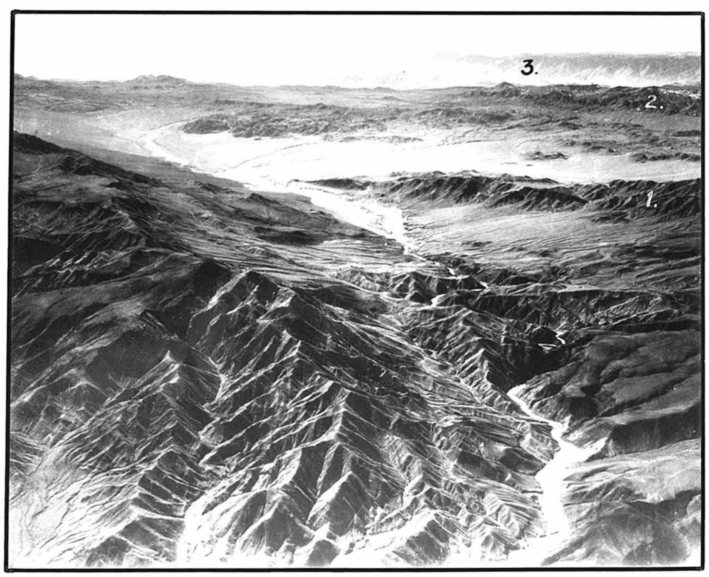


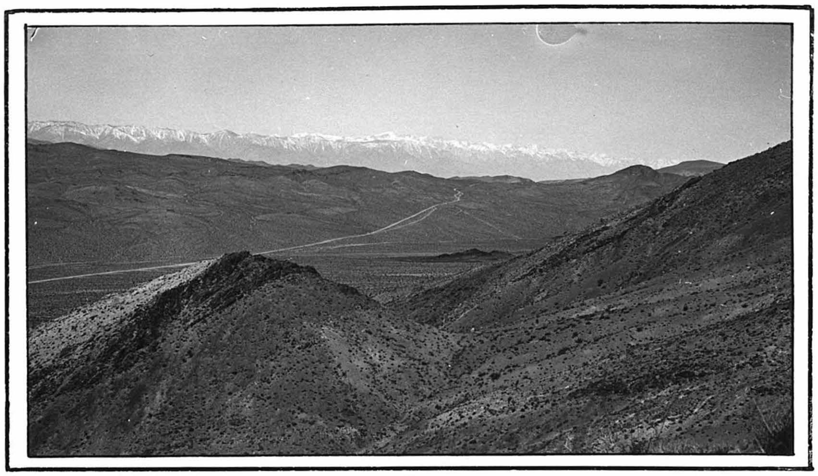
B.

Plate IV

A. Northwest across the Darwin Plateau as seen from the west flank of the Darwin Hills with the Sierra Nevada in the distance.

B. The Argus Range as seen from near the Defiance Mine looking southeast along the axis of the Darwin Hills.

C. The lava-capped steps of the north end of the Argus Range as seen from the Darwin Hills. Darwin Wash in the foreground and the snow covered Panamint Range in the distance.



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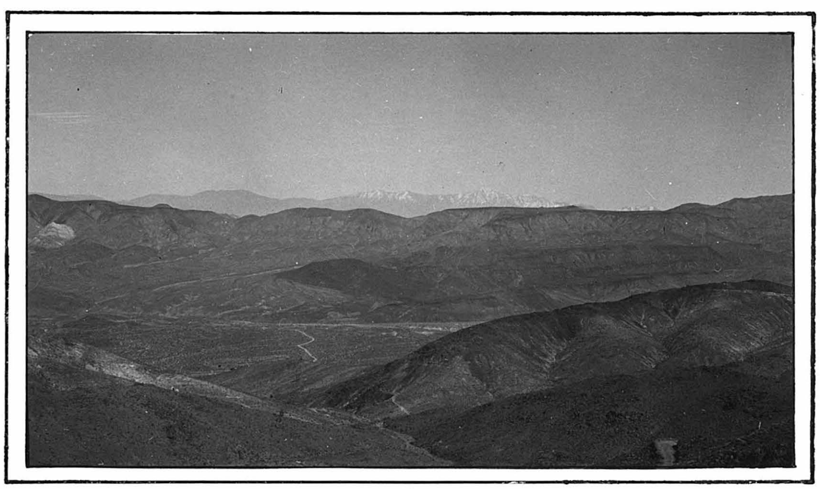


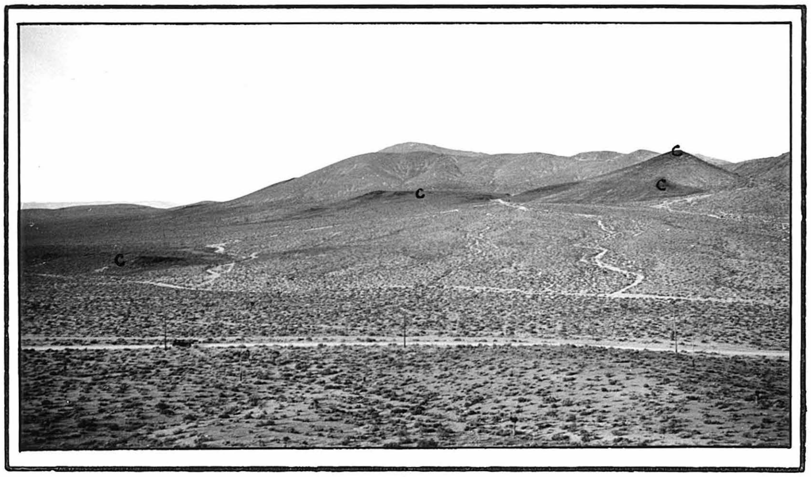
C.

Plate V

A. The west front of the Darwin Hills near the road to the Lucky Jim Camp. Note the displaced remnants (c) of early Quaternary lava sheets.

B. Ophir Peak in the Darwin Hills from the southwest.

C. The west front of the Darwin Hills near Darwin (1) and the Darwin Lead Company's Camp (2).



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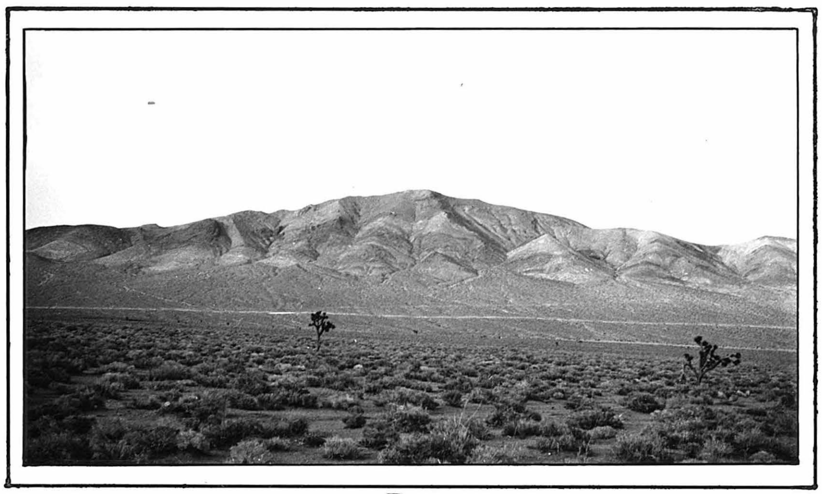
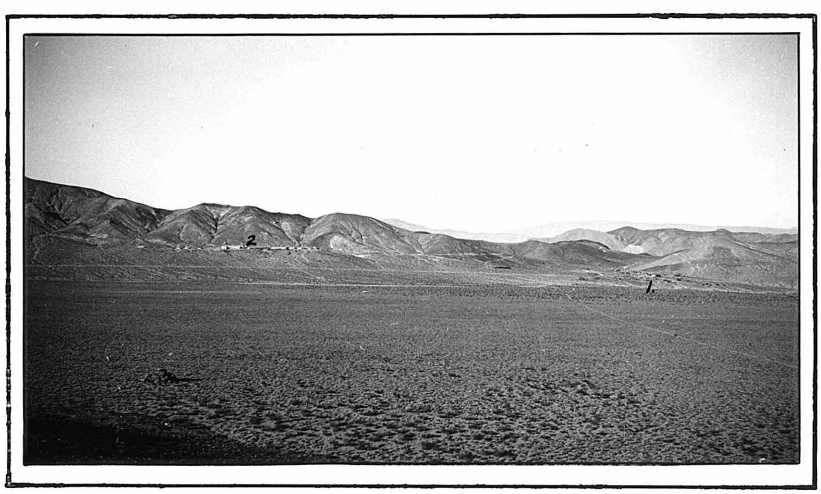


B.



C.

placed lava sheets indicates that even the Darwin Hills are a small fault block on the plateau surface. (See Plate IV-A.)

Erosion of the Darwin Hills has reached the stage of late youth or early maturity since their elevation in Quaternary. Throughout most of this period the erosional base of the hills has been the surface of the plateau itself. Very recently headward erosion in the Darwin Canyon and Wash has cut into this old base east of the hills and is at present effecting their rejuvenation in preparation for a second dissection (Plate III-B).

CLIMATE

The climate at Darwin is similar to that of the basin and range province in general. Scant rainfall, low humidity, and continued moderate shifting winds are the characteristic climatic elements. On the whole the climate at Darwin is perhaps somewhat more equable than in the adjacent areas. In the winter the temperature is apt to be very little lower than that of the Owens Valley to the west where cold air masses settle from the snow covered Sierra Nevada and Inyo Range. During the summers the temperatures are correspondingly cooler than in the adjacent desert basins. The summer temperature rarely exceeds 105° F.

The average rainfall at Keeler, the nearest station for which records have been kept, is only slightly over three inches. Although the rainfall is undoubtedly greater at Darwin it probably does not exceed an average of four or five inches. Most of this comes during the winter months. Scattered rainfall in the form of thunder showers are common during the months of July and August, but much of this runs torrentially into the adjacent basins.

WATER SUPPLY

No water for domestic or mining purposes is available in the Darwin Hills. The deepest mines in the district, the Lucky Jim and the Lane, are dry on their lowest levels which are 1000 and 800 feet respectively. The lowest level in the Lane Mine is lower than the bottom of the Darwin Wash two miles down the alluvial slope to the east where abundant water is available. The dryness of the Lane Mine thus indicates the influent nature of the Darwin Wash.

A gravity water supply for mining and domestic purposes was developed as early as 1875 by an eight-mile pipe line from a spring in the Coso Mountains. This sold at the rate of a half cent a gallon for mining purposes and a cent a gallon for domestic purposes. Water for subsequent mining and milling operations was obtained from a shallow well near the head of Darwin Canyon where the large underground water supply from the 160 square miles of watershed on the Darwin Plateau is forced near the surface. The water is pumped through a four inch pipe line with a lift of 800 feet in three miles to the mill and 1800 feet in four miles to the mine and camp. The Keystone Darwin Limited plans to pump water to their camp from a new well in the wash near that of the Darwin Lead Company. Abundant water should be available in the wash upstream from these wells but at greater depths. In 1937 the domestic supply for the town still came from the spring in the Coso Mountains at a cost of one cent a gallon.

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PAST WORK

From time to time since the discovery of the district in 1874 the reports of the State Mineralogist have contained brief descriptions of the mines and geology. These have usually been data reports on the existent mining operations, equipment, and production with notes on the local geology. The only strictly geological report was written by Adolf Knopf as the result of a five day examination of the district following his work in the Inyo Range in 1913.

As in the present report, Knopf's observations were confined almost exclusively to the Darwin

Hills. Knopf determined the age of the limestones as Pennsylvanian, summarized the general geology, and from study and description of the individual mines and prospects he deduced a genetic relationship between the pyrometasomatic deposits and the fissure veins of the district. In addition he briefly described the general character and composition of the intrusive rocks and the associated tactites.

SCOPE OF PRESENT WORK

The present report is the outgrowth of nearly three months field work during the summers of 1935 and 1936 in which time a topographic and geologic map of the Darwin Hills was made on the scale of 1000 feet to the inch. In addition, geologic reconnaissance mapping was extended over much of the Darwin Plateau and small portions of the Argus and Coso Ranges with the view of obtaining a broader geologic background for the detailed work in the Darwin Hills. Detailed geologic maps were made of the Defiance-Independence mine group on the scale of 200 feet to the inch.

During the present work the following were emphasized: (1) the character of the silicate zone about the intrusive, (2) the origin of the zone, (3) the form of the intrusive, (4) the structural pattern of the fissure system, and (5) the geologic occurrence

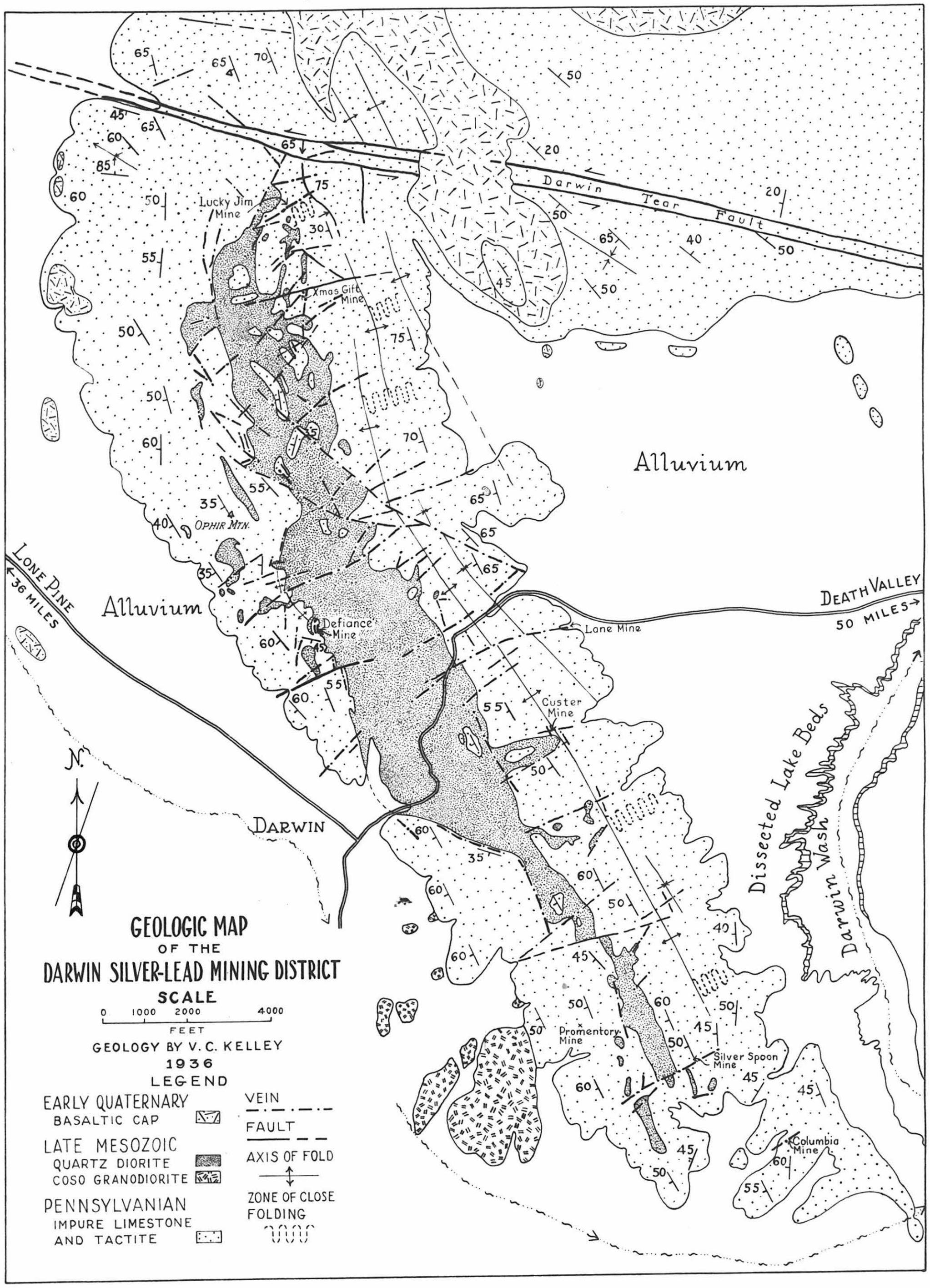
GEOLOGIC MAP
OF THE
DARWIN SILVER-LEAD MINING DISTRICT
SCALE
0 1000 2000 4000
FEET
GEOLOGY BY V. C. KELLEY
1936
LEGEND
EARLY QUATERNARY
BASALTIC CAP
LATE MESOZOIC
QUARTZ DIORITE
COSO GRANODIORITE
PENNSYLVANIAN
IMPURE LIMESTONE
AND TACTITE
VEIN
FAULT
AXIS OF FOLD
ZONE OF CLOSE FOLDING
Darwin Tear Fault
Lucky Jim Mine
Xmas Gift Mine
Alluvium
Ophir Mtn.
Lone Pine
36 Miles
Defiance Mine
Death Valley
50 Miles
Lane Mine
Custer Mine
Dissected Lake Beds
Darwin Wash
Darwin
Promentory Mine
Silver Spoon Mine
Columbia Mine
N

Plate VI

of the ore bodies. The wide silicate zone about the intrusive originated under the influence of magmatic emanations which thoroughly penetrated the surrounding impure limestones. Although the composition of the original beds was in many places the controlling factor in the resulting mineralogic make-up of the zone, concrete evidence is present for the introduction of large quantities of new materials, principally silica. The deposits are classed as mesothermal in contrast to the pyrometasomatic grouping given by Knopf. The period of metallization is sharply set off in time from the silication process by consolidation of the magma and by post-intrusive fracturing.

ACKNOWLEDGEMENTS

The field work and compilation of this report were completed while attending the California Institute of Technology in the Balch Graduate School of the Geological Sciences. The choice of the Darwin district as subject for the thesis was in part influenced by the late Professor Frederick L. Ransome. Most of the work, however, was carried on directly under Professor Horace J. Fraser to whom the writer wishes to express sincere thanks for help both in the field and in the preparation of the thesis. The writer wishes also to thank Professors Ian Campbell and George H. Anderson for criticism of parts of the thesis and for certain suggestions in the field. At Darwin many of the residents helped with information about the history of the camp, locations and names of mines, etc. Special thanks are due H. E. Olund, manager, and Sam Davis, assistant manager of the Darwin Lead Company; L. D. Skinner, owner of the Christmas Gift Mine; A. Yoder, manager and superintendent of the Keystone Darwin Limited; Theo Peterson, owner of the Darwin Garage; and Alex Rouna, owner of the Standard and Fairbanks Mines.

GENERAL GEOLOGY

GENERAL GEOLOGIC SETTING

Two contrasting rock types underlie the Darwin Plateau (Plate II). The southwestern portion, generally south and west of the road from Darwin to Keeler, is underlain by granodioritic rock closely comparable in texture, composition, and structure to the intermediate rock of the Sierra Nevada batholith. Occasional patches of older rocks are present as for example on Centennial Flats where large deposits of iron ore occur in a remnant of schist and marble. Commonly the granodiorite of this region is cut by basic dikes which often display marked persistency for considerable distances. The widespread granodioritic body of the area is referred to in this report as the Coso batholith.

The northeasterly part of the plateau is underlain chiefly by folded upper Paleozoic rocks similar to those in the Darwin Hills and in the north end of the Argus Range. Knopf[1] has described these rocks in the south end of the Inyo Range where they form folds of Mesozoic age. In the Inyo Range southeast of Keeler these folds are covered by extensive lava sheets, but they emerge again along the strike

1. Knopf, A., U.S.G.S. Prof. Paper 110, pp. 37-48. 1918.

to the southeast on the Darwin Plateau. There, they are partially cut off and offset in their distribution around the Coso batholith. The same system of folds passes through the Darwin Hills and thence southeastward, by step-faulting up, into the Argus Range. (See Plate IV-C.)

Here and there the Paleozoic rocks are pierced by small intrusives which may well be offshoots from the Coso batholith. Knopf[1] described such intrusives as common in the Inyo Range. In the general Darwin region such are exemplified by the quartz diorite stock of the Darwin Hills, the small granitic intrusion near the Lee Mine, the gabbroic stock at Darwin Falls, the monzonite plug at the north end of the Argus Range, and several smaller intrusives southward in the same range. Northeast of Darwin the truncated Paleozoic beds are extensively capped by basaltic flows which form a large part of the plateau surface and may conceal the presence of other intrusive stocks (Plate III-A).

SEDIMENTARY ROCKS

Pennsylvanian Series

A series of Pennsylvanian strata consisting largely of pure and impure limestones intercalated

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1. Knopf, A., op. cit.

with some quartzite and shale constitute the oldest rocks of the hills. Fossil corals, crinoids, fusulinae, bryozoa, and occasional ammonites occur in these beds. The state of preservation of the fossils is usually rather poor and exact determinations are therefore difficult. On the basis of determinations made by George H. Girty, Knopf[1] called the formation Pennsylvanian. The strata dip westerly across most of the width of the hills and therefore, excluding complete overturning for which there is no evidence, the younger beds crop out on the west flanks of the hills. The oldest beds or the lowest in the exposed series crop out on the east side of the hills and locally they are considerably folded. The lower strata east of the stock and on the east side of the hills are generally drab and uniform gray or brown with few distinct horizons or marker beds. The younger strata, on the other hand, which crop out on the western slopes of the Darwin Hills consist of and are marked by prominent, contrasting light and dark colored members as shown in Plate IV-A. The beds along the western half of the hills generally dip steeply west and aggregate about 2500 feet in

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1. Knopf, A., Darwin Silver-Lead Mining District. U.S.G.S. Bull. 580A, p. 5. 1913.

thickness. The contrasting nature of the members of a portion of this series is shown by the following section from the sill beneath the east escarpment of Ophir Peak to the western edge of the hills:

(1) 4-500 feet of pure, massive, white limestones
(2) 3-400 feet of dark-gray to black limestones
(3) 4-500 feet of white and grayish white limestones
(4) 2-300 feet of thin-bedded, dark-gray, impure limestone

Alluvium overlaps the youngest strata at the base of the hills and the Coso granodiorite probably intrudes the limestones a short distance beneath the alluvial cover. The members of the above series appear to finger and wedge out southward toward the Darwin Lead Company's camp where they are further confused and their identity obliterated by local folding and silication. An isolated patch of folded, pure white limestone probably equivalent to the third member above occurs at the entrance of the Radiore tunnel.

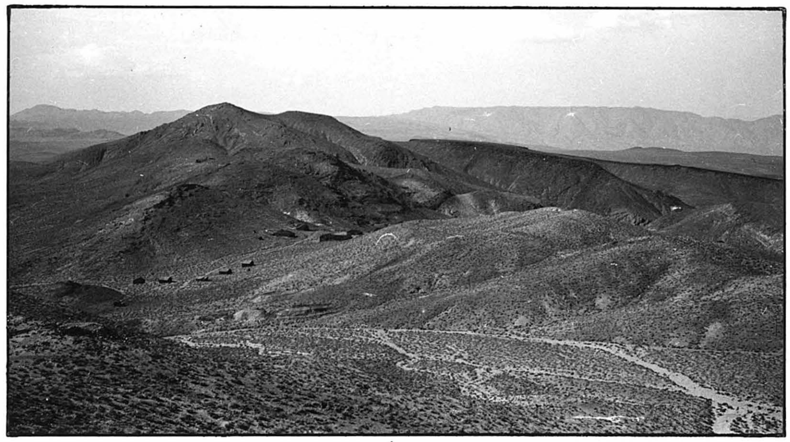
A section across the southern end of the hills shows an apparently inclined series dipping 40-60° west. The thickness of this section, although neither the top nor the bottom of the series is exposed, approximates 5000 feet. At the top of this section is a prominent member of dark-gray impure limestone which marks the bold front of the hills southward from the town of Darwin. To the north

Plate VII

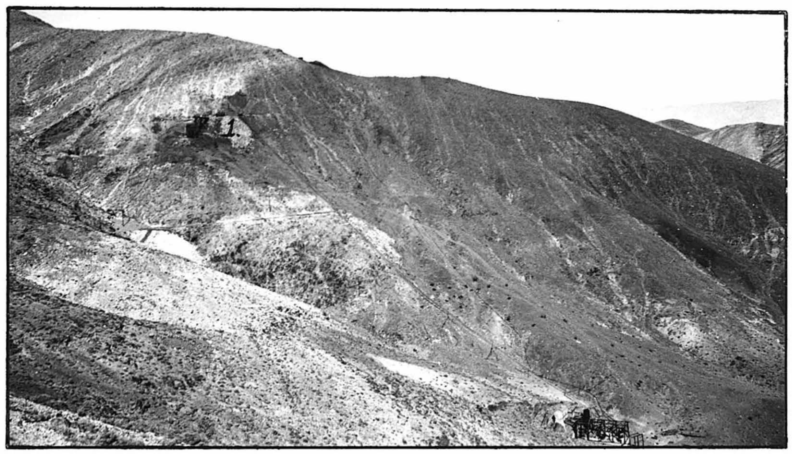
A. The Lucky Jim Camp in the north end of the Darwin Hills. Note the slightly tilted lava caps which cover the northeast portion of the Hills.

B. The irregular configuration of the west contact of the stock near the Independence Mine (1). Tactite at the left and quartz diorite of the stock at the right. Equipment at the Thompson Mine can be seen at the lower right.

C. Ophir Peak from the east. Dark quartz diorite of the stock in the foreground and stratified tactite and limestone in the distance. Note the gossanized veins (v) cropping out in the quartz diorite and tactite.



A.



B.

C.

near Darwin the character of this member is obliterated by bleaching and silication; to the south it is partially cut out by a lobe of the Coso batholith. In the center of the hills along this east-west section silication has again obliterated the original nature of the sedimentary material, but along the southeastern tip of the hills at the stratigraphic bottom of the section a dark-gray to black limestone member 6-700 feet in thickness makes up the oldest Pennsylvanian rocks in the Darwin Hills. This member occurs just east of the Columbia Mine where it forms bold cliffs 2-300 feet high facing the Darwin Wash.

The east slope of the Darwin Hills consists of closely folded, thin bedded limestone strata in which conspicuous lithologic members are absent except as noted above. The beds in general are drab brown and gray color. No white limestone strata occur and only occasional relatively thin, blue-gray limestone beds are present.

The blue-gray limestone which makes up so much of the Pennsylvanian rocks throughout the hills is commonly spotted in texture. In many instances this is due to fusulinal and crinoidal remains which, because of their differential coloring and solubility, cause a spotted texture. A similar spotty texture is also due to small lenses and nodules of chert in the limestone.

The lithology in the north end of the Darwin Hills north of the large east-west fracture here referred to as the Darwin tear fault (Plate XI-B) is noticeably different. Magenta, lavender, and brown, thin-bedded shales are common. A massive quartzite bed 30-40 feet in thickness crops out as a prominent ridge about 1300 feet north of the Lucky Jim mine. An even more striking feature of these beds is the increased spottiness of the limestones. Although some of this texture is biogenic, much of it is fragmental and undoubtedly many of the beds are depositional limestone breccias. No age determination was made of those beds north of the fault, but from the structure and direction of displacement along the fault they are most likely older than the beds south of the fault.

In connection with studies of the silication process a chemical analysis of a sample of typical blue-gray limestone from the ridge above the Thompson mine was made and this showed a content in $CaCO_3$ considerably higher than the average for limestones of Carboniferous age[1]. The table below shows the comparison of the Darwin limestone with Twenhofel's

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1. Twenhofel, Treatise on Sedimentation,

analyses of Carboniferous and Cretaceous limestones.

Limestones	Ratio $CaCO_3 : MgCO_3$	Ratio Ca : Mg
Carboniferous	8.8 : 1	12.4 : 1
Darwin	22.8 : 1	31.5 : 1
Cretaceous	40.2 : 1	56.3 : 1

Richard Wallace of Darwin reports analyses of the white limestone on the west slope of the hills which show a content in $CaCO_3$ of 98 per cent. The high ratio of calcium to magnesium in the Darwin limestone suggests that dolomitization has been relatively unimportant in the Pennsylvanian rocks.

Pleistocene Lake Beds

About 50 feet of nearly horizontal, white lake beds have been exposed by recent dissection in the wash east of the Darwin Hills. The material of the beds is fine-textured and thick-bedded and probably originated in part at least from volcanic ash. The beds are capped by recent alluvium; their base is unexposed. In the Coso Mountains J. R. Schultz[1] has found similar beds of early Pleistocene or late Pliocene age overlying older gravels and in turn capped by basaltic lavas which are probably age equivalents of the lava sheets at Darwin. At Darwin, however,

1. Schultz, J. R., Late Cenozoic Vertebrate Fauna from the Coso Mountains. Carnegie Inst. Wash, Pub. No. 487.

the age relationship between the lake beds and the lava sheets is reversed. The lake beds in the Darwin Wash are not capped by lava. Furthermore, about 700 feet east of the lake beds in the wash, on a small tilted fault block at the base of the Argus Range, basalt directly overlies Paleozoic beds with lake beds absent. From this relationship it appears that the lake beds are not only younger than the basaltic lavas, but also that they are younger than the faulting which dislocated the basalt. Although beyond the scope of this report, the evidence suggests that the lowermost step fault in the Argus Range was at one time the obstruction to the drainage of the wash which created the lake in which the white beds accumulated. These lake beds, then, are distinctly younger than those described by Schultz in the north end of the Coso Mountains. If those in the Coso Mountains are early Pleistocene, then the Darwin lake beds may be middle or even late Pleistocene in age. No fossils have been found. Headward erosion in the Darwin canyon has subsequently dissected the lake beds by cutting through the outlet of the lake.

Recent Alluvium

The alluvial deposits of the broad washes and fans surrounding the Darwin Hills are of two types, older dissected gravels and recent gravels. The younger gravels are in part derived from the older and in places they grade into each other. These two types do not result from diastrophic rejuvenation, but rather from the down-cutting of the outlet to the Darwin Lake which was the former temporary base level for the erosion around the Darwin Hills. The dissected gravel where overlying the exposed lake beds is usually not more than 10 to 20 feet in thickness. Upstream from the exposed lake beds and especially in the wash south of the Darwin Hills the gravels are much thicker and arroyos as much as 50-75 feet in depth have been carved. Dissection of the gravels on the west side of the hills is very slight compared to that on the east by reason of the bench of hard rock through which the stream flows at the south tip of the Darwin Hills. At this point a dry falls exists which is 50-60 feet in height. Adjacent to the limestone hills not only the alluvium but also the lake beds are well cemented by calcium carbonate.

IGNEOUS ROCKS

Coso Granodiorite

The Coso granodiorite is batholithic in extent and underlies most of the plateau south and west of the Darwin Hills. A small area of this rock crops out in the southwest edge of the hills where it forms low rounded hills in contrast with the sharper relief of the limestones. Along the road to the Promentory mine it can be seen in intrusive contact with dark-gray limestones. Although thin sections from the rock of this area indicate it to be granite, the designation granodiorite is retained because it more nearly proximates the average composition of the batholithic material throughout the plateau . Megascopically it is a coarse-grained, light-colored, granitoid rock in which the principal minerals are quartz, feldspar, and green hornblende. Under the microscope most of the feldspar proves to be orthoclase or microcline. Biotite is common and such accesory and secondary minerals as sphene, apatite, chlorite, and epidote may be present. A few dark-green kersantite dikes cut the granite in the Darwin Hills.

Darwin Quartz Diorite

General Features.

The formation name, Darwin quartz diorite, is here applied to the elongated stock which occupies the center of the Darwin Hills. All metallization is associated with this intrusive. The stock is about 3500 feet in its greatest width which is just northeast of Darwin (Plate VI). To the north and south it narrows and terminates in smaller isolated stocks, dikes, and sills. It ends entirely within the hills and its total length is about five miles.

The drab brown color of the intrusive causes it to stand out nearly everywhere in strong contrast to the surrounding white silicate zone (Plate VII-B). The greater ease with which the intrusive weathers has caused it to form a lower interior belt of subdued topography surrounded by boldly outcropping stratified rocks (Plate XI-A). Due to variations in composition and texture, the igneous mass itself weathers and erodes differentially. Thus, near the Defiance mine are several small knobs and ridges of quartz diorite standing out in otherwise subdued relief.

Composition and Variations

The stock as a whole displays considerable heterogeneity of composition, but for the most part these variations are only phases of the one intrusive. In nearly all of its phases the rock is medium grained and non-porphyritic. It is typically a light colored, white or light-gray rock when fresh. Pinkish and greenish-gray types are also common. In general, variations in the intrusive range from quartz monzonite to diorite or gabbro. Nearly all of the phases are of the oversaturated type in which quartz is always present in essential quantities. In the types from quartz monzonite to quartz diorite the principal variation comes, then, in the relative proportion of orthoclase and plagioclase. In the quartz diorite or even the granodiorite the euhedralism of the plagioclase is the striking textural feature under the microscope. With increase of orthoclase this tendency of the plagioclase diminishes. In composition the plagioclase appears to vary with the phase from labradorite even to albite although oligoclase is perhaps the most abundant type.

In the oversaturated phases the ferromagnesian minerals are ordinarily not abundant. The most common ferromagnesian mineral is biotite. Hornblende and augite are decidedly less common and in many phases absent. Where the ferromagnesian content is high the mineral is most commonly augite. In some of the more basic phases of the stock augite and labradorite may be nearly the sole constituents.

Distribution and Origin of the Phases

The more basic phases of the rock occur in the north and south ends of the elongate stock. The change towards basicity is gradual yet very irregular. There is greater heterogeneity of phases and greater concentration of the melanocratic phases in the narrower terminations. Examples of the basic rock areas are well shown near the Christmas Gift mine where the rock is augite diorite or gabbro. Again near the southern end of the Christmas Gift Extension claim is a considerable area of very dark-colored rock which is almost entirely composed of augite with a little labradorite. In the southern end of the hills west of the Silver Spoon mine and south of the Promentory mine are areas of dioritic or locally augitic rocks. It should be restated here for emphasis that these various types of rocks are not separate intrusions, but that they belong in some way to a pre-consolidation heterogeneity of the magma.

Compositional variations within small intrusions are well known, but the causes are less well known. It is generally assumed that somewhere at depth molten material is nearly homogeneous and that various types result from some sort of differentiation. The ways and means of the process of differentiation are discussed in current texts and it suffices here to say that at present no general agreement exists in the matter unless it be the tendency to grant several modes of operation.

If it be assumed that the deep reservoir of molten material which gave rise to the Darwin stock was originally homogeneous then the rock variation within the stock may have resulted in either of two ways. First, the homogeneous reservoir may have differentiated *in situ* and the separated parts injected into the present seat of the stock. Second, the homogeneous material may have been emplaced in stock form with differentiation resulting thereafter either by crystal fractionation, gaseous transfer, filter pressing or some other process. There is no direct line of evidence which indicates that the stock differentiated in place. Furthermore, except locally, reactions with the country rock do not appear to have influenced the composition. No border phase of more basic rock exists. Instead, the total impression gained is that the phases are due to original variations in the intruded material.

It may be that the first intruded material was basic and that later surges, intermediate in composition, pushed the basic material outward and toward the ends. The stock grew centrally with more acidic material continuing to concentrate there.

Related Dikes

In places the border portion of the intrusive and the nearby contact aureole contain many dikes. Some of these are direct offshoots of the stock and

Plate VIII

A. Alaskite dikes (white) cutting tactite above the Defiance mine.

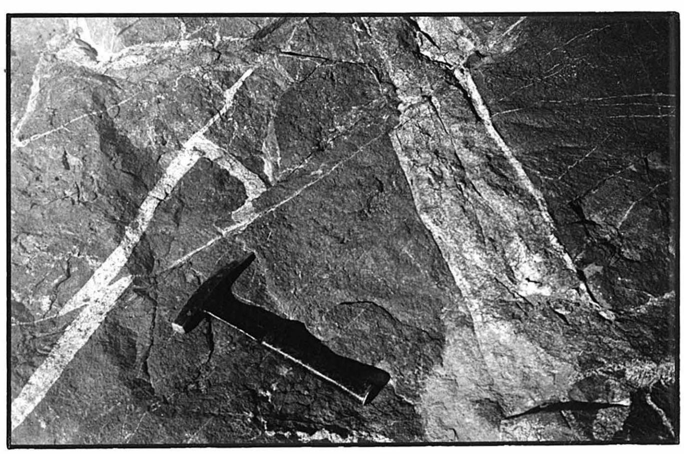
B. Alaskite sill with offshooting dikes in tactite near the Defiance mine.

C. Acidic dikes cutting quartz diorite near the contact at the Bernon mine.

Note: Many similar dikes in the tactite are composed entirely of orthoclase and in others quartz is present in only small quantities. (See text, page 33.)

A.

B.



C.

cut only the country rock. Others are later and cut the intrusive also (Plate VIII-C). These dikes are all more acidic than the intrusive. In a few cases offshoots from the intrusive where traced outward become increasingly acidic, changing sometimes to alaskitic or syenitic dikes. The syenite dikes are very common in the contact aureole between the Defiance mine and the Thompson mine. It is coarse grained and composed almost entirely of orthoclase. The color varies between pink, green, and white. Whereas these and other dikes may have originated as magmatic dikes in the ordinary sense, the evidence suggests in some cases an origin by metasomatic processes. South of the George Washington shaft in the southern part of the hills alaskitic material has spread in anastomosing manner from stratification planes through several adjacent beds converting them completely to alaskite or quartz-orthoclase rock. In other places feldspar dikes appear to fray out and permeate adjacent walls in a manner suggesting replacement. This subject is treated more fully under igneous metamorphism. Likewise the subject of alteration of the intrusive is dealt with in the same chapter.

Plateau Basalt and Tuff

Many square miles of the Darwin Plateau are covered by basaltic flows (Plate III-A). The surface upon which this material was extruded was remarkably smooth, but it has since been broadly warped and block- or step-faulted. As a result the sheets are not everywhere continuous and in large areas they have been entirely removed by erosion. Furthermore, in downwarped or downfaulted areas much of the volcanic material has been covered by alluvium.

The northeastern edge of the Darwin Hills is covered by a basaltic sheet sloping 10-15° toward the east (Plate VII-A). At the west edge of the sheet the thickness is about 20 feet, but eastward it thickens to 400-500 feet and four or five flows are distinguishable. Several thin isolated remnants of basaltic cap occur at distinct levels along the west flank of the hills (Plate V-A), and while the uppermost of these is being exhumed by erosion the lower patches are being covered by the outspreading alluvial apron. The pronounced difference in thickness of the sheet on the higher slopes of the Darwin Hills and to the east near Darwin Wash and Panamint Valley may be in part due to the lateral stripping of the flows in the higher area, but for the most part this difference is probably original. The difference in thickness and number of flows together with the occurrence of agglomeratic ejectamenta beneath the lavas in the lower course of the Darwin Wash suggest that the source of the volcanic flows in the northern part of the Darwin Hills was from the east, probably near the edge of the present Panamint Valley. The base of the basalt series is nearly everywhere characterized by loosely consolidated brown cinder beds. Near Darwin these are only a few feet in thickness, but toward the east they thicken considerably.

The extensive basaltic sheets of this region are all pre-basin and range faulting and were thought by Knopf to be probably of early Quaternary age. In this respect it is interesting to note the presence in this region of small basaltic cones which are younger than most of the basin and range faults. As in Owens Valley to the west many of these have had their position determined by the basin and range faults. To the east of the Darwin Hills along the flank of the Argus Range are two such cones. One of these has its locus along the Darwin tear fault and the other rose along one of the step faults of the Argus Range (Plate IV-C).

STRUCTURE

SHAPE OF THE STOCK

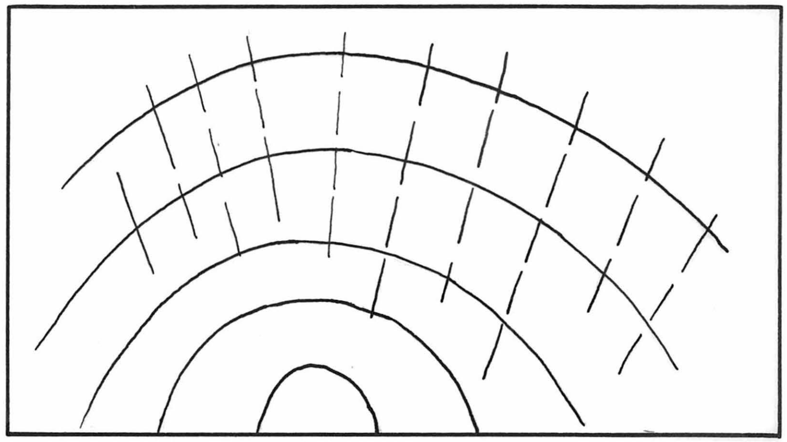
The Darwin stock has a length of five miles and a maximum width of about two-thirds of a mile midway of its length. From the central part it tapers irregularly into narrow north and south tips which are only a few tens of feet wide (Plate VI). The general trend, N 25° W, is parallel to that of the sedimentary formations into which it is intruded. In detail its original outline was quite irregular with many large and small protuberances and outliers. However, much of its present irregularity has been caused by subsequent cross faults which have offset the body in many places. In the northern part, the stock is characterized by many inliers of tactite which attest to the proximity and irregularity of its apex in this region.

In general the contact of the stock dips outward on both sides and so it widens in depth. On the west side the contact dips under the tactites approximately parallel to their stratification (Plate X) which is inclined on the average 50 to 60° westward. On the east side, especially in Lane canyon, the contact crosscuts the westward dip of the tactites. Toward the north and south ends of the stock the contact may conform to the west dip of the tactites in which places the stock would appear sill-like in cross section.

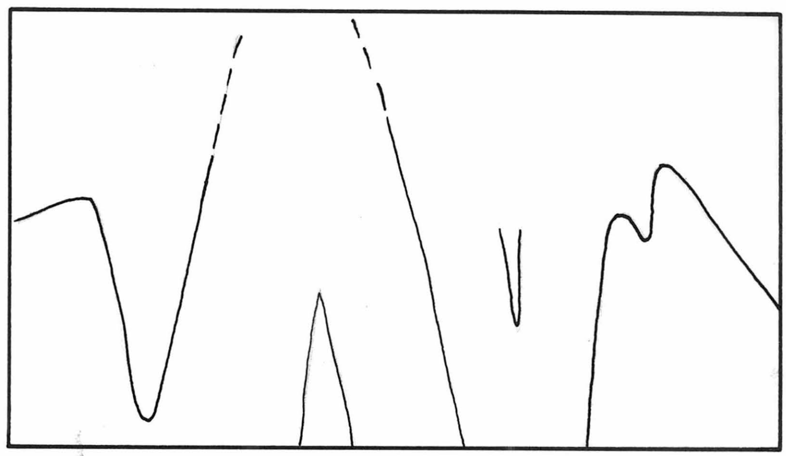
FOLDS

The stock is intruded into steeply inclined beds of a folded Pennsylvanian series. The deformation of the Pennsylvanian rocks on the west side of the stock differs from that on the east side. The series on the west side of the stock is practically homoclinal and dips generally S 65° W at 50°. Two types of small local folds interrupt this general attitude of the beds. The first are small, nearly upright and horizontal folds with axes parallel to the trend of the formation. Only two or three such folds occur in the series, the most noteworthy of which is the one near and parallel to the intrusive contact between the Defiance and Essex mines. The second class of local folds are in the nature of warps in the regional trend and, although the axial attitudes are difficult to determine, they are steep and usually at a considerable angle to the general strike of the beds. One such fold with axis pitching steeply westward occurs in the hills west of the Fairbanks mine (Plate XI-B); another occurs high on the slope of Ophir Peak and can be seen from the highway approaching Darwin. These folds are like local knots in the otherwise even grain of the formation. It seems likely that the stresses which produced this

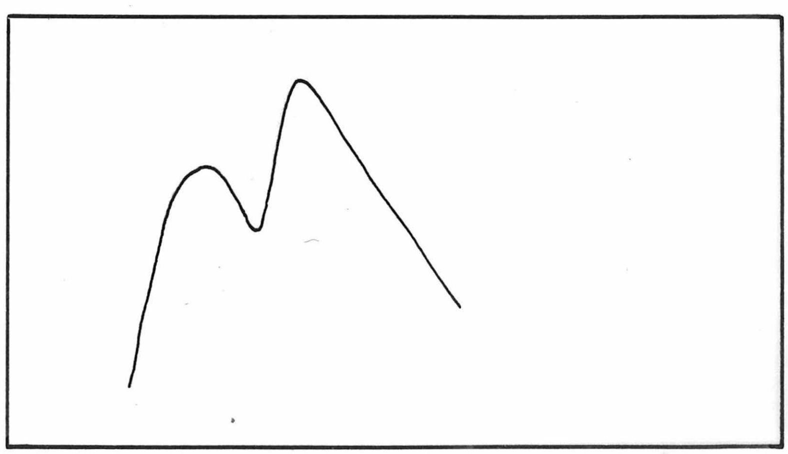
PLATE IX



A. Small concentric anticline developed in the zone of folding along the east flank of the Darwin Hills. Note the radial tensional jointing.

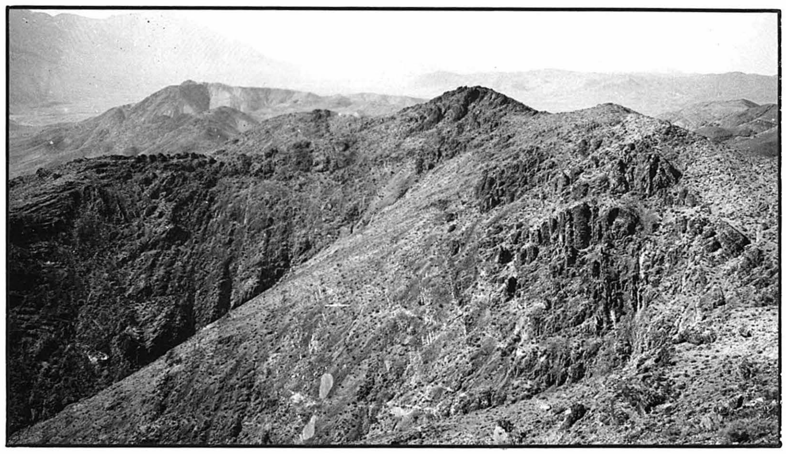


B. Closely folded beds along the same zone.



C. Detail of the small fold at the right in B.

A.

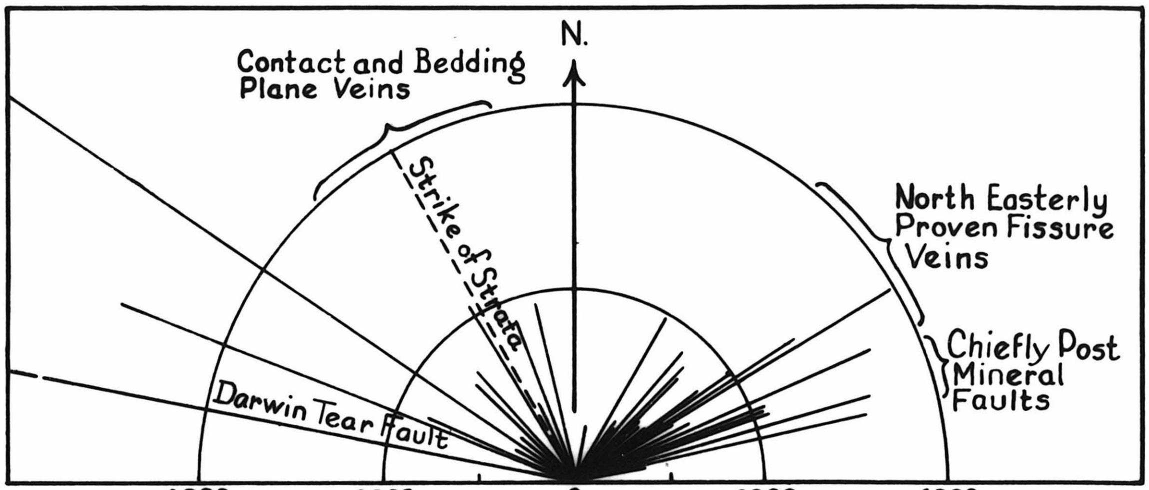


B.

C.

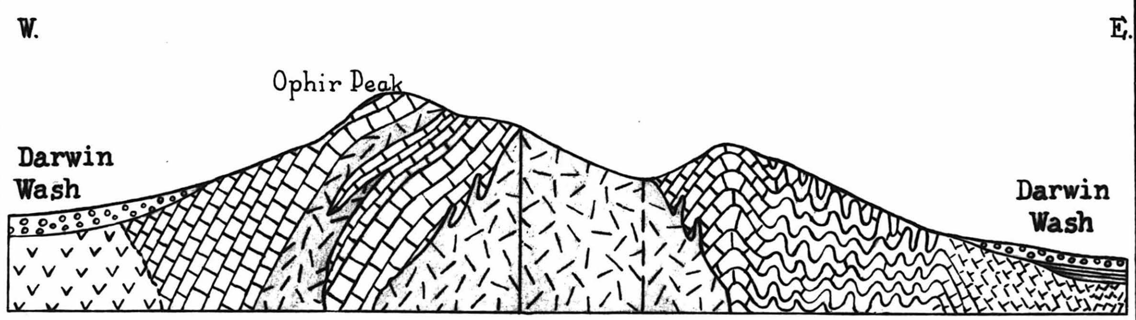
second class of folds were different in direction from those which caused the first class of folds.

The beds on the east side of the stock are considerably folded. Immediately east of the contact the beds dip west into the stock, and the first fold is usually encountered at a distance of 1000 to 2000 feet from the contact. In places this is a large anticlinal fold with limbs dipping 60 to 80°. Along the highway through the hills the folding consists of one anticline and syncline between the east contact of the stock and the alluvial edge, a distance of about a half mile. If this simple folded belt is followed northward to the steep slopes of the hills east and southeast of the Christmas Gift mine, the folding resolves into an intricate belt consisting of many closely spaced and nearly isoclinal folds (Plate IX). To the south of the highway along this same folded belt, which occupies generally the east front of the hills, are similar closely folded zones particularly in the vicinity of the Fernando mine and south of the Keystone mine. Immediately east of the Lucky Jim mine in the north end of the hills, another zone of close folds exists in which one of the folds is overturned and broken into a high angle overthrust to the east. In many other places the close folds



Analysis of Direction and Magnitude of Faults and of Veins in the Darwin Hills.

A.



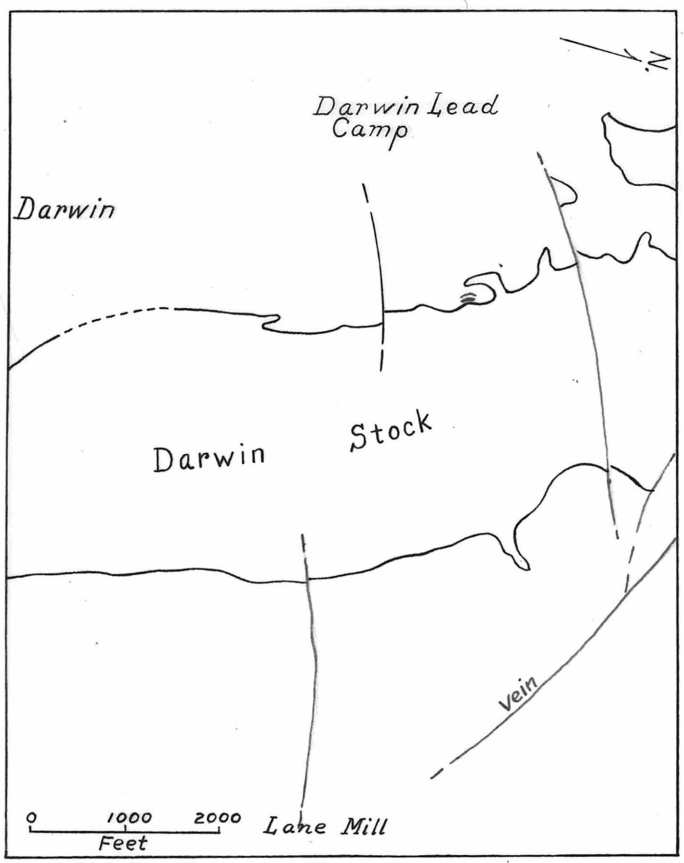
Generalized Structure Section Through the Darwin Hills Near Ophir Peak

LEGEND

Recent Alluvium
Pleistocene Lake Beds
Darwin Quartz Diorite
Coso Granodiorite
Pennsylvanian Limestone and Tactite

B.

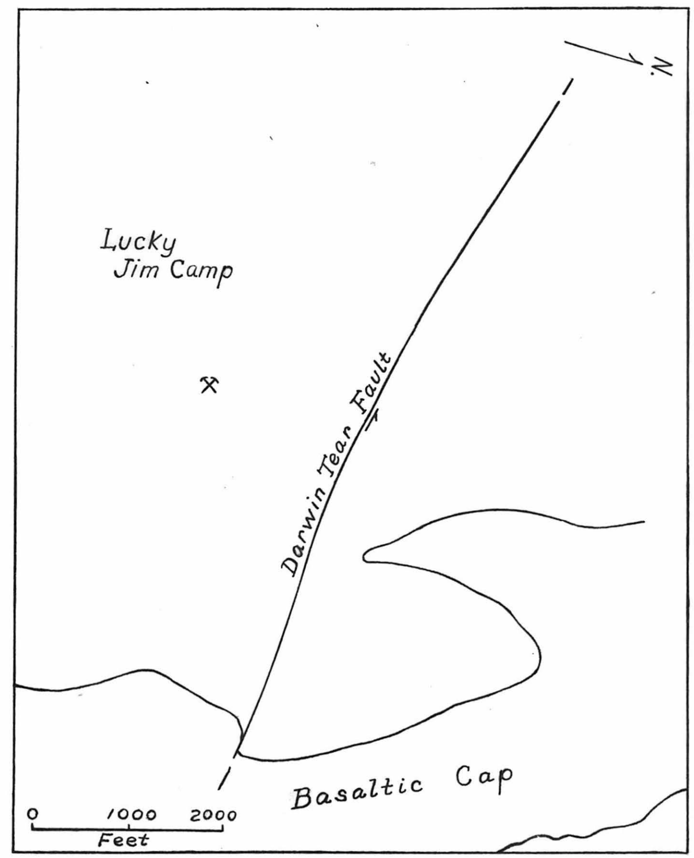
Plate X



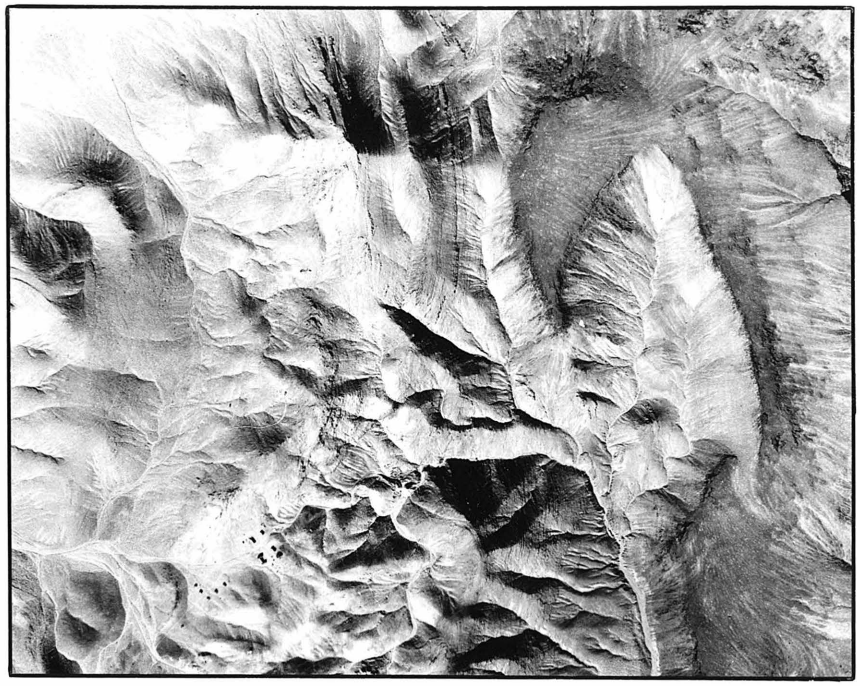
A. Darwin Hills in the vicinity of the town and the Darwin Lead Camp.

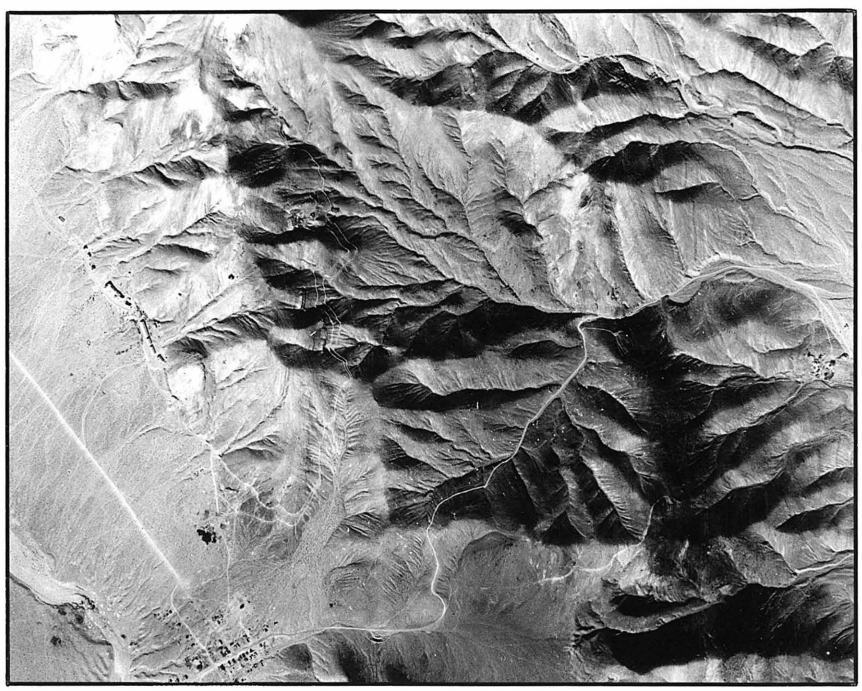
Plate XI

Vertical Views



B. Northern end of the hills near the Lucky Jim Camp.





are slightly overturned toward the east, and, if the isoclinal belts are viewed from the east front of the hills, the beds appear as an unfolded series dipping steeply west. The eastern edge of this zone of close folds coincides approximately with the base of the hills. It seems best to consider the zones as incompetent folds superimposed upon the larger and broader folds of the region. There is some suggestion that these zones may be due to crowding of the stock during emplacement, but where the stock is widest and crumpling by shouldering of the intrusive might be expected to be the greatest, the folding consists of a single anticline and syncline. The zones of close folding parallel the narrower portions of the stock. Furthermore, since protuberances from the stock cut the limbs of the broader folds it is probable that all of the folding antedates the intrusion of the stock.

FAULTS

Faults in the Darwin Hills and displacements thereon can be given the following age grouping: (1) post-Pennsylvanian and pre-intrusive, (2) post-intrusive and pre-mineralization, (3) post-mineralization and pre-lava sheets, and (4) post-sheets.

No faults of the first group have been positively identified in the district. However, it appears unlikely that the folding of the Pennsylvania beds prior to the intrusion of the stock was unaccompanied by at least some fracturing. A few of the faults described as post-intrusive in age may have had their inception before the intrusion. No evidence is available of the age relationship between the Darwin tear fault and the intrusive inasmuch as the fault crosses the hills north of the stock. This fault may be older or younger than the stock. However, all of the displacements on the smaller cross faults which cut the stock are in the same direction as that on the Darwin tear fault. This may be evidence that the large fault is also later than the intrusion and hence belongs to the following group.

Faults of the second group are numerous and they are the structural feature which controls much of the metallization in the district. These faults, of which many were later mineralized to form fissure veins, developed after the consolidation of the stock and may be divided into two subgroups. The first, which has proven to most economic significance, are most numerous, shorter, and roughly normal to the intrusive contact. Practically all of their strikes fall between N 45° E and N 65° E. (See Plate X.) Many show no measurable displacement. The maximum displacement is not over 100 or 200 feet. Some of the more persistent of these such as the Lane and Standard Extension have lengths of 4000 feet. Most of them occur within the tactite zone around the intrusive and end at or shortly within the intrusive contact (Plate VI). Only rarely do they cut entirely across the stock as in the case of the Standard Extension fissure. Where direction of displacement is ascertainable the movement is dominantly horizontal with the north side moving relatively westward.

The faults of the second subgroup of this age are rather limited in their distribution and they strike N 50-70° W. These faults, few in number, constitute a shear zone which cuts through the entire stock in the first canyon and valley north of Lane Canyon (Plate XI-A). The direction of movement is the same as that on the previous group, but the displacement is greater and later. Both subgroups have been subjected to post-consolidation mineralization (Plate VII-C). The length of this zone of faults is 8000 or 9000 feet. Although they crosscut the strata on the east, to the northwest and on the west side of the stock they either die out or are taken up by unrecognizable strike slip along bedding planes. The northwesterly faults which displace the Lucky Jim vein belong to this group although not within the immediate zone.

The time period represented in the next group of faults, post-mineralization and pre-lava sheets, is great and actually several distinct periods of movement are suspected but cannot be definitely proven. Many of the fissures previously described show signs of movement after mineralization and this movement in some cases appears to have had steep vertical components as evidenced by the slickensided gouge zones in many of the fissures. Some of this may represent minor adjustments which resulted from the block faulting following the lava eruptions in early Quaternary time.

A few faults which offset veins are also present. These faults have a trend which is more nearly east-west than the previously described fissures. They strike N 70-80° E and the direction of movement on them was the same as on the previous two groups, that is, the north side shifted relatively west. A notable example is the Christmas Gift fault which offsets the Christmas Gift vein and oreshoot (Plate VI). The displacement on this fault near the mine is 300-400 feet. Another such fault crosses the ridge east of the Darwin Lead Company's camp and near the Rip Van Winkle shaft. Here the displacement is about 150 feet.

The largest fracture in the district is the Darwin tear fault. It cuts across the hills about 1000 feet north of the Lucky Jim mine. The fault strikes N 75° W and dips 75° south. This steep southerly dip is also characteristic of the above described faults offsetting the fissure veins. In most places it is a shear zone 200-300 feet in width. The striking manner in which the northerly trending beds are dragged parallel to the fault zone clearly indicates the direction of movement. The Darwin tear is of considerable extent and can be traced for several miles to the west of the hills where it gradually passes into a series of folds. About three miles east of the hills it causes the Darwin Wash to swing easterly along the belt of weakness. It is traceable to the top of the Argus Range where it passes beneath the basalt capping. It has a total length of at least ten miles.

The Darwin tear fault appears to be the master fracture of the district and all of the smaller dislocations formed prior to the lava flows are in a way related to it. The direction of movement on the smaller faults in the hills is the same as that on the large tear. In strike the Darwin tear fault appears closely related to the northwesterly trending fractures described above. The age of the Darwin tear is rather uncertain. It may have had its inception prior to, during, or after the development of the fissure veins, but evidence is present that at least some of the movement is later than the lava caps of early Quaternary age. Near the top of the Argus Range the lavas appear to be somewhat deformed by late movements on this fault.

The fourth group of faults are large fractures which trend northwesterly and are to be identified as basin and range faults developed in Quaternary time. These were undoubtedly instrumental in forming the Darwin Hills. Their presence and position is in part based on physiographic evidence, but this is supported by the positions of certain remnants of basalt flows surrounding the hills. From several such remnants located at levels along the northwestern edge of the hills it appears that they have been elevated or perhaps tilted towards the east along at least two parallel faults (Plate V-A). On the east side of the hills the slopes are very steep (Plate III-B), a fact which caused Knopf[1] to postulate a fault along their base. He also noted that toward the north the fault must terminate because unbroken lava sheets cross the extension of the postulated fracture. The ruggedness of the eastern slope, especially in its southern part, is due to some extent to undercutting by the Darwin Wash, but that some of the relief is due to faulting appears evident from the position of the lake beds and the lava caps in the giant step faults in the Argus Range east of the Darwin Wash.

From the geologic map, Plate VI, it is evident that the regional trend of the folded Pennsylvanian rocks determined the trend and elongate shape of the stock. The question arises as to the influence of the intrusion on the development of fracturing in the adjacent rocks. Ingersoll and Zobel[2] have supposed that cooling and contraction of the rocks behind a heat wave advancing from the intrusive have been the cause of fracturing in which later mineralization takes place. Emmons[3] has pointed out that the fissures

1. Knopf, A., U. S. G. S. Bull. 580A, p. 3.
2. Ingersoll, L. R., and O. J. Zobel, An Introduction to the Mathematical Theory of Heat Conduction, p. 129. 1913.
3. Emmons, W. H., Relation of Ore Deposits and Batholith, Ore Deposits of the Western States, p. 339. 1933.

formed in the outer part of intrusives and in the adjacent country rocks are often formed by the forces of intrusion or the pressures generated during cooling.

At Darwin the displacements on the fracture systems are clearly related to tectonic forces. The uniform direction of displacement and accompanying shearing attests to this fact. It may be true, however, that some of the fractures upon which displacements later took place owed their origin to forces developed by the intrusion. The answer to this could be obtained by the determination of the relative abundance of fissures adjacent to the stock as compared to their abundance and trend at a distance. Not enough detailed mapping has been done in areas outside of the Darwin Hills to determine whether the fracture systems outlined are extensive over the larger terrain of the plateau.

It might be noticed in favor of the tectonic character of the fracture systems that Knopf and Kirk[1] found much the same trend of fractures on a larger scale in the Inyo Range. The general conclusion reached for the Darwin Hills is that the fractures

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1. Knopf, A., and E. Kirk, Geologic Reconnaissance of the Inyo Range. U. S. G. S. Prof. Paper 110, p. 21. 1918.

and especially the subsequent movements thereon are not related to intrusion, but rather to tectonic forces.

In summary, the structure of the Darwin Hills is characterized by a considerably folded series of impure Pennsylvanian limestones intruded by an elongated stock which occupies the center or core of the range of hills. Although parallel to the strike of the formations the stock transects the west limb of a large fold in depth. The east limb, about 1000 feet east of the stock, is considerably crumpled into a series of closely spaced nearly isoclinal folds. A system of northeast and northwest fractures transverses the whole. The common direction of movement on all of these has been westward on the north side. The total effect of the displacements on all of the fractures has been to move the north tip of the elongate stock several hundred feet west of its original position with reference to the south tip. Uplift along faults roughly bounding the hills slightly tilted the range above the plateau in Quaternary time.

IGNEOUS METAMORPHISM

HISTORY

Lindgren[1] gives credit to Bernard von Cotta for the first recognition in 1865 of mineral deposits formed by the action of intrusive rocks on limestones. However, the pioneer work of the classification of such deposits and their distinction from other types was done largely by Von Groddeck[2] and Vogt[3].

The first description of the contact metamorphic type of deposit in America was that by Lindgren of the Seven Devils District, Idaho[4]. During the first decade of the century deposits about intrusive contacts received much able description particularly by Blake[5] in Arizona, Weed[6], Barrell[7], Kemp[8],

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1. Lindgren, W. Mineral Deposits, 3rd ed., p. 783. 1928.
2. Von Groddeck, A., Die Lehre von den Lagerstatten der Erze, Leipzig, p. 260. 1879.
3. Vogt, J. H. L., Zeitschr. Prakt. Geol., pp. 177, 464; 1894; p. 154, 1895.
4. Lindgren, W., Min. and Sci. Press, 78, p. 125. 1899.
5. Blake, W. P., Trans. Am. Inst. Min. Eng., 34. 1904, pp. 886-890.
6. Weed, W. H., Ore Deposits near Igneous Contacts. Trans. Am. Inst. Min. Eng., 33, p. 179. 1903.
7. Barrell, J., U. S. G. S. Prof. Paper 57. Marysville Mining District, Mont., pp. 116-150. 1907.
8. Kemp, J. F., Ore Deposits at the Contacts of Intrusive Rocks and Limestone. Econ. Geol., vol. 2, pp. 1-13. 1907.

Lindgren[1], Spurr[2], Leith[3], and others. Barrell[4] pointed out the relationship between metamorphic minerals and the original composition of the rocks and demonstrated the volume changes necessary in recrystallization of impure calcareous sediments. Barrell at Marysville distinguished between contact metamorphism, or pure recrystallization, and metasomatism in which emanations from the intrusive added some materials. The latter he thought was principally confined to zones at the contact and to narrow borders along jointing. In general Barrell's studies led him to favor recrystallization although recognizing some infiltration. Leith and Harder in a description of the metamorphic aureole at Iron Springs, Utah concluded that great quantities of carbon dioxide and lime were expelled and this was accompanied by a volume reduction of as much as 80 per cent. Such a shrinkage was thought by Kemp[5] to be incredible.

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1. Lindgren, W., Copper Deposits of the Clifton Morenci District, Ariz. U. S. G. S. Prof. Paper 43. 1905.
2. Spurr, J. E., and G. H. Garrey, Velardena District. Econ. Geol., Vol. 3, pp. 688-725. 1908.
3. Leith and Harder, Iron Springs, Utah. U. S. G. S. Bull. 338. 1908.
4. Barrell, J., Physical Effects of Contact Metamorphism. Am. J. Sci., 4th series, vol. 13, pp. 279-296. 1902.
5. Kemp, J. F., Discussion. Econ. Geol., vol. 4, pp. 782-790. 1909.

In 1911 V. M. Goldschmidt published his famous book, Die Contactmetamorphose im Kristianiagebiet, in which he described an inner early zone of recrystallization and an outer later zone of pneumatolytic action. About this time Uglow[1] published a review of the literature in which he purported to weigh the evidence for recrystallization and magmatic additions. Uglow concluded that recrystallization was the dominant factor in the development of the silicate zones. This paper provoked an acrimonious discussion during which the proponents of the infiltration hypothesis restated their evidence and conclusions much more clearly and precisely. The resulting discussions which were entered into by Stewart[2], Kemp[3], Higgins[4], Uglow[5], Lindgren[6], and Leith[7] lasted well into 1914 and the

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1. Uglow, W. L., Origin of the Secondary Silicate Zones. Econ. Geol., vol. 8, pp. 19-50, 215-234. 1913.
2. Stewart, C. A., Discussion. Econ. Geol., vol. 8, p. 500, 1913; vol. 9, p. 278, 1914.
3. Kemp, J. F., Discussion. Econ. Geol., vol. 8, p. 597, 1913; vol. 9, p. 282, 1914.
4. Higgins, D. F., Discussion. Econ. Geol., vol. 9, p. 73, 1914.
5. Uglow, W. L., Discussion. Econ. Geol., vol. 9, p. 175, 1914.
6. Lindgran, W., Discussion. Econ. Geol., vol. 9, p. 283, 1914.
7. Leith, C. K., Discussion. Econ. Geol., vol. 9, p. 292, 1914.

airing that the subject received doubtless did much to stimulate keener study of contact metamorphism in districts subsequently examined. The evidence and arguments presented by the magmatic additionists appear to be the more conclusive. It should be stated, however, that while advocating convections of heat and materials as the more important in the production of the silicate zone, these men fully recognized and admitted that siliceous and other impurities in the limestones entered materially into the reactions. Nevertheless, to similar deposits described in the next succeeding years a greater role was given to emanations and additions from the magma.

European workers, on the whole, have favored pure recrystallization in the role of the development of the silicate zone. This is especially true of Rosenbusch, Zirkel, and Brogger. These men in their early days thought that ores as well as silicates were developed by recrystallization of sediments. In the recent text, Metamorphism, by Harker there is a disappointing lack of consideration of the role of igneous emanations especially upon calcareous sediments.

More recently Tilley[1] at Scawt Hill and Neckolds[2] at Barnavave have found convincing evidence of the introduction of magmatic materials into calcareous rocks. At Scawt Hill Tilley showed that near the dolerite contact substances had been added to nearly pure chalk in amounts directly proportional to the composition of the intrusive. Hence, he believed there was an infiltration of doleritic solutions involved in the reactions producing the silicate zone.

As a complicating third factor, but one which undoubtedly served its purpose as an alternative hypothesis, Lawson[3] proposed that recirculating meteoric waters were not only the cause of much of the alterations both in the wall rock and intrusive, but also the major agent in concentration of the associated ores. Daly[4] also considered resurgent waters as operative in metasomatism and recrystallization. Most economic geologists were inclined to doubt the the importance of such waters. Lindgren[5] and

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1. Tilley, C. E., The Dolerite Contact at Scawt Hill. Min. Mag., vol. 22, p. 445. 1931.
2. Neckolds, S. R., Contributions to the Petrology of Barnavave. Geol. Mag., vol. 74, pp. 128-132. 1937.
3. Lawson, A. C., Min. and Sci. Press. Feb. 3, 1912.
4. Daly, R. A., Econ. Geol. vol. 12, p. 490. 1917.
5. Lindgren, W., Discussion, Econ. Geol., vol. 9, pp. 284-285. 1914.

Umpleby[1] at about the same time presented evidence which rather convincingly disproved the idea held by Lawson and others. More recently Knopf[2] explained the formation of the Mother Lode of California and the wall rock alterations in part by resurgent waters.

Volume reductions resulting in shrinkage or increased porosity or both are generally admitted as necessary in thermal metamorphism in which any considerable quantity of carbon dioxide is liberated without the simultaneous introduction of outside material. It has been difficult to find evidence of contraction resulting from such volume reductions. Preservation of any of the primary sedimentary structures such as bedding, fossils, etc., have been used as evidence that no shrinkage occurred and hence materials were introduced and substituted for the expelled carbon dioxide.

Knopf[3] at Darwin believes there must have been considerable introduction of silica because of the lack of evidence of shrinkage and collapse of

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1. Umpleby, J. B., Genesis of the Mackay Copper Deposits. Econ. Geol., vol. 9, pp. 346-353. 1914.
2. Knopf, A., The Mother Lode System of California. U. S. G. S. Prof. Paper 157. 1929.
3. Knopf, A., The Darwin Silver-lead Mining District, Calif. U. S. G. S. Bull. 580, p. 5. 1913.

primary structures. Likewise, Emmons and Calkins[1] at Phillipsburg, Butler[2] in the San Francisco district, Utah, Spencer[3] at Ely, Nevada, and Umpleby[4] at Mackay, Idaho believe the evidence shows considerable introduction of silica and other constituents into the limestones. At Mackay, Umpleby, like many investigators, noted two types and periods of metamorphism: the first, contact metamorphism (recrystallization) in which the magmatic emanations were chiefly aqueous, and a second in which silica and other substances were added.

In later years the subject of contact metamorphism has received somewhat less attention, but the question as to relative importance of the two principal processes in the formation of the silicate zone has not been dicisively decided. Nolan[5] at Gold Hill, Utah recognized as early recrystallization followed by metasomatism so unrelated to the immediate contact as to cause him to discuss the whole subject under the heading "contact" metamorphism. Gilluly[6] in the Stockton and Fairfield quadrangles, Utah found

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1. U.S.G.S. Prof. Paper 78. 1913.
2. U.S.G.S. Prof. Paper 80. 1913.
3. U.S.G.S. Prof. Paper 96. 1917.
4. U.S.G.S. Prof. Paper 97. 1917.
5. U.S.G.S. Prof. Paper 177, pp. 91-94. 1935.
6. U.S.G.S. Prof. Paper 173, pp. 101-107. 1932.

only little evidence of introductions and concluded that the silicates were largely produced by recrystallization of impure limestones.

An impartial examination of the foregoing evidence indicates that either pure thermal recrystallization or magmatic additive processes may locally be the dominant factor in "contact" metamorphism . Many have found two periods of metamorphism, an early one of recrystallization of constituents already present in the rock and a later one by magmatic emanation. However, it is probable that the two processes are not separable, operating together for the most part. Furthermore, the process as a whole varies with the intrusive and wall rock. Of the two processes the evidence at Darwin indicates that additive materials played the dominant part. Most writers have concluded that the silicate zone is developed either at the time of the intrusion or shortly thereafter, but never prior to the emplacement.

ALTERATION OF THE SEDIMENTARY ROCKS

General Character

Since most of the minerals of the silicate zone about the intrusive are calcium silicates the term, tactite, proposed by Hess[1] is applied herein to the rocks as a whole. Hess applied the term to calcium silicate strata or rock formed by magmatic emanations. It is preferred here to use the term for silicated limestone whether by recrystallization or by metasomatism. The term, hornfels tactite, is used for the fine-grained or aphanitic tactites. Other adjectival terms are prefixed to the term, such as wollastonite tactite or garnet-diopside tactite. In keeping with the recent suggestion by Tarr[2], the term, tactization, is used for the process in preference to tactitization.

At Darwin the tactites are whitish, medium to fine-grained, stratified rocks. The width of the tactite zone varies from a few tens of feet to nearly 2000 feet. The outer limit of the zone is roughly determinable by the extent of bleaching of the original rocks. An aureole about 1000 to 1500 feet in width is most common. The retained stratification is the principal existent structure (Plate XIII-C). Although in many places the tactite is fine grained or aphanitic, large areas of stratified tactite composed

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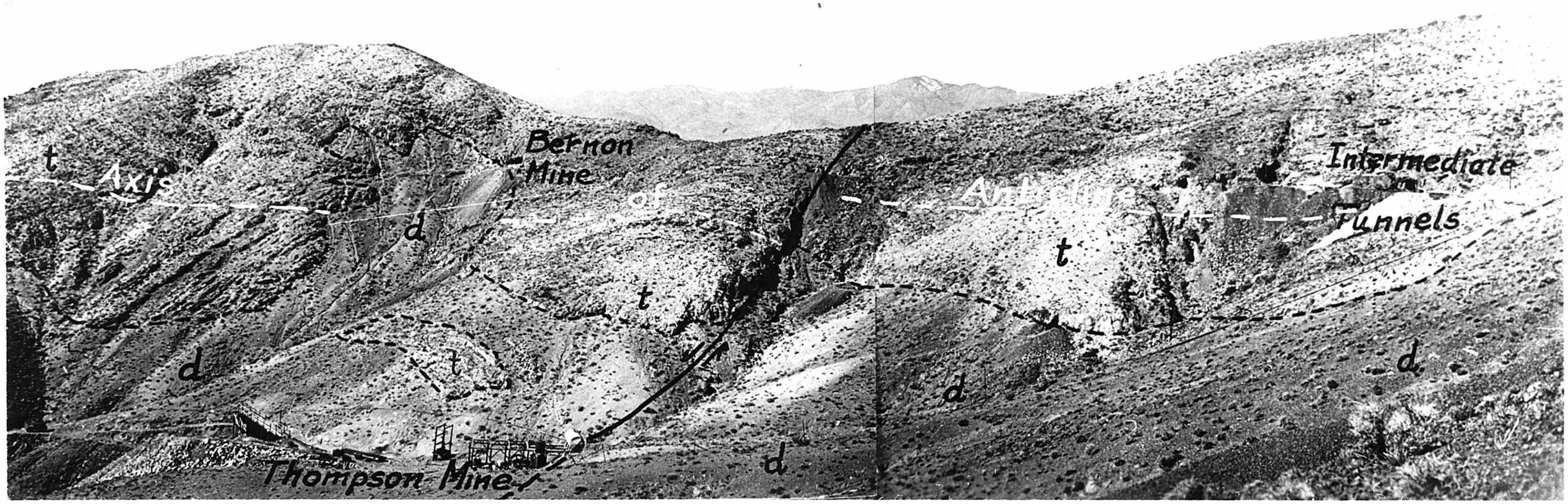
1. Hess, F. L., Tactite, the Product of Contact Metamorphism. Am. Jour. Sci., vol. 48, pp. 377-378. 1918.
2. Tarr, W. A., Carbonation vs. Carbonatization. Science, vol. 85, p. 198. 1937.

Plate XII

General view of the contact of the stock (d) and the tactite (t) zone along the ridge between the Defiance and Independence mines.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Thompson Mine

Plate XIII

A. Detail of tactite "breccia" on the ridge south of the Defiance mine.

B. Garnet metacrysts in marble near the Fernando mine.

C. Typical outcrop of stratified tactite. Wollastonite is the principal constituent of these beds.

A.

B.

C.

Plate XIV

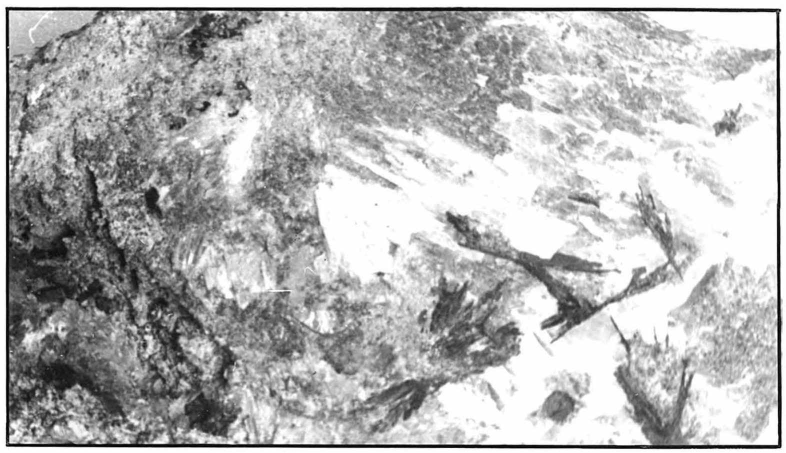
A. Spotted limestone partially silicated. The dark lenses are gray impure limestone. The enclosing matrix is greenish white and under the microscope shows needles of wollastonite, calcite, and idocrase.

B. Blades of specular hematite in calcite (white) and diopside (dark).

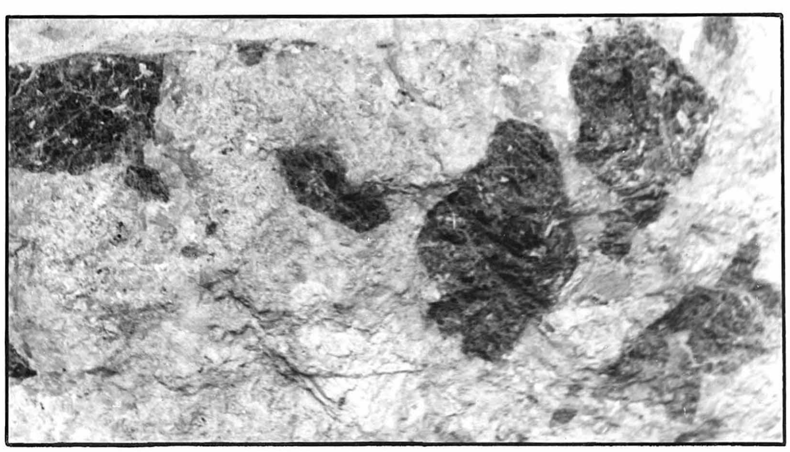
C. Idocrase metacrysts in marble from the Lucky Jim mine.

Note: All about natural size.

A.



B.



C.

of visibly felted aggregates of wollastonite occur. Locally, decidedly coarse textures are found. Light green garnets one to three inches in diameter imbedded in wollastonite are common and one garnet a foot in diameter was found south of the Defiance mine. On the prominent white ridge south of the Lucky Jim camp are areas of tactite in which wollastonite prisms three to six inches in length are abundant associated with garnet and considerable idocrase. Idocrase crystals attain dimensions of one to two inches (Plate XIV-C). In general, the coarser the texture, the less is the mineral diversity. Coarseness of grain, except in a broad way, is not related to proximity of the igneous contact. Thus, at the Defiance mine the tactite at the igneous contact is dense, fine grained, white rock, while westward from the contact to the top of the ridge are many beds of medium and coarse grained tactite.

Minerals and Textures

Wollastonite.

Wollastonite is perhaps the most abundant mineral of the silicate zone. It occurs in felted masses which may comprise bed after bed of the tactites over considerable areas. Locally, usually near the igneous contact, wollastonite forms in large reticulating prisms associated with small quantities of garnet or idocrase. In the outer part of the tactite zone it occurs in small radiating groups imbedded in fine grained calcite or limestone in such a way as to make it apparent that its formation was the first manifestation of the silication process (Plate XV-A). Even in this initial stage of silication it is common to find small amounts of idocrase associated with the wollastonite. Wollastonite also occurs in veinlets with garnet and idocrase cutting a matrix of hornfels tactite or in some cases impure limestone (Plate XX-B). Thus it is common to find wollastonite in the groundmass and in veinlets cutting that matrix.

Garnet

With the exception of wollastonite, garnet is the most conspicuous mineral of the tactites. It is typically a light green colored garnet. Qualitative tests indicate approximately equal quantities of aluminum and iron in addition to calcium. It is, therefore, most generally a mixture of grossularite and andradite molecules. By far the greatest percentage of the garnet is birefringent, showing remarkable zoning and polysynthetic twinning (Plates

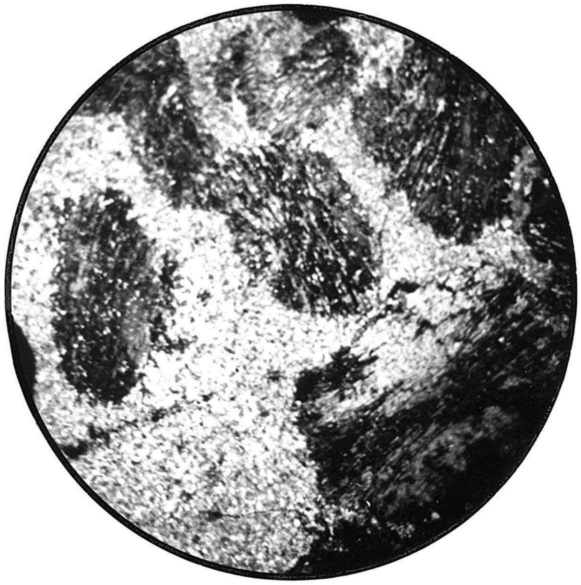
Plate XV

A. Spots of wollastonite in fine-grained limestone. An early stage in the development of wollastonite tactite. Crossed nicols. 11X. No. 12-i(3).

B. Radiated wollastonite with interstitial calcite, a more advanced stage in the formation of wollastonite tactite. Crossed nicols. 20X. No. 11-k.

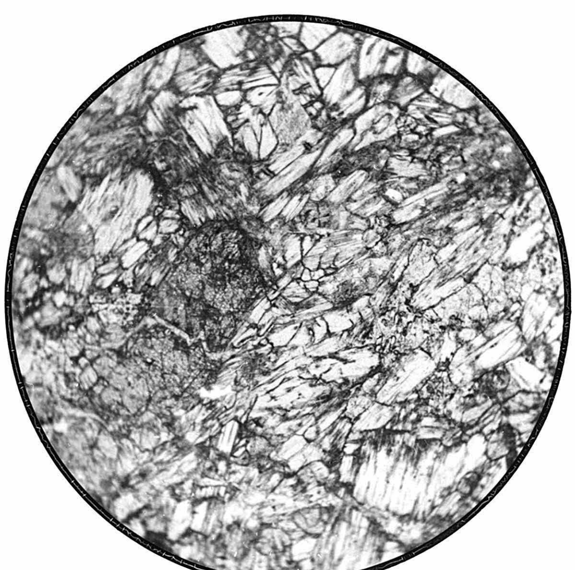
C. A wollastonite tactite. Crossed nicols. 20X. No. P.A-9(2).

D. Large wollastonite crystal (wo) with twinned calcite and isotropic garnet. Crossed nicols. 20X. No. 7-d(1).

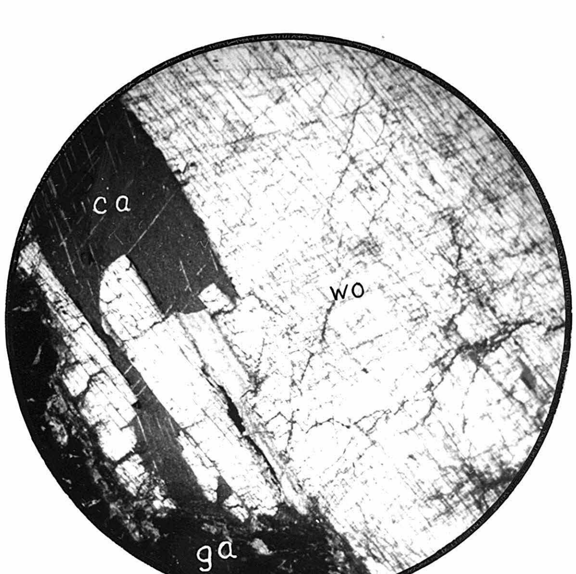


A.

B.



C.

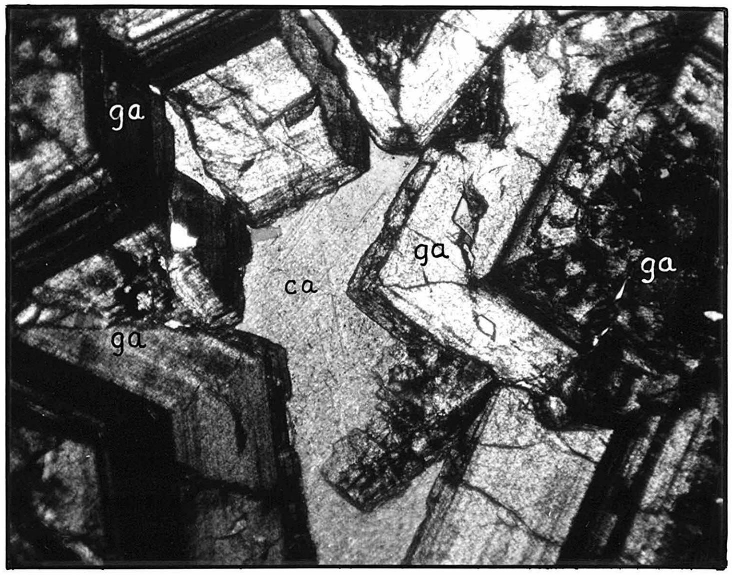


D.

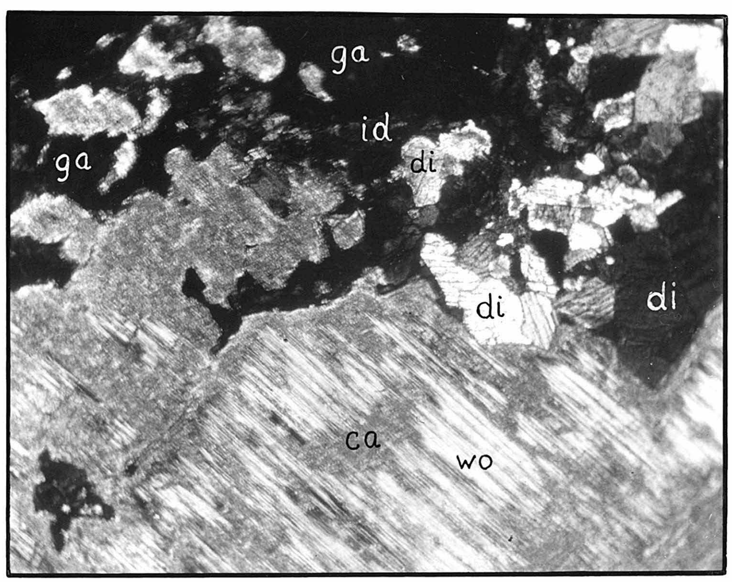
Plate XVI

A. Polysynthetic twinning in garnet (ga) with interstitial calcite (ca) from the tactite near the Thompson mine. Crossed nicols. 75X. No. I.M. 11.

B. Wollastonite (wo) replaced by garnet (ga) and calcite (ca) with some diopside (di) and idocrase (id). The shaded areas along the wollastonite cleavage and fractures are calcite. Crossed nicols. 75X. No. P. A-10(1).



A.

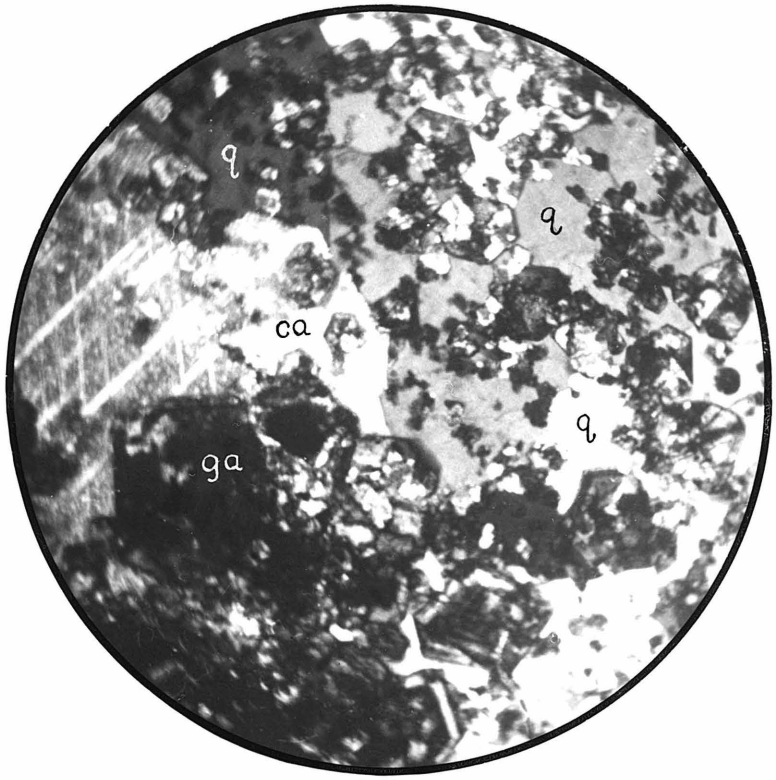


B.

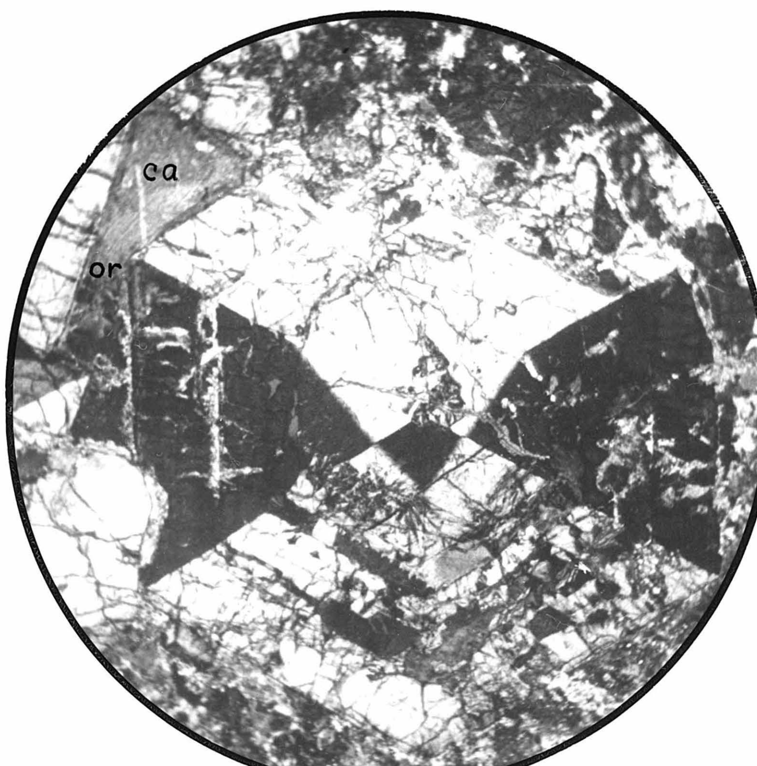
Plate XVII

A. Metacrysts of anisotropic garnet (ga) in quartz (q) and calcite (ca). Small crystals of diopside and apatite are occasionally present. Crossed nicols. 27X. No. P.A-17 (1).

B. Remarkable zoned and twinned garnet.
Note: Calcite (ca) and orthoclase (or) fill in around the garnets in this section and small crystals of sphene and tourmaline are occasionally present in the garnet. Crossed nicols. 27X. No. 14-i.



A.



B.

XVI-A and XVII). In addition to the regular arrangement of the birefringent parts, it often shows wavy and irregular anisotropism. Also it often shows two stages of growth in which the core may be greenish and the periphery colorless or vice versa. Perimorphs of garnet are very common in calcite (Plate XIX-B). Some of the totally isotropic green garnet is probably almandite. Rarely a little dark brown or black garnet is found and it also is isotropic.

Garnet is widespread throughout the zone, but the larger and more perfect crystals occur near the igneous contacts. In some places massive garnet zones a few feet in thickness border the immediate contacts. Garnet is found in association with all of the silicate zone minerals, but most commonly with calcite which occurs not only interstitially to the garnet crystals but in veins replacing it. Garnet replaces wollastonite and in some instances appears to form pseudomorphs after the latter mineral. Garnet also forms veinlets cutting a matrix which may include earlier garnet among other silicate minerals. Locally garnet develops as a post-fissuring silicate mineral cementing or replacing earlier silicates, calcite, or igneous rock (Plate XXI). Small crystals of tourmaline or sphene are commonly found included in the garnet.

Diopside

Diopside is practically the only pyroxene present. It is abundant in fine grained tactites with wollastonite, garnet, calcite, and other minerals. Poikilitic diopside and sometimes hedenbergite in orthoclase are common near the contacts. Diopside is occasionally found replacing wollastonite, but it did not continue to form as long as garnet.

Idocrase

Idocrase, although not as abundant as the preceding minerals, is nevertheless common at Darwin. It occurs in dense green masses closely resembling garnet and in euhedrons in calcite or wollastonite. Calcite is nearly always present veining the idocrase. Under crossed nicols the Darwin idocrase shows strikingly anomalous Berlin Blue or green colors. Polysynthetic twinning and zoning similar to that in the garnet are common (Plate XVIII-A). Idocrase replaces wollastonite and is idioblastic against it, but in contact with garnet the latter mineral is euhedral. The large metacrysts of idocrase are found only near the igneous contact, but disseminated grains and small veins are found in the outer portion of the tactite zone associated with wollastonite.

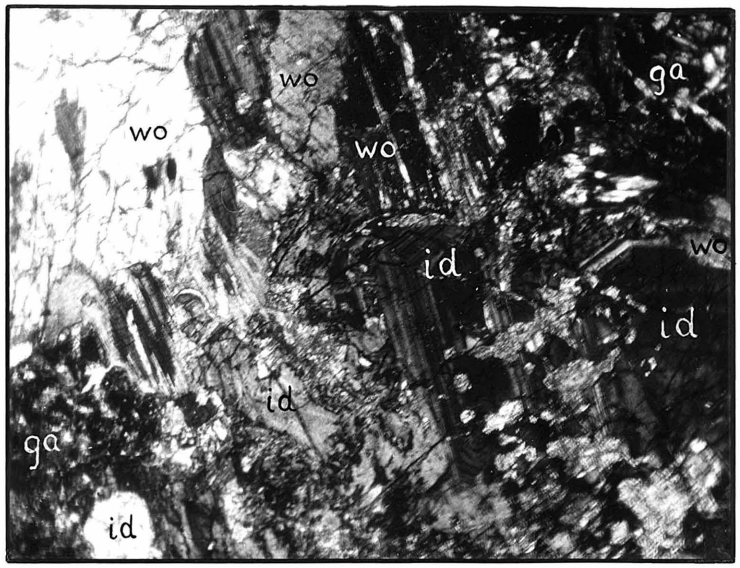
Epidote

Epidote occurs only sparingly in the tactites proper. It is mostly confined to the immediate contact where it forms in veins replacing orthoclase in dike rocks or in the intrusive proper.

Plate XVIII

A. Polysynthetic idocrase (id), wollastonite (wo), and garnet (ga).
Note: Idocrase replaces wollastonite throughout this section and garnet is euhedral against idocrase.
Crossed nicols. 75X. No. P.C-12.

B. Sutured intergrowth of calcite and oligoclase.
Note: Wollastonite is absent where oligoclase is present in the tactite.
Crossed nicols. 75X. No. P.A-13.



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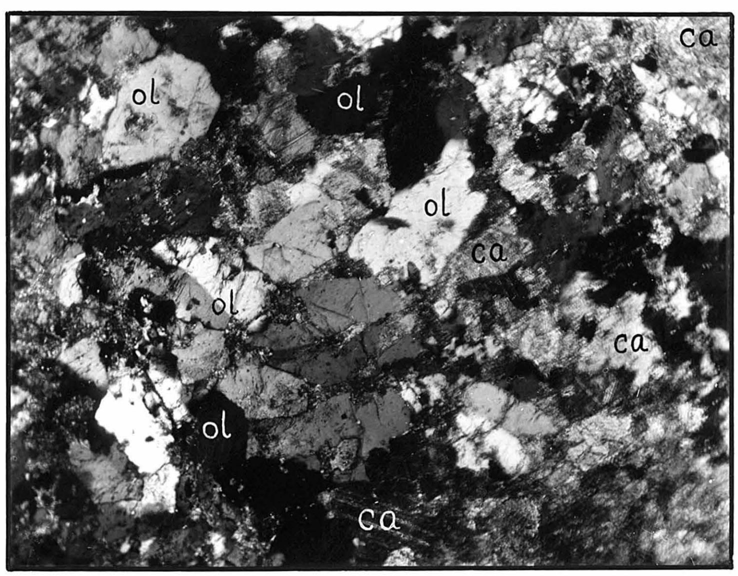


B.

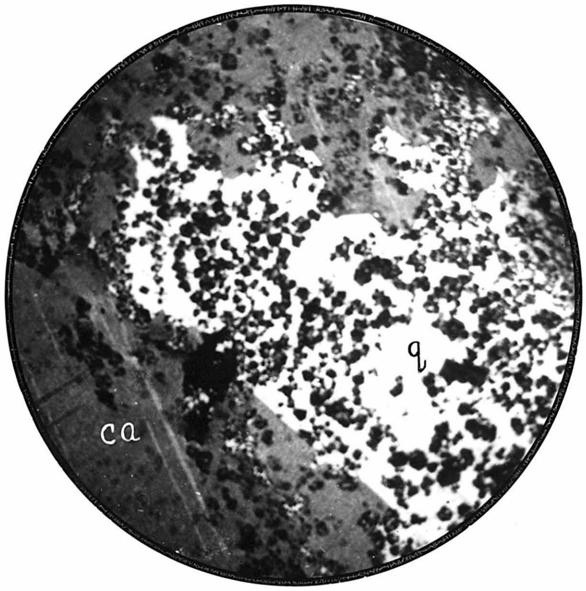
Plate XIX

A. Swarms of garnet (ga) in calcite (ca) and quartz (q). Crossed nicols. 20X. No. I.M. 11.

B. Twinned calcite (ca) beset with perimorphs of garnet (ga) and replaced by bands of sphalerite (sp). Pyrite (py). Crossed nicols. 11X. No. D.M. 13(1).

C. Hematite (hm) altered from magnetite replacing garnets (ga) and calcite (ca). Oligoclase (ol). Plain light. 20X. No. P.A-16.

D. Zoned garnet (ga) set in calcite (ca) and orthoclase (or). Diopside (di). Crossed nicols. 20X. No. 14-1.



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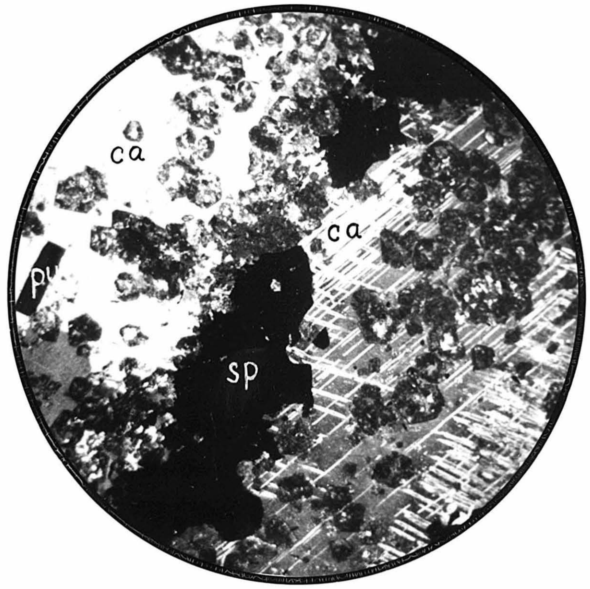

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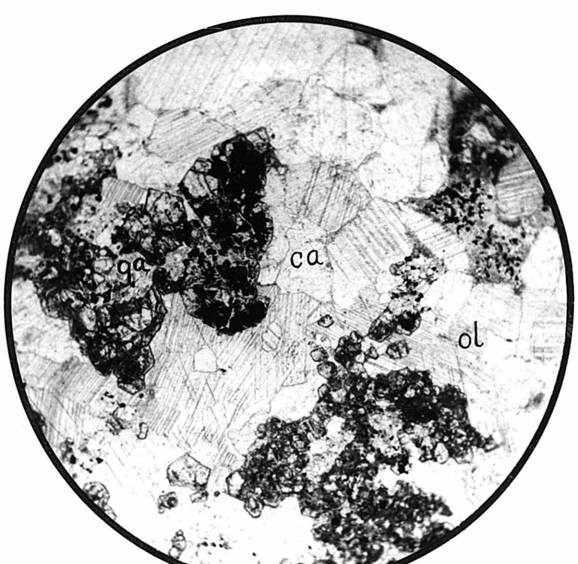

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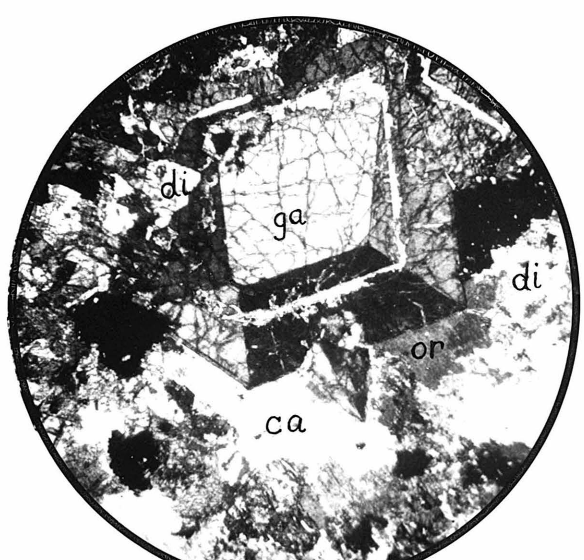


D.

Orthoclase

Orthoclase is a very common mineral in the tactites, especially in the areas of more intense alteration or near the igneous contact. Likewise, border phases of the intrusive are sometimes unusually rich in orthoclase enclosing poikilitic garnet, plagioclase, hedenbergite, or biotite. Orthoclase is found intimately intergrown with wollastonite, diopside, garnet, and calcite in the hornfels tactites. Its occurrence in dikes anastomosing through the tactites has already been mentioned. Orthoclase is also found lining post-consolidation fractures in the intrusive, indicating its late deposition in part.

Calcite

Calcite is the most widespread mineral of the tactite zone. In many of the tactites, both coarse and fine, it forms a matrix with lesser quantities of orthoclase, plagioclase, or quartz for the more idioblastic minerals such as wollastonite, garnet, or diopside. Coarsely crystalline, marmorized limestone is not exceedingly common in the tactite zone. More common are remnants of blue gray limestone in which calcite is clouded by argillaceous impurities. Late calcite veinlets in all other minerals are very abundant.

Quartz

Quartz is only sparingly present in the silicate zone. Under the microscope quartz is sometimes found intergrown with calcite and the two minerals scattered through with garnet. Occasionally it is found interstitial to euhedral aggregates of garnet. Also small veinlets of quartz are found cutting most of the silicate minerals. Many of these veinlets are chalcedonic (Plate XX-A). As will be mentioned later, quartz is more abundant as a post fissure mineral.

Plagioclase

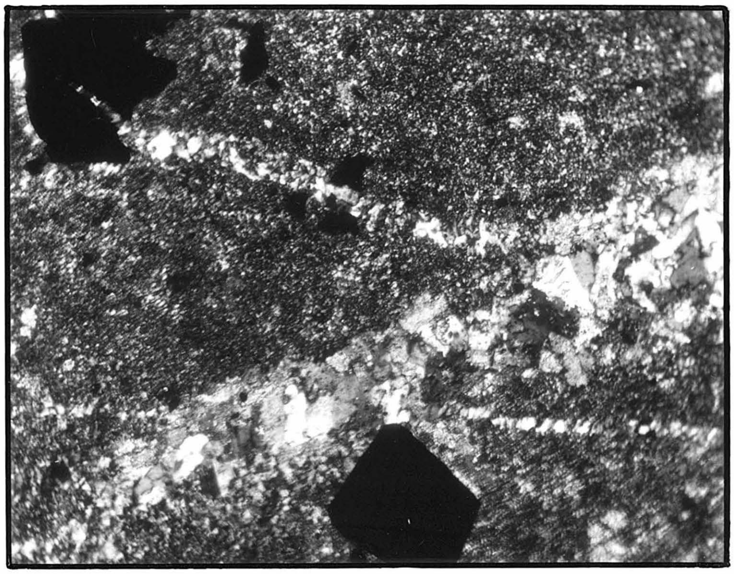
Plagioclase is very abundant in some of the tactites. Practically all of the plagioclase seen in the tactites is untwinned oligoclase. It is for the most part quite fresh and closely resembles quartz for which it is easily mistaken by reason of the fact that the two are not usually found together. The oligoclase occurs in a much sutured intergrowth with calcite, the latter mineral being the more abundant of the two (Plate XVIII-B). Idioblastic and xenoblastic garnet is scattered through both minerals and oligoclase appears to replace the garnet in several instances. A noticeable feature of the oligoclase-calcite tactite is the absence of wollastonite. Thus, in one petrographic profile taken normal to the igneous contact, sections of the first one hundred feet show abundance of wollastonite and some garnet, diop-

Plate XX

Evidences of Metasomatism from the Outer Portion of the Silicate Zone

A. Quartz and calcite veinlets cutting fine-grained quartzite and crystals of pyrite.
Crossed nicols. 75X. No. P.A-24.

B. Veinlets (large) of wollastonite and idocrase cutting impure partially silicated limestone or tactite (dark) and in turn cut by chalcedonic quartz veinlets.
Crossed nicols. 75X. No. C-17.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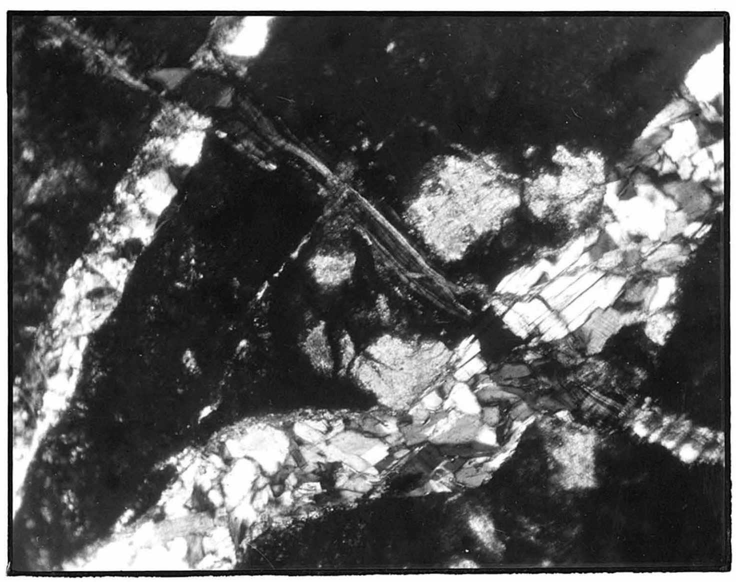

B.

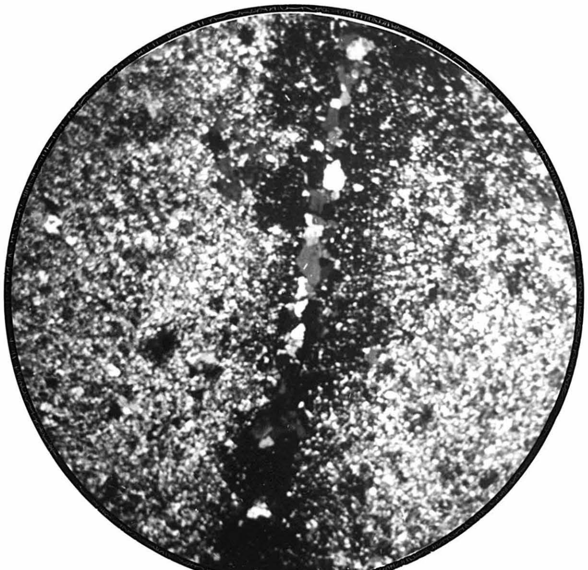
Plate XXI

A. Fine-grained wollastonite-diopside tactite cut by a vein of garnet, wollastonite, and idocrase. Wollastonite occupies the center of the vein, then garnet, then idocrase grading out into the groundmass.
Crossed nicols. 11X. No. 18-j(a).

B. Fine-grained tactite of diopside, garnet, and wollastonite cut by garnet vein (dark) and calcite vein (light).
Crossed nicols. 20X. No. P.A-8(3).

C. Graphic intergrowth of quartz and orthoclase from an acidic dike near the igneous contact. Sphene, tourmaline, and garnet occur in the dike.
Crossed nicols. 20X. No. P.A-3.

D. Tactite of diopside, garnet, and wollastonite cut by garnet veins (dark). The larger vein is parallel to the bedding.
Crossed nicols. 11X. No. P.A-9(2).



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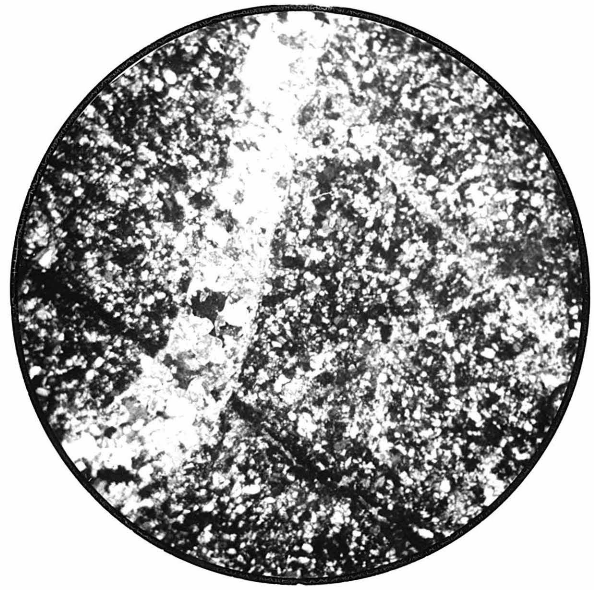

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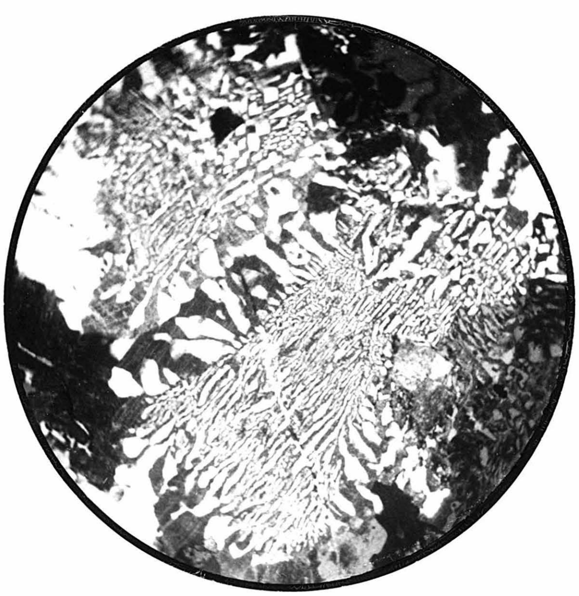

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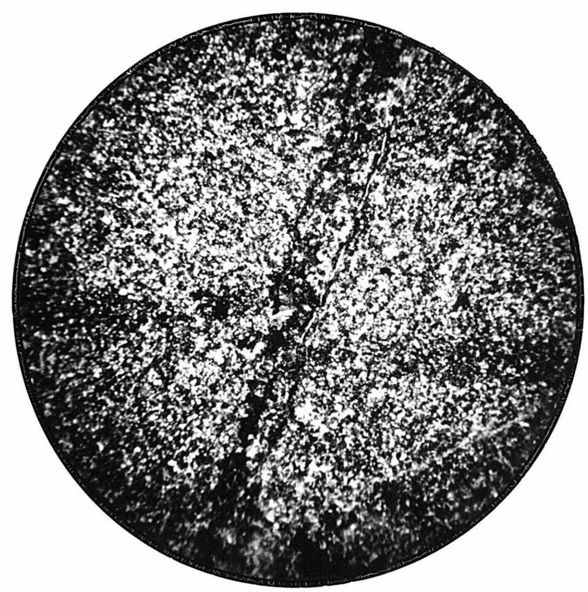


D.

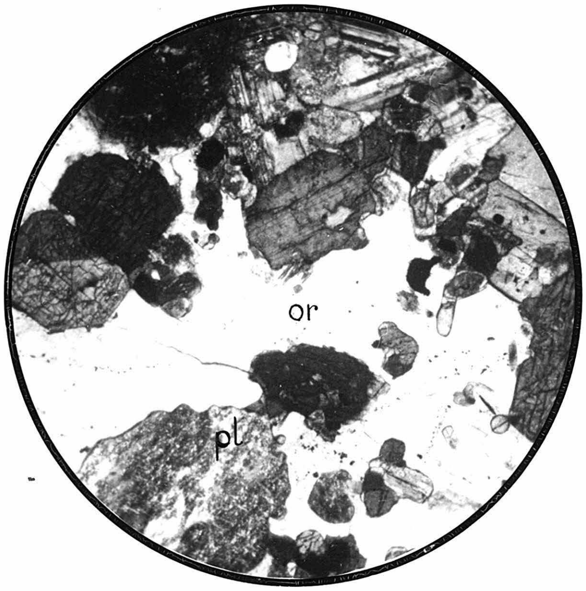
Plate XXII

A. Poikilitic hedenbergite (he) and andesine (an) in orthoclase (or) from a dike rock near the igneous contact.
Crossed nicols. 20X. No. P.A-7.

B. Poikilitic hedenbergite in orthoclase.
Plain light. 20X. No. P.A-7.

C. Salt and pepper diopside in orthoclase (or) and quartz (q) from acidic dike near the contact of the stock.
Plain light. 20X. No. P.A-4(2).

D. Epidote (ep) and actinolite (ac) with quartz and orthoclase from near the igneous contact.
Sphene (sph).
Plain light. 20X. No. P.A-5.



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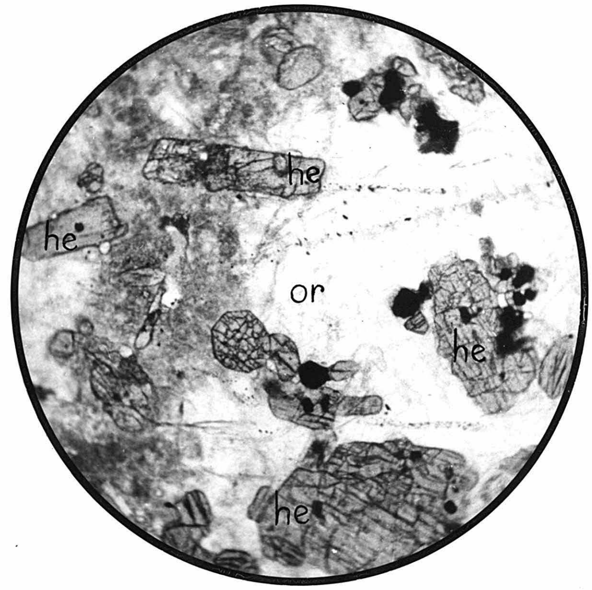

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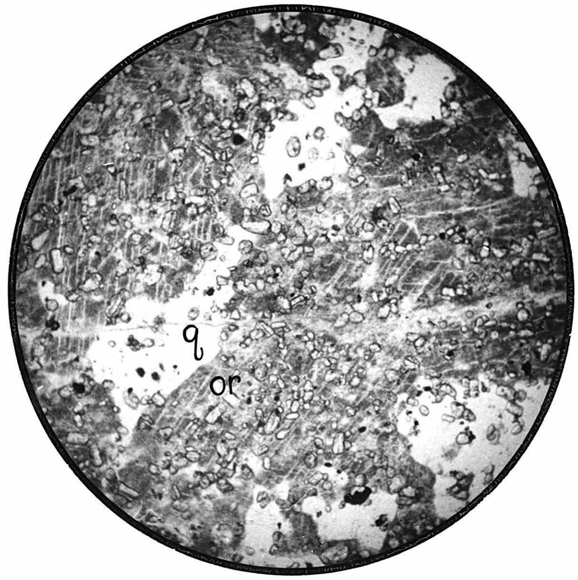

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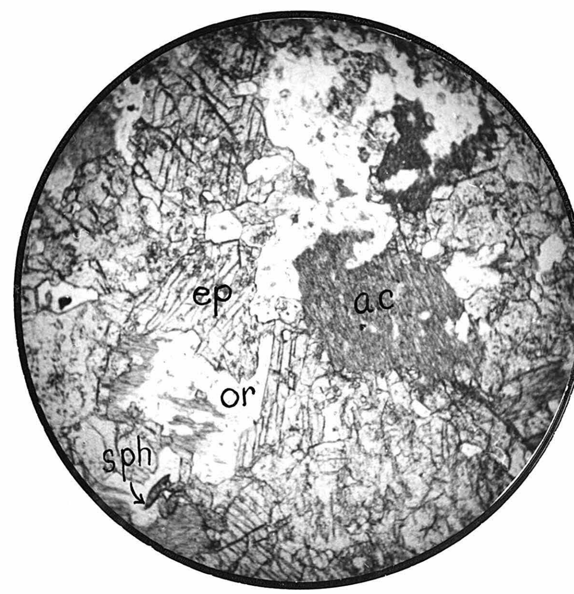

D.

side, and calcite, but no oligoclase. Sections of the next 100 feet reveal considerable oligoclase with calcite and garnet as mentioned above, but no wollastonite. Still farther away the situation is reversed again. Since this profile was taken across the strike of the tactites it seems likely that the original composition of the sediments was the controlling factor. However, it appears likely that oligoclase and wollastonite are incompatible. The case is undoubtedly analogous to the observations made by Harker[1] that anorthite and wollastonite combine to form grossularite and quartz, although in the case of oligoclase it is not quite clear what becomes of the albite molecule. A small quantity of twinned poikilitic plagioclase occurs in orthoclase in small dikes near the igneous contacts.

Miscellaneous Minerals

Tourmaline and sphene are common in the tactites. Of the two, sphene is the more common and it forms larger crystals. It is nearly euhedral and is more abundant in the more highly silicated rocks. Tourmaline is common in small crystals in the hornfels tactites. Apatite is not common, but is found

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1. Harker, A., Metamorphism, p. 94. 1932.

occasionally near the igneous contacts. Tremolite and forsterite which are common to many contact zones are rare at Darwin. Their scarcity is probably the result of the relatively low magnesian content of the original sediments. The little tremolite encountered is the actinolite variety and its occurrence is practically at the contact. A little fluorite is found in the tactites, but much of this is probably late and principally the result of hypogene mineralization.

<u>Origin of the Silicate Zone</u>

A question of paramount importance in the origin of a silicate zone about an intrusive such as at Darwin is whether the silicates are the result solely of thermal recrystallization of the original ingredients of the beds or whether they are primarily the result of additive processes or metasomatism. Doubtless, in many cases the two processes are inseparable. Perhaps the most common type of rock metamorphism is accomplished with only scant pore space solutions in which case metasomatism is practically absent. On the other hand, especially in districts of intense metallization, metasomatism may operate so intensely as to very considerably or completely change the original composition of the rocks.

Where extreme variations in chemical compositions are set up by reason of intrusion, metasomatism is greatly aided. According to Goldschmidt[1] the energy of metasomatism is brought about by the "inclination towards equalization of rock types of extreme composition." Such is the condition of carbonate rocks invaded by acidic intrusives.

Magmatic emanations carrying siliceous distillates may pass through argillaceous or arenaceous rocks and contribute little in the way of metasomatism, because from a chemical standpoint the solutions are more or less in equilibrium with the invaded rock. In the case of carbonates, solution and reaction are more easily effected and metasomatism more readily accomplished.

The classical reaction, $CaCO_3 - SiO_2 = CaSiO_3 - CO_2$ is often set up where silication of limestones is discussed. The temperature of reaction in dry mixtures is about 500° C. In aqueous solutions the reaction proceeds as low as 260° C.[2] Heat is important insofar as it affects solubility, but of greater importance is the character of the solutions and the mutual effect

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1. Goldschmidt, V. M., Metasomatic Processes in Silicate Rocks. Econ. Geol., vol. 17, p. 121. 1922.
2. Grout, F. F., Petrography and Petrology, p. 396. McGraw-Hill. 1932.

of dissolved salts. By such means metasomatism and silication is accomplished in limestones at considerable distance, beyond the effective reach of diffused heat.

The work of Ingersoll and Zobel[1] showed that heat conduction away from an igneous body through solid rock is extremely slow. It does not appear probable from the curves which they constructed or those of Schneiderhohn[2] that sufficient heat to form garnet, diopside, or wollastonite could be conducted through the limestones to distances of 1000-1500 feet from a medium grained intrusive unless enormous stores of latent heat and considerable time are assumed. Emanations could accomplish more in shorter time and at lower temperatures. In the words of Lindgren "convection outdistances diffusion" in heat transfer.

In all probability, except for a small zone a few feet in width near the igneous contacts, the temperature in the tactite zone never reached that necessary to form wollastonite from calcium carbonate

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1. Ingersoll, L. R., and O. J. Zobel, An Introduction to the Mathematical Theory of Heat Conduction, pp. 128-129. 1913.
2. Schneiderhohn, H., Time-temperature Curves in Relation to Mineral Association in Cooling Intrusions. Econ. Geol., vol. 29, p. 473. 1934.

and silica in a dry mixture. The formation of wollastonite and other silicates at a distance was a result of the thermal and chemical activity of solutions permeating the rock. The formation of quartz and calcite in proximity to igneous contacts in association with calcium silicates is further indication that the temperature was not above the stability of silica and calcium carbonate in dry mixtures. The formation of quartz and calcite in one place and wollastonite in another was not merely a heat problem, but was the result of the concentration of the pervading solutions, and the solubility of the substances already present controlled the metasomatic changes. In no case at Darwin was wollastonite found in a manner indicating formation by reaction from adjacent grains of calcite and quartz.

Recrystallization in conjunction with metasomatism operated widely at Darwin, but the extent of such reactions, and in most cases the very existence of it, was dependent upon heat or materials carried by magmatic emanations which permeated great volumes of the Pennsylvanian rocks. Recrystallization with little or no metasomatism operated in argillaceous and arenaceous beds and in marmorization of pure limestones near the contacts. In the calcerous beds including the impure limestones which constitute the great bulk of the

Pennsylvanian strata, metasomatism has equalled or surpassed recrystallization.

Metasomatism in the Development of the Tactites

Considerable evidence exists that magmatic materials rather thoroughly penetrated the limestones at an early stage and effected widespread but often incomplete silication. The most striking illustration of this is shown on the ridge immediately west of the Essex and Thompson mines (Plate XII). Toward the south end of the ridge a large irregular silication patch cuts across a blue gray limestone member 20 to 30 feet in thickness. In the bleached silicate area the retained bedding and the general structural evidence is such as to forbid any appreciable volume reduction and hence recrystallization alone is ruled out. Samples were taken along the strike of the blue gray limestone at intervals to illustrate the change into tactite. Since the original blue gray limestone is not composed entirely of calcite, but appears to be clouded with a small amount of argillaceous impurities, it was desirable to check the petrographic evidence with chemical analyses. Accordingly, two samples were selected, one from the unaltered limestone and the other from the white stratified tactite directly along the strike about 20 feet from the first sample. From the persistent uniform nature of the blue gray limestone bed to the point of tactization little doubt exists that it originally continued into the silicated area without change of width or composition. The following analyses show the changes of composition in the two rocks.

	Limestone Sp. Gr. 2.75	Tactite Sp. Gr. 2.84	Tactite Recalculated		Gains and Losses
SiO_2	13.90	40.02	41.33	plus	27.43
Al_2O_3	3.49	6.32	6.52	plus	3.03
Fe_2O_3	.85	.57	.59	minus	.26
FeO	.16	2.43	2.51	plus	2.35
MgO	1.72	3.20	3.30	plus	1.58
CaO	46.10	39.54	40.80	minus	5.30
SO_3	2.81	5.12	5.28	plus	2.47
CO_2	30.52	2.66	2.75	minus	27.77
Totals:	99.55	99.86	103.12		

The alkalies, titanium, manganese, and phosphorous were not determined. Because of the increase in the specific gravity of the tactite its composition was recalculated accordingly to 103.12 per cent. This makes it possible to compare unit volumes for losses and gains as shown in the last column. Aside from the very small loss in ferric iron the losses during silication were confined to calcium and carbon dioxide. The loss of calcium was probably accomplished by leaching of the calcite. The major loss, however, appears in carbon dioxide which was expelled in volumes approximately equal to the quantity of silica added.

In addition to the silica, gains are recorded for ferrous iron, aluminum, magnesium, and sulphur. The additions of ferrous iron and sulphur are clearly due to impregnation by pyrite. Aluminum and magnesium together show gains approximately equal to the loss in calcium and they were probably introduced by the magmatic emanations which brought in the silica.

The gray limestone, the analysis for which is given above, was chosen in the field because it was unbleached and appeared not to be affected by the magmatic emanations. Under the microscope it is composed largely of untwinned calcite forming a hazy intergrowth of large and small grains. The calcite is clouded by dark partially opaque material which is probably largely kaolinitic. Carbonaceous material may be present also. Occasional very small, radiate groups of wollastonite are present attesting either to some initial recrystallization of to introduction of silica.

With the faintest suggestion of bleaching of the limestone, wollastonite becomes more abundant and numerous irregular grains of garnet appear. Pyrite forms also at this stage. Some of the wollastonite takes the form of veinlets which traverse the entire matrix. A very little diopside is present.

A peculiar feature of the early stages of silication is an increased white cloudiness which gives to the thin section the appearance of being irregularly thick. The chemical analysis prohibits the cloudiness being kaolin or finely divided ferruginous material. A strong possibility exists that the semi-opaque material may be amorphous silica. In other localities at Darwin white opal is sometimes seen replacing wollastonite in hand specimens, but it is difficult to determine whether this is due to primary carbonated solutions or to surficial alteration. However, in thin section the white opal looks identical to the cloudiness under consideration. If the cloudiness is due to opaline silica this may be an indication that silica was introduced in the outer zone of the pervading solutions at temperatures too low to react with the limestone. With increasing silication this cloudiness disappears.

In the more highly silicated rock, or the tactite whose analysis is given above, the texture becomes distinctly felted and under the microscope wollastonite is very abundant. Many of the wollastonite crystals are considerably increased in size. Idocrase appears. Garnet is increased in size of grain and more abundant. Diopside is present in variable quantities in rather small crystals. Pyrite is more abundant. Scattered through some of the felted masses of wollastonite is a small, acicular and unidentified mineral with large extinction angle and moderate birefringence.

The occurrence of idocrase with its hydroxyl content and admittedly of metasomatic origin[1] lends further support to the origin by magmatic introductions. The existence of irregular silicate patches across original stratification is the best evidence of the metasomatic development of the tactites as a whole.

Veins of calcium silicates are always good evidence of transfer of material and metasomatism and as mentioned earlier there are many such structures in the tactites. The bulk silication effected by such veins is, however, not great and they are for the most part a late stage of tactization. They are in part restricted to fractures and joint planes in contrast to the early wholesale tactization which developed by the rather thorough permeation of the beds by magmatic emanations.

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1. Uglow, W. S., Origin of the Secondary Silicate Zones. Econ. Geol., vol. 8, p. 23. 1913.

The preponderant importance of magmatic emanations and introductions in the formation of the tactites at Darwin is supported and favored by other evidences, some of which are less direct than the case outlined above. In many places protuberances and margins of the stock are rather thoroughly garnetized. This mineralization is of two types, that along fractures, and that of irregular development in a considerable mass. The distribution of lime silicate materials through igneous rock strongly suggests that circulation of silicate solution occurred in the sediments and was therefore effective in the silication process.

The presence of unaltered impure limestones at or near the igneous contacts is evidence that heat alone was insufficient in many cases to produce more than very local recrystallization. Since emanations from or along an intrusive are nonuniform in their extent and nature, it is expectable that some sedimentary beds would escape impregnation and hence silication. The evidence afforded by the Coso batholith in the south end of the Darwin Hills is a case in point. Along the road to the Promentory mine is exposed an intrusive contact of the granite and blue gray limestone. The Coso batholith, although many times the size of the Darwin stock, has produced no metamorphism in this area. Cherty nodules remain in the unbleached limestone only a few feet from the contact. This is indeed a striking comparison with the silicate zone about the Darwin stock which is hundreds of feet in width. Examples of this sort are well known and they strongly emphasize the importance of magmatic additions in the development of the silicate zone. The contrasting effect produced by two intrusives on the same rock at the Crestmore quarries, California is analogous to the situation at Darwin. At Crestmore the limestone was unusually free from siliceous impurities and surrounding the quartz monzonite porphyry large aureoles of garnet, idocrase, and wollastonite are developed clearly indicating the addition of silica and iron. At the same locality the granodiorite has scarcely affected the limestones.

An unusual type of alteration of the sedimentary rocks occurs on the ridge just south of the Defiance mine. A small irregular stock, about 400 feet in width and 600 feet in length and separated from the main stock, cuts across the stratified tactites. Marginal to this intrusive is a tactite zone, 100 to 200 feet in width, in which all vestiges of stratification are gone (Plate XXX). In the weathered outcrop it has a decidedly brecciated appearance (Plate XIII-A). Beyond the "breccia" zone are normal stratified tactites. The change from brecciated tactite to stratified tactite is in most cases rather sudden. The intrusive rock is very fine grained, nearly white, and rather extensively impregnated with pyrite. Under the microscope it is largely a felted mass of feldspars. Its very fine grain and rather hazy intergrowth of feldspars makes identifications difficult or impossible. Twinning shows only faintly in most of the plagioclase present and the indices are low so that much of the rock is probably composed of albite. In some of the coarser and slightly more porphyritic phases orthoclase can be identified in the sections. The rock is decidedly leucocratic and is probably either trachyte or latite. However, the most distinctive feature of the rock, especially in relation to that of the Darwin stock, is the lack of quartz. The tactite breccia forms bold outcrops, but the intrusive largely because of its high pyrite content weathers to a brownish mantle.

The lack of quartz may have significance in regard to the obliteration of the bedding in the tactized breccia zone. From the development of very irregular veins and general impregnation of orthoclase in the breccia zone about this type of intrusive it appears that magmatic materials were introduced in large quantities. The process was a sort of orthoclasization in which all of the elements of the mineral were added. During the orthoclasization, thermal activity caused recrystallization of the impure limestones peripheral to the intrusion. The simultaneous orthoclasization and shrinkage resulting from recrystallization of the impurities of the limestone with the released lime produced a sort of "collapse" breccia of the tactite. Some fluorite is scattered through the collapsed tactite attesting to the presence of mineralizers. The shrinkage during the formation of the tactite breccia was in part taken up by the orthoclasization and emplaced stock. Tectonic mechanical brecciation does not appear tenable as an explanation of the zone.

In summary the evidence for the metasomatic origin of the Darwin tactites is as follows:

(1) Formation of silicates along the strike of a limestone bed without obliteration of stratification in such way as to indicate chemically and petrographically that silica was introduced.

(2) Irregular development of tactites not in direct relationship to the igneous contact, and the

presence of unaltered impure limestones near some contacts.

(3) Lack of silication adjacent to the Coso batholith in comparison to its extensive development about the Darwin stock.

(4) Garnetization of the intrusive indicating migration of calcium silicates.

(5) Greater development of andradite garnet showing increase in iron adjacent to some contacts.

(6) The presence of such minerals as idocrase, tourmaline, apatite, and sphene in the tactites. Especially the presence of idocrase with wollastonite in its initial stages of development.

(7) Veins of calcium silicates such as wollastonite, garnet, and idocrase cutting limestones and tactites.

(8) Veins, dikes, and general impregnation of orthoclase in some parts of the tactite.

Evidences of Zoning and Mineral Sequence

Zoning is not conspicuously present in the tactites at Darwin. The existence of mineral zones of metamorphism about intrusives are well known. However, the best examples of metamorphic zoning are in argillaceous rocks. Furthermore, homogeneity in bulk composition of the country rocks is necessary to establish clear cases of zoning.

At Darwin the igneous contacts generally parallel the stratification of the tactites and hence no uniformity of original bulk composition can be assumed normal to the heat source. The pure and impure limestones do not mineralogically zone with the readiness of some argillites. As a result of the irregular permeation of the country rock by igneous emanations, no uniformity of temperature gradient existed away from the contacts.

For these reasons mineral zones are only meagerly developed. However, certain tendencies can be indicated:

(1) Decrease in size of grain away from contacts and metasomatic centers.

(2) Epidote practically confined to the immediate contact.

(3) Darker colored garnet zones adjacent to some contacts indicating introduction of iron into the lime silicates near the intrusive.

(4) Hedenbergite in place of diopside near contacts, probably indicating a similar enrichment.

Sequence of mineralization in the silicate zone at Darwin is difficult to establish and overlapping appears to exist in most cases. Wollastonite is without much doubt the earliest mineral to form. It is clearly replaced by idocrase and garnet. Sequential relationships between diopside, garnet, and idocrase do not admit of positive proof. Orthoclase appears to form more abundantly near the contacts while oligoclase forms at a greater distance and it appears that oligoclase is indicative of lower grade metamorphism and therefore formed earlier. The paragenesis of the principal silicate minerals is about as follows: wollastonite, idocrase, garnet, diopside, plagioclase, and orthoclase. If this order of formation is correct, then it may be observed that the earlier minerals are the highest in lime and that the trend is towards increased silica and alkalies. This is perhaps the expectable trend in the metamorphism of a carbonate rock adjacent to a siliceous intrusive, and it further demonstrates the metasomatic nature of the silication process.

ALTERATION OF THE IGNEOUS ROCK

The intrusive rocks have suffered considerable yet variable alteration paralleling that in the tactites and in the ore bodies. The alteration minerals fall into two groups. The earlier higher temperature group includes garnet, orthoclase, diopside, calcite, clinozoisite, and epidote. The second, lower temperature group includes sericite, chlorite, pyrite, quartz, kaolin, leucoxene, and jarosite. It must be admitted, however, that the division between the two groups is not sharp and proof that some of the minerals in the two groups did not develop contemporaneously is wanting. In general, garnet, diopside, calcite, and epidote are products which involved some transfer of material, particularly lime from the sedimentaries. These minerals are common in the intrusive near the contacts. Thus, in the quartz diorite near the Thompson mine there has developed considerable calcite, epidote, and pyrite, the last mineral being clearly related to fractures. In addition, diopside, clinozoisite, chlorite, sericite, and tourmaline are present in smaller quantities.

Garnetization of the intrusive has already been mentioned and this type of alteration is very well shown in many places. In the sill-like offshoot of the stock about 200 feet above the Defiance mine garnet is abundantly developed. In some places here nearly the entire rock may be converted to light green, granular garnet. In other places the garnet is distinctly devèloped along joints. Another area of intense garnetization occurs about 300 yards west of the Christmas

Gift mine on the Hahn claim where the igneous material has been almost entirely converted to medium grained, light brown garnet.

It is a noticeable feature that orthoclase is more abundant in many of the border phases and offshoots of the intrusive. The intrusive near the Defiance mine is quartz diorite, but at the immediate contact back of the blacksmith shop orthoclase makes up nearly 90 per cent of the rock. Sometimes this development of orthoclase takes the form of small dikes or veins which in places so permeate the rock as to lose identity. Where orthoclase forms much of the rock poikilitic plagioclase, diopside, epidote, or sphene are commonly present. Perhaps epidote is the most common associate of orthoclase of this occurrence. The formation of the potash feldspar is roughly correlated with orthoclasization of the limestones.

Sericitization is widespread and sometimes very intensely developed. In places near the igneous contacts the rock is composed almost entirely of quartz and sericite. Sericitization first begins in the plagioclase and pseudomorphs of sericite after plagioclase are preserved in completely altered rock. In feeble alteration where only the plagioclase is attacked orthoclase is more or less kaolinized. In the more advanced stages, sericite spreads to the potash feldspar and at the same time quartz appears to increase as though it were a by-product of the sericite. In the final stage sericite even invades the quartz (Plate XXIII).

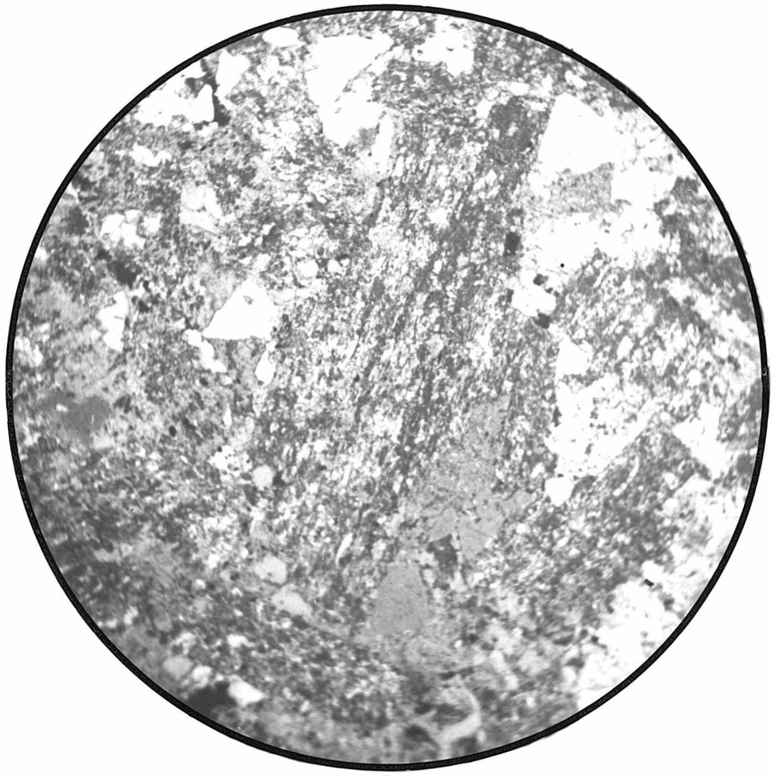
Much leucoxene accompanies the sericitization process and most of the leucoxene is an alteration of a black metallic mineral, inferentially ilmentite. Associated with the leucoxene alteration is a small quantity of jarosite. The jarosite occurs partly as veins cutting all other minerals and partly as grains intimately associated with leucoxene and sericite alteration in areas clouded with kaolin and containing minute grains of sphene. The occurrence of jarosite intimately associated with leucoxene and sericite probably indicates that the assemblage is of hydrothermal origin. Sericitization probably represents a lower temperature, hydrothermal continuation of orthoclasization. The orthoclasization, along with the development of garnet, tourmaline, sphene, calcite, diopside, and epidote is best correlated with the bulk of tactization. On the other hand, sericitization and accompanying products are more nearly to be correlated with later hydrothermal processes and the metallization epoch.

Pyrite is extensively developed in the igneous rocks and for the most part is of late hydrothermal origin contemporaneous with metallization.

Plate XXIII

A. Sericitized and kaolinized plagioclase characteristics of the initial alteration of quartz diorite.
Crossed nicols. 40X. No. P.A-1.

B. Sericite (s) and quartz (q) in an advanced stage in the alteration of the quartz diorite.
Crossed nicols. 40X. No. P.A-1.



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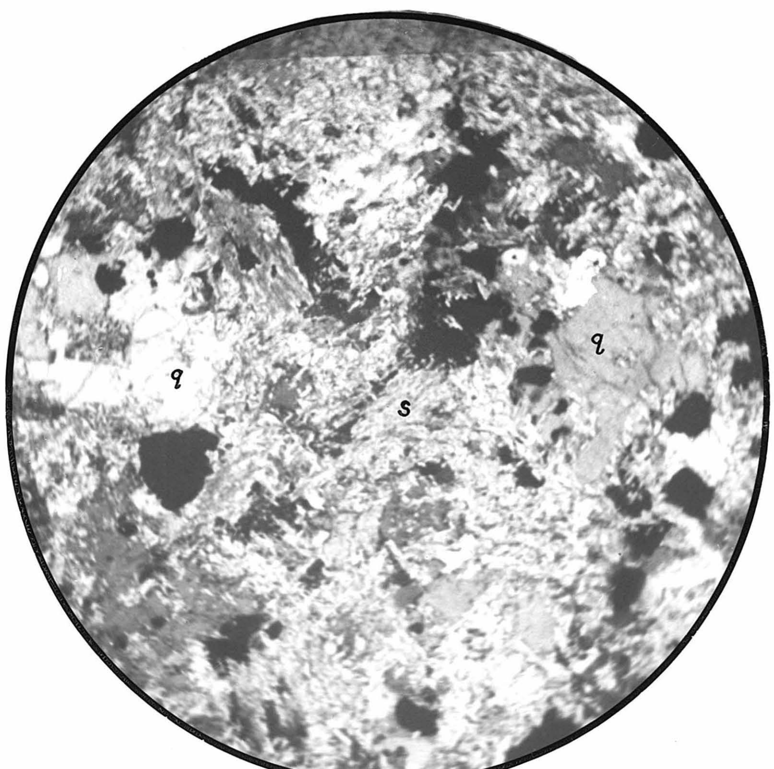


B.

HYPOGENE ORE AND GANGUE MINERALIZATION

The mineralization which gave rise to the silver-lead deposits at Darwin is sharply set off from the silicate mineralization described in the previous chapter. The silication of the limestones is conceived as having taken place during the emplacement of the stock, whereas the ore and gangue mineralization occurred after the formation of the tactite zone in subsequent fractures and other structural loci. Quantitatively, the major metalliferous deposition occurred within the tactites. This post-consolidation mineralization may be discussed in two groups: gangue, and ore mineralization.

GANGUE MINERALIZATION

The gangue mineralization consists chiefly of calcite, pyrite, jasper, and fluorite. In addition garnet, orthoclase, quartz, hematite, siderite, and barite are present in lesser quantities. Garnet, orthoclase, quartz, and pyrite are deposited in the above order, replacing the quartz diorite walls of the Lane vein near the igneous contact in Lane canyon. Again in the Wonder mine 300-400 feet from the contact a similar assemblage is to be found replacing tactite walls and here coarse calcite and fluorite are intergrown and directly associated with the ore minerals. However, the occurrence of garnet and orthoclase as post fissuring gangue minerals is quantitatively of minor importance and in by far the majority of deposits calcite, fluorite, jasper, kaolin or pyrite make up the early formed gangue minerals. Spongy and earthy iron oxides, derived from oxidation of the jasper and pyrite, are very closely associated with galena.

A small quantity of scheelite occurs in coarse calcite with pyrite and chalcopyrite on the Bruce claim in Lane canyon where ore carrying as much as two per cent tungsten and traces of molybdenum are reported.

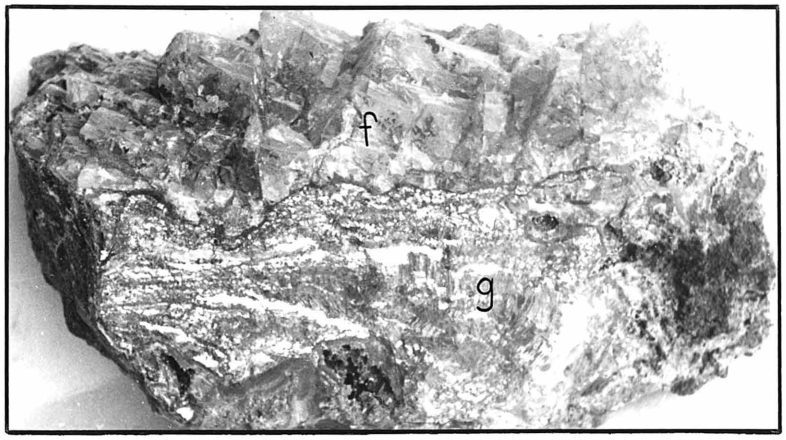
There is a general decrease in the grain size and abundance of certain of the gangue minerals with distance from the stock. Extremely coarse calcite in cleavable masses eighteen inches on a side characterize such deposits as the Defiance, Custer, and Wonder, all of which are at or near the intrusive. Farther from the contact calcite is finer textured and somewhat less common. Rose, green, or white varieties of fluorite, common associates of galena in deposits near the igneous contacts, are much less common or are absent at a distance. Pyrite, or

Plate XXIV

A. Banded galena (g) with fluorite (f). Note the dark seam of anglesite between the galena (below) and the fluorite. Defiance mine.
$\frac{3}{4}$X.

B. Galena (g) with jasper (j) and cerusite (s) from the Fernando mine.
$\frac{5}{8}$X.

C. Banded hematite from the discovery veins south of the Promentory mine.
$\frac{3}{4}$X.



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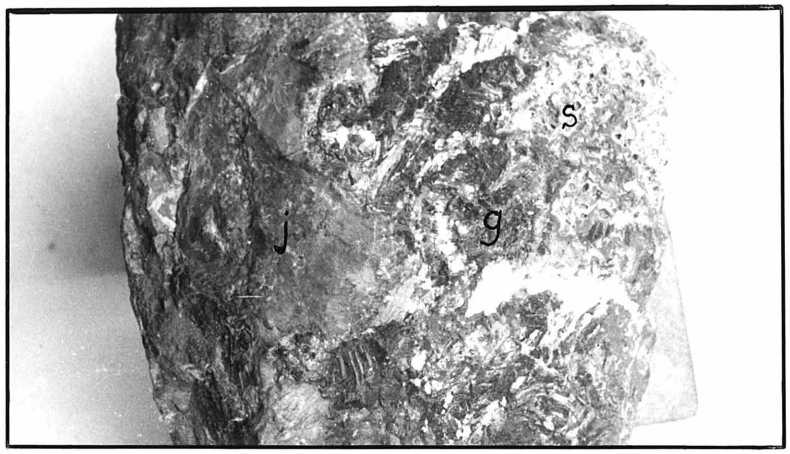

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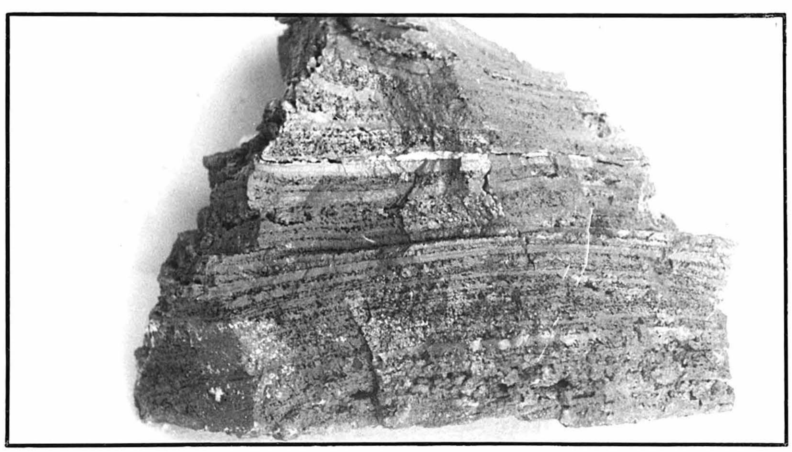


C.

pseudomorphs of limonite after pyrite, in sizeable pyritohedrons and cubes are abundant in deposits near the stock. In contrast, the pyrite in deposits at some distance from the intrusive is granular, less common, or absent. Likewise, the early garnét-orthoclase mineralization is relatively more common in proximity to or within the intrusive. Jasper, on the other hand, is universally present, but relatively more abundant as a gangue mineral in those deposits situated some distance from the stock.

ORE MINERALIZATION

Galena and its alteration products constitute the principal ore minerals of the district. Galena is found in association with all of the gangue minerals mentioned above and in a few places, as at Essex mine, it has impregnated and replaced the silicate minerals of the tactite. Occasionally it is found replacing igneous rock along fractures. Notwithstanding its varied associations, its dominant occurrence is in lenticular or tabular deposits with calcite, fluorite, pyrite, or jasper or the oxidation products therefrom. Sphalerite and to a lesser extent chalcopyrite occur with the galena in many places.

Megascopic Features of the Ore

The primary ore is predominantly argentiferous galena and it occurs in bunches, lenses, or tabular veins distributed through the gangue of the deposits. The galena varies in texture from fine grained or steel galena to coarser material in which individual interlocking crystals may attain one or two inches in diameter. The most common variety is medium grained and it is often characterized by a banded texture in which curved cleavage faces are the rule rather than the exception (Plate XXIV-A). Nearly all of the galena contains occasional visible inclusions of chalcopyrite. In one or two of the deposits of the district chalcopyrite and its oxidation products make up the entire ore mineralization. However, as a rule the quantity of chalcopyrite seen in the galena is small. Sphalerite and pyrite are associated in greatest abundance with galena. Sphalerite is very common in parts of the Defiance, Thompson, and Intermediate ore bodies. Some of the masses of sphalerite in the Thompson mine are very coarsely crystalline with individual cleavage pieces two or three inches in diameter. Masses of argentite are reported from some of the deposits, but none was found during the present work. Likewise thin sheets of native silver are reported from several of the properties, but this was probably a secondary product resulting from local reduction of silver solutions or silver minerals.

The sulphides are later than the primary gangue minerals. In polished hand specimens from the Rip Van Winkle and the Essex ores small veinlets of pyrite and galena cutting quartz, fluorite, and calcite can be seen.

In the north end of the Darwin Hills about one mile northwest of the stock there is an antimony prospect containing irregular bunches and radiating groups of stibnite. Blades three to four inches in length replace a matrix of arenaceous limestone along bedding planes and small cross fractures. The stibnite has been largely oxidized to cervantite. Numerous cavities containing pseudomorphs of cervantite after stibnite are present. The isolated nature of this deposit makes it impracticable to relate it to the lead mineralization about the stock.

Microscopic Features of the Ore

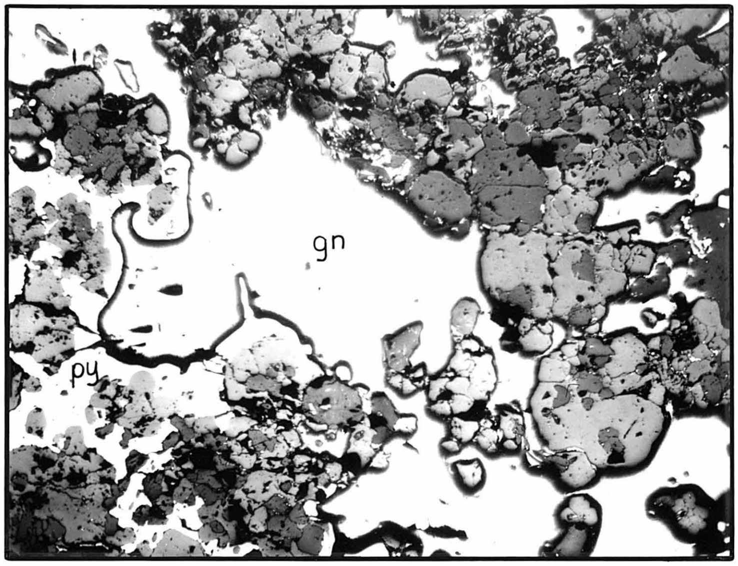
Specimens were polished of all of the varieties of primary ores that could be obtained in the district. The mineralogy was found to be rather simple and the paragenesis in all of the ores examined, whether from near the intrusive or at a distance, was essentially similar. Galena is the latest primary mineral to form (Plate XXVII). It replaces all other minerals including sulphides and nonmetallic gangue minerals alike. It commonly contains numerous inclusions of pyrite, chalcopyrite, sphalerite, luzonite, and tennantite (Plate XXVI). All of these inclusions are clearly residual to the galena replacement. They may occur as individual inclusions or more often as irregular intergrowths of the two. The sulpharsenides of copper are the most likely to carry the silver values in the galena, but a microchemical test gave no test for silver.

A noticeable feature of polished galena from the Christmas Gift mine and from the Promentory mine is that inclusions of luzonite and tennantite are more numerous than in galena from the Defiance-Independence group of mines. The Defiance and Independence ores have averaged about one ounce of silver to each one per cent of lead, whereas ores from the Lucky Jim, Christmas Gift, and Promentory have averaged about two or three ounces to each one per cent. In other words, the silver values have been higher from the deposits near the ends of the stock which were in association with the more basic rocks. Since it is common for the sulpharsenides of copper to be

Plate XXV

A. Galena (gn) replacement of pyrite (py) in a gangue of garnet, calcite, and fluorite. 75X. Essex mine no. 7.

B. Galena (gn) replacement of sphalerite (sp) dotted with chalcopyrite inclusions. Gangue is mostly garnet. 75X. Essex mine no. 7.



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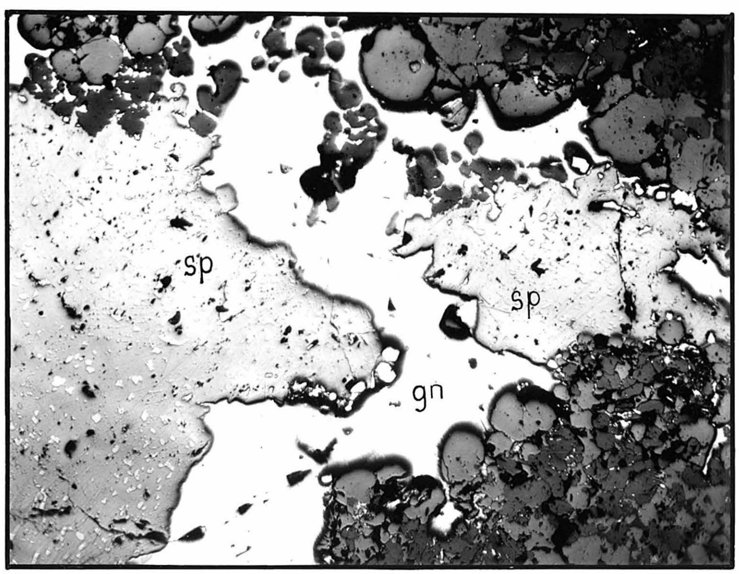
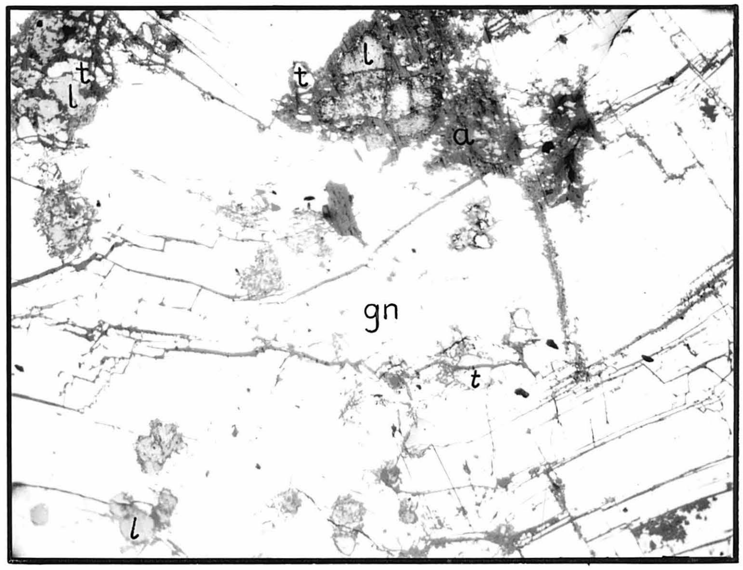


B.

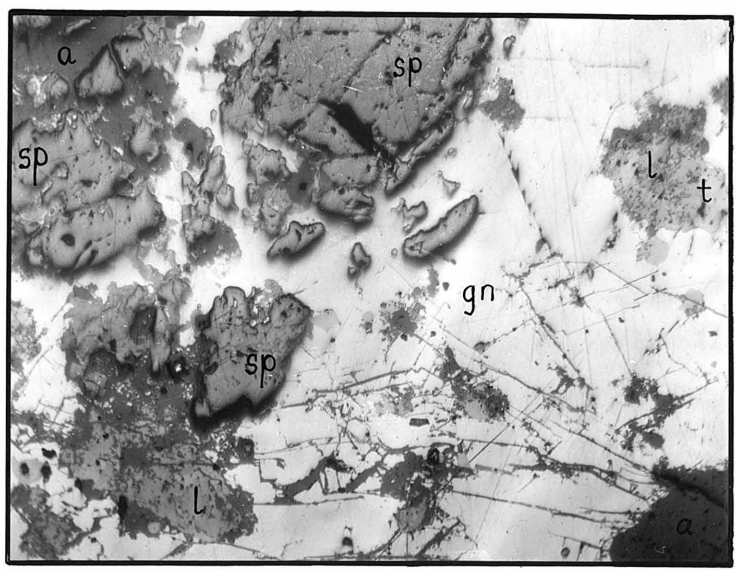
Plate XXVI

A. Galena (gn) with numerous inclusions of luzonite (l) and tennantite (t). Note the structure of the galena brought out by anglesite replacement along the cleavage lines. Christmas Gift mine. 75X.

B. Galena (gn) with inclusions of sphalerite (sp), luzonite (l), and tennantite (t). Anglesite (a) is dark gray. Many small feathery veinlets of covellite are present and principally confined to sphalerite or the gray coppers. Christmas Gift mine. 75X.



A.

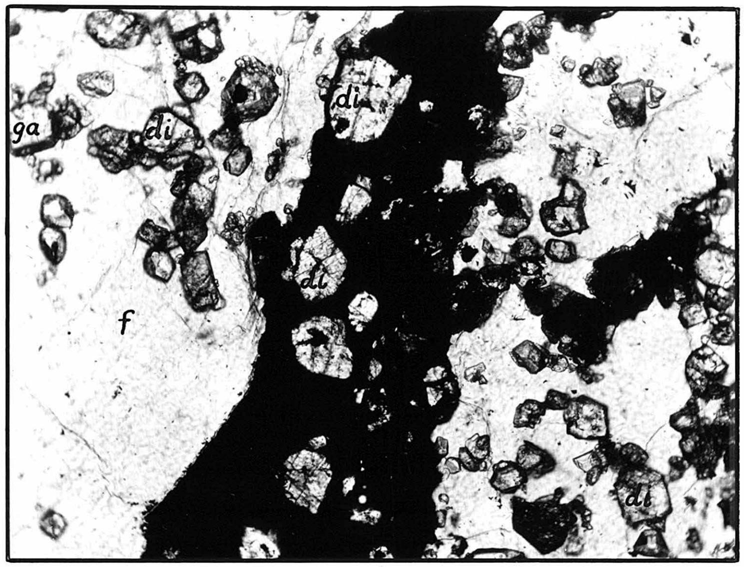


B.

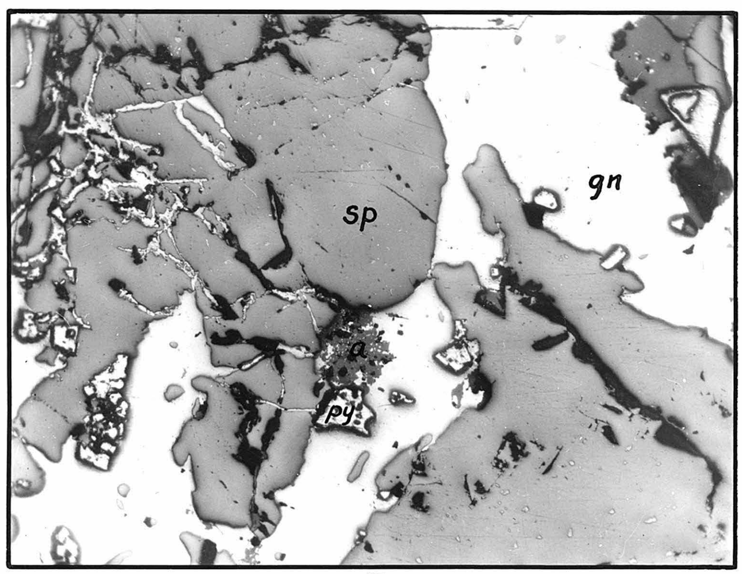
Plate XXVII

A. Replacement of fluorite (f) by galena with residual metacrysts of diopside (di) and garnet (ga). Primary ore from the Essex mine. Plain light. 75X.

B. Galena (gn) replacement of sphalerite (sp) and pyrite (py). Anglesite (a). 75X.



A.

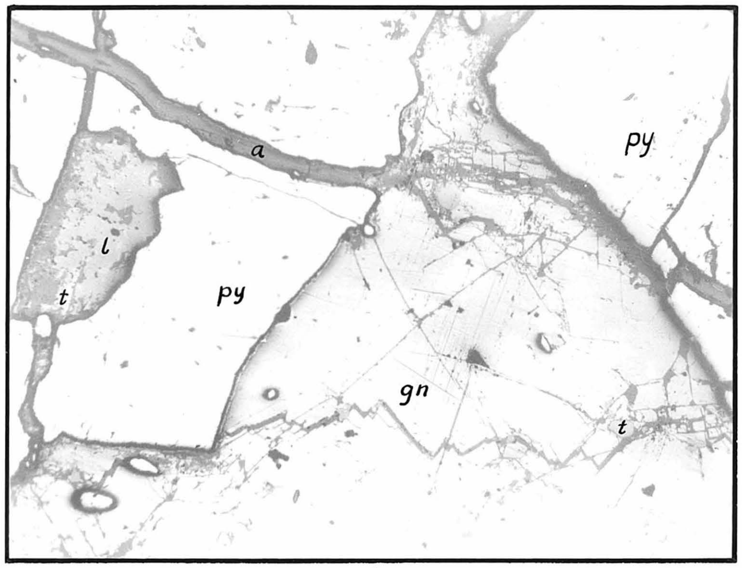


B.

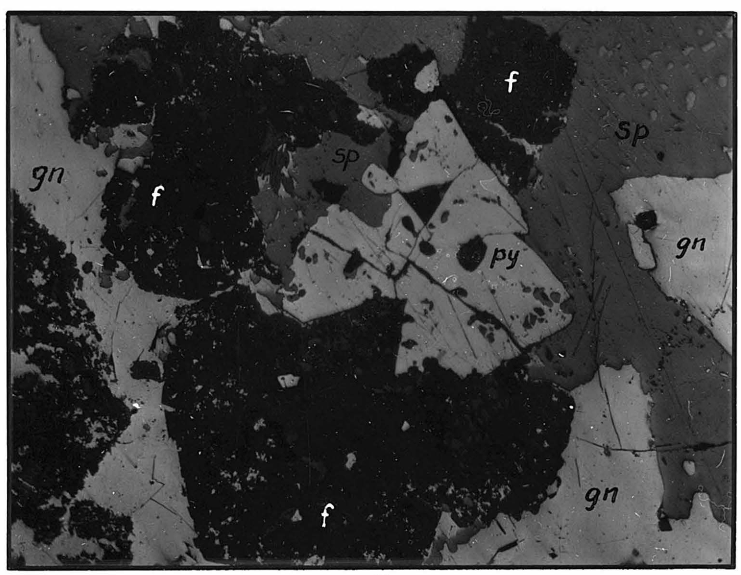
Plate XXVIII

A. Pyrite (py) replaced by galena (gn) and both replaced by anglesite (a). The luzonite (l) and tennantite (t) at the left are later than the pyrite and earlier than the galena. Promentory mine. 75X.

B. Pyrite (py) replaced by sphalerite (sp) in turn replaced by galena (gn). Note the mottled replacement of fluorite (f) by galena. Essex mine. 75X.



A.



B.

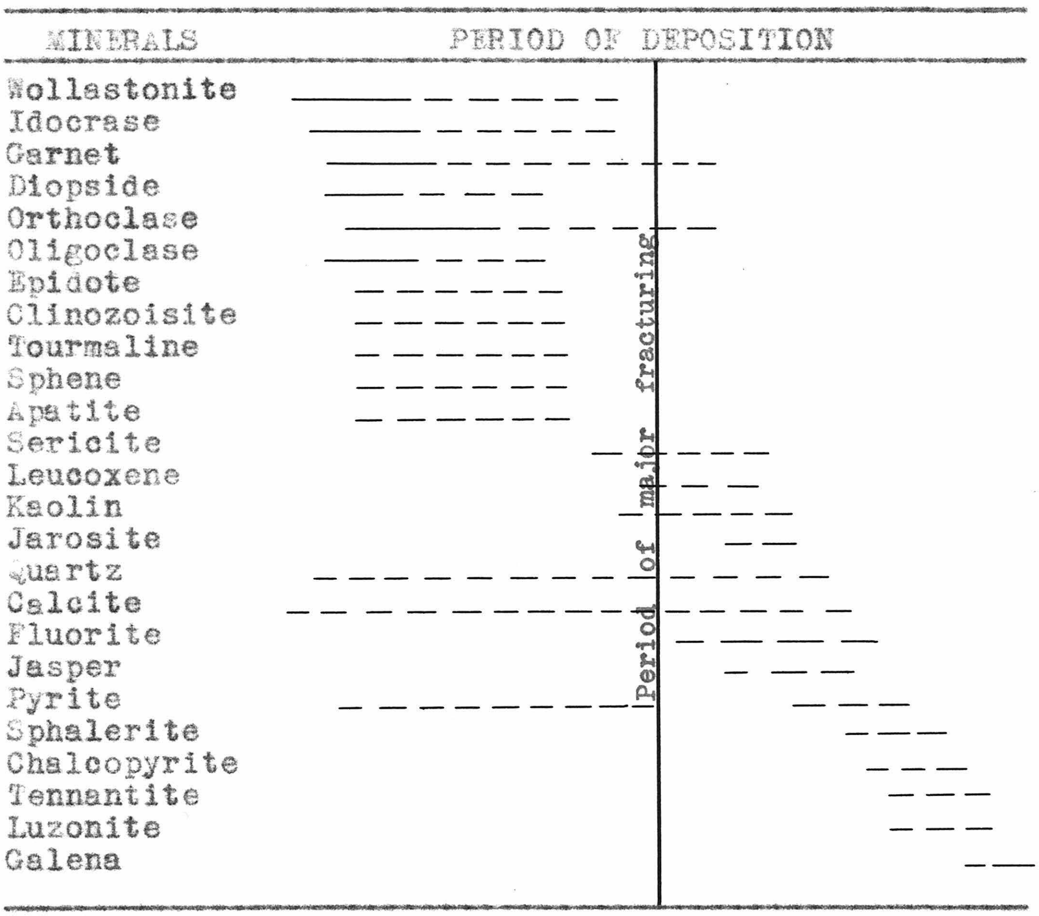
the source of silver in galena ore it may be that the increase in silver values is proportional to their abundance.

The microscopic evidence indicates a sequence of deposition in the following order: pyrite, sphalerite, chalcopyrite, tennantite-luzonite, galena. The accompanying photomicrographs show most of these relationships. Sphalerite commonly contains small spines of chalcopyrite more or less uniformly scattered through it in a manner suggesting an origin by unmixing.

SUMMARY OF THE MINERAL PARAGENESIS

The earliest minerals formed, wollastonite and idocrase, were rich in lime. The later minerals formed were increasingly enriched in silica. Silica was introduced into the limestones at an early stage and continued until the deposition of the sulphides. The early high temperature introductions of silica produced silication. The final consolidation of the igneous rock was followed by a period of fracturing. However, silica continued to be supplied, but under lower temperatures silication gave way to <u>silification</u> in the intrusive and in the epigenetic deposits first as quartz and later as jasper. In a similar manner, but to a lesser extent, iron was added over a long period beginning during the silication with the formation of garnet zones adjacent to some contacts and continued under hydrothermal conditions in the form of jasper and pyrite.

A generalized picture of the paragenetical relationships is given in the table below.



SUPERGENE ALTERATION

At Darwin, as might be expected from the aridity of the climate, oxidation and supergene alteration have extended to great depths. The present depth of mining operations which is only 1000 feet in the Lucky Jim mine has not penetrated below the zone of oxidation. Oxidation has been very thorough as revealed by the abundance of porous, gossanized gangue in nearly all of the deposits. The gossanized material has been almost entirely derived from pyrite, jasper, and hematite. A little has been derived from the decomposition of iron bearing sphalerite.

Cerussite greatly predominates among the oxidized lead minerals. To date a larger portion of the lead production has been obtained from cerussite than from galena, thus indicating the completeness of oxidation. Anglesite is not common except in thin coronas immediately surrounding the galena masses. Plumbojarosite is reported from some of the deposits and its origin was probably supergene. Also in the more highly oxidized near surface ores it is probable that the oxides of lead formed in small quantities although none were observed. Native sulphur is rather common associated with some of the sulphide oxidation products. Considerable horn silver was probably present in the surface ores although none was found during the present work. It was probably so intermixed with either the iron oxides or oxidized lead ores that it was seldom seen. In any event its presence seems substantiated by the fact that the surface ores, spoken of as the "cream" of the deposits, were often very high in silver. Moreover, some of the early mining reports describe the ore as consisting in part of horn silver[1]. This is, of course, in keeping with the known facts in regard to concentration of silver values near the surface during oxidation of the primary ores.

Some thin sheets of native silver reported to have been found in the Thompson and Lucky Jim mines probably resulted from alteration and local reduction of the primary argentiferous lead ores.

A little smithsonite in keeping with the quantity of sphalerite present is also found in places. Likewise the small quantities of chalcopyrite and sulpharsenides of copper found in the primary ores have contributed to the formation of chrysocolla and melaconite in many of the oxidized ores. An almost insignificant amount of secondary sulphide enrichment

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1. Inyo County: Calif. Min. Bur., 12th Ann. Rpt., p. 24. 1893.

is seen in some of the primary sulphides in the form of covellite and more rarely chalcocite.

STRUCTURAL CONTROL OF ORE DEPOSITION

From the position and nature of the deposits about the Darwin stock it is evident that structure was the dominant control in their location. However, to some extent the composition of the enclosing wall rocks has had a modifying influence on the local accumulation of ore. There are three types of structural controls: (1) intrusive contacts, (2) bedding planes, and (3) transverse fissures. A single deposit may be localized by two controls or pass from one into another.

DEPOSITS ALONG INTRUSIVE CONTACTS

The deposits formed at igneous contacts are the largest in the district. Along straight stretches of the contact deposits of this type may be long, narrow, tabular bodies resembling the fissure deposits. In general, however, the contact deposits are lenticular in plan and although shorter in outcrop length than the cross fissure deposits, they are usually thicker. They vary in length along the contact from a few feet to two or three hundred feet. Likewise the width may vary from less than one foot to 20 or 30 feet. They extend downward irregularly along the igneous surfaces.

The configuration of the contact appears to exercise some control in the localization of such deposits. Irregular protuberances of the intrusive into the country rock often show more pronounced mineralization. Also local warping of the adjacent strata or flattening of the contact surface appears to be instrumental in impounding of ore. Such features may have been effective along the contact between the Defiance and Independence mines where the intrusive has forced its way into a small anticlinal fold paralleling the stock and thus flattening the contact surface to some extent. However, insufficient underground development has been done on these deposits to permit a full analysis of their localization.

The Defiance and Independence ore bodies are the outstanding examples of deposits along igneous contacts (Plate XXX), but similar smaller deposits are to be found at several points north and south of these. On the west side of the stock the contact roughly parallels the stratification of the tactites thus forming an effective structural trap along this surface for deposition of ore. Contrasted with this the east side of the stock bears cross cutting relationships to the stratification. Hence the contact surface formed practically no effective trap for the ore solutions which could more readily pass outward along the bedding planes and fractures (Plate X). As a result of this structural condition there are no mines of any consequence located on the east contact of the stock. The only deposits at the contacts which have produced are those located on the west side of the stock. The type of ore mineralization and associated gangue is similar or identical to that of many of the bedding plane and fissure deposits.

BEDDING PLANE DEPOSITS

Numerous deposits have been formed along bedding planes, particularly along the east side of the stock where ore solutions found easier avenues of escape from the contact both by reason of more numerous cross fractures and by bedding planes which dip steeply into the contact. The outstanding deposits of this type are the Custer, Jackass, Fernando, and Keystone on the east side and the upper Defiance and Promentory on the west side. Many of the deposits are layered or sheeted as a result of replacement of several thin beds. Others such as the Fernando and the Keystone have formed at the intersection of fissures with favorable stratification planes and as a result they have a chimney-like shape. At the Keystone the deposit is dominantly on the fissure. In some instances where the igneous contact cuts slightly across the stratification, contact deposits continue or branch into bedding plane deposits. The Custer and upper Defiance bedding plane deposits are only 20 or 30 feet from the igneous contact. Others such as the Promentory and the Keystone deposits are 1000 to 1500 feet from the contact.

TRANSVERSE FISSURE DEPOSITS

Deposits of this type are the most numerous in the district and, although very important, it is doubtful whether they will outproduce the deposits formed at the igneous contacts. The fissure deposits are most important and numerous on fractures trending northeasterly, nearly at right angles to the elongate direction of the stock. Many of these are confined to the tactite or only extend a short distance into the intrusive where they are taken up by multiple adjustments along joint planes. Others such as the Standard or Lane veins cut entirely across or extend well into the stock. Fissures of this type are mostly vertical, but where inclined the dip is steeply to the north.

Fissure veins of this type are intersected by a northwesterly belt of mineralized fissures which lie north and east of Ophir Mountain. On these fissures much shearing is evident in places and this is accompanied by greater width of mineralization in the form of jasper, calcite, and barite. Metallization, however, is sporadic and the ground of these veins is as yet unproven.

The Christmas Gift, Lucky Jim, Lane, and Columbia mines are the outstanding producers from the fissure veins. The width of the fissure veins averages two to six feet, but locally stopes 25 to 30 feet in width have been mined. Ore and gangue mineralization in the transverse fissure veins is in many places the same as in the deposits along the igneous contacts. Those veins which extend from the tactite into the igneous rock show by contrast the influence of the wall rock on deposition. In the intrusive the veins become restricted and ore and gangue scarce and sporadic.

In the following table the mines of the district are arranged according to their distince from the stock and the dominant structural control is indicated. Mines on deposits along contacts are restricted to the west side of the stock.

MINES	STRUCTURAL CONTROL			FEET FROM
	CONTACT	BED. PL.	FISSURE	IG. CONTACT
West of stock:				
Independence	x			0
Essex	x			0
Defiance	x	x		0
Bernon		x		50
Thompson			x	100
Lucky Jim	x		x	200
Belle Union		x		200
Rip Van Winkle			x	500
Promentory		x		1000
Fairbanks			x	1500
East of stock:				
Standard Ext.			x	50
Custer		x		50
Christmas Gift			x	300
Standard			x	400
Silver Spoon			x	500
Wonder		x		1000
Fernando			x	1000
Jackass		x		1200
Keystone		x		1500
Santa Ana			x	2000
Lane			x	2200
Columbia			x	3000

ORIGIN AND CLASSIFICATION OF THE DEPOSITS

The position of the Darwin silver-lead deposits is clearly controlled by the form and extent of the stock. The stock was guided in its emplacement by the structure of the Pennsylvanian strata. Advancing with and ahead of the igneous material were emanations which carried great quantities of silica and lesser quantities of other metals, chief among which was iron. Heat energy with which to promote recrystallization and metasomatism was carried largely by the magmatic emanations. The effect of conducted or diffused heat was distinctly subordinate to that of conveyed heat. The heat and chemical action of the pervading emanations caused great quantities of carbon dioxide to be liberated and driven off. Simultaneously with the liberation of carbon dioxide silica and other metals were added, thus preventing any appreciable volume reduction and consequent obliteration of bedding structures.

The stock was intruded into rocks already considerably silicated and thoroughly heated. This is evidenced by the absence of chilling on the margins of the stock or in small dikes in the tactite and by the lack of any detailed relationship of silicate aureoles to these offshoots of the stock. A lesser amount of silicate replacement accompanied or followed the intrusion as shown by garnet zones marginal to the stock or replacing it.

The development of the tactite aureole and the final consolidation of the intrusive was followed by a period of fracturing. Many of the fissures of the resulting fracture system are rather persistent and continue through the stock and the wide silicate aureole alike. Displacements which offset the igneous contacts occurred along some of the fissures prior to their mineralization.

All of the hypogene lead mineralization and deposition of ore in general occurred after this period of major fracturing. Some dislocations do post-date the period of metallization and have brecciated or offset the orebodies. This period of fracturing distinctly separates the period of silication, in which the tactites developed, from the period of metallization in which all of the ore of the district formed. The silication developed under high temperatures attending the intrusion. The ore deposition developed under low temperature, hydrothermal conditions.

Knopf thought the deposits indicated a "sequence in time" with decreasing temperature as

"The fissure veins are regarded as representing the low temperature end of a genetically related series of deposits formed at progressively decreasing temperatures,"[1] and "the galena ore of the Darwin district began to be deposited under pyrometsomatic conditions, but its maximum deposition occurred at a lower temperature,"[2] and further, in comparison, "the Coeur d'Alene district represents a sequence in space", while "the genetic sequence in the Darwin district represents a sequence in time."[3]

Admittedly a temperature gradient existed away from the intrusive, but this only effected a crude zoning of grain size and to a lesser extent of mineralization. If decreasing temperature determined the place of deposition it is more likely that deposition would first take place at a distance from the intrusive in fissures and bedding planes and later, as the temperature fell, at the contact, But there is no indication of long continued deposition of ore with falling temperatures, and temperature was not the controlling factor in the relative time of position of the deposits. The simplicity of the ore and paragenesis does not warrant a long continued deposition

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1. Knopf, A., Darwin Silver-Lead Mining District. U. S. G. S. Bull. 580A, p. 9. 1913.
2. Ore Deposits of the Western States, p. 552.
3. U. S. G. S. Bull. 580 A, p. 10.

and there is no overlapping of mineralization. Instead the controlling factors were (1) a deep seated supply of differentiated metals and their associated gangue substances following consolidation of the intrusive and fracturing of the rocks, and (2) the effective opening of fissures, stratification, and contacts to the ore bearing solutions. The ore deposition was all accomplished during a single short period under nearly constant temperature conditions following fracturing. The only division or classification to be made is one of structural control as already described.

In want of a better example of a pyrometasomatic lead deposit Knopf[1] has chosen Darwin. As evidence of a connection between pyrometasomatic deposits and fissure veins Knopf[2] cited the Independence ore body as an example of the contact pyrometasomatic type of deposit and the Defiance ore body as intermediate or transitional link between the contact type and the fissure veins of the district. This conclusion was based on finding apatite in orthoclase associated with primary sulphides at the Defiance mine and andradite garnet with galena at the Independence.

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1. Ore Deposits of the Western States, p. 552.
2. U. S. G. S. Bull. 580A, p. 9.

Both deposits occur near each other along the same intrusive contact and on the whole the mineralization is much the same except that in the Defiance ore body exceedingly coarse calcite is more abundant. Galena and other sulphides have impregnated the tactite walls to some extent in both deposits, but certainly the association does not indicate that the sulphides formed under the high temperature and pressures that the garnet or orthoclase did. In fact, there is little in either deposit which can be used to set them apart or to set either apart genetically from the fissure veins, especially as regards time, sequence, and substances available through ore forming solutions. In a sense it is better to view them all as fissure deposits. During metallization some fissures were effectively opened along contacts and bedding planes and others along transverse fractures.

The deposits along contacts and in fissures are similar mineralogically and structurally and there is no necessity for demonstrating a transition for they are genetically identical. The fissures have the regularity of strike and dip of mesothermal deposits. The walls are smooth and well defined. Furthermore, the regularity and sharp definition of the contact deposits compares with that of the fissures. The mineralization directly associated with the deposits is not on the whole of the pyrometasomatic type. Jasper, which is one of the most common gangue minerals in the deposits, is indicative of formation at temperatures attributed to mesothermal deposits. Both fluorite and barite are common minerals of low temperature deposits. During the existence of the pyrometasomatic environment about the stock the characteristic minerals developed were garnet, orthoclase, quartz, specularite, and scheelite, but this mineralization was not great. The lead mineralization developed at a later stage in association with fluorite, calcite, barite, and jasper in a mesothermal environment. Both fluorite and barite are common to mesothermal or epithermal deposits.[1] Initial pressures and temperatures may have been such that a hypothermal stage was not represented.

Umpleby[2] from findings at Mackay, Idaho and from study of numerous other districts has formulated the generalization that ore about intrusive bodies tends to form on the limestone side of garnet zones.

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1. Lindgren, W., Differentiation and Ore Deposition; Ore Deposits of the Western States, p. 154. 1933.
2. Univ. of Calif. Publication in Geology, vol. 10, p. 26. 1916.

It was his observation that where ore came directly against the igneous contact practically no barren lime silicate would extend beyond the ore. Darwin appears to be an exception to this, for the silicate rocks in most cases extend far out beyond ore bodies at contacts. Of the two contacts, silicate-igneous and silicate-limestone, the latter would in all probability be more easily penetrated by ore solutions. Where the silicate zone is wide, stratification well preserved, and fissures common the rule formulated by Umpleby would be less applicable because of the preponderance of structural control.

MINING HISTORY AND PRODUCTION

During the early seventies the rich ores of Panamint City and the Ballarat district were shipped by pack train through Shepherd Canyon in the Argus Range and thence by a route following springs along the east front of the Coso Mountains to Owens Valley. A Mexican searching for a mule lost from the packers' camp at Old Coso or Coso Springs is reported to have discovered an outcrop of ore in the Darwin Hills. The initial discovery is reported to have been made in 1874. The lode which was found was evidently rich enough to have attracted considerable attention for during the year many other deposits in the district were located. Most of the important mines were started during the years 1874 and 1875. A good sized town soon sprang up and was named after Dr. Darwin French who had lead a party of 15 men through Darwin Canyon in 1860 in search of the mythical Gunsight silver lode in Death Valley.

During the early boom days of the seventies there were eight blocks of buildings along the main street and six in the other direction. The population is said to have then exceeded that of Los Angeles. Darwin was twice burned to the ground by wind whipped fires in the early days which probably accounts for the present lack of any indications of the former size or character of the town.

From 1875 to 1877 three smelters were built near Darwin. The Cuervo had a capacity of 20 tons per day; the Defiance 60 tons; and the New Coso 100 tons. The lead well of the New Coso smelter was started from lead obtained from Cerro Gordo. Iron oxides used at the smelter were obtained from iron mines on Centennial Flats in the Coso Mountains. Charcoal was obtained from timber burned in the Coso Mountains. It is also interesting to note that many of the eight by eight stulls still present in some of the older workings were hand hewn from timber obtained in the Coso Mountains.

During the early days of mining all freight had to be hauled by team from Los Angeles and consequently costs were very high. Only the richest ores were sent to the smelter and according to De Groot[1] at the Defiance mine about one foot broken out of the ledge averaging twelve feet in width constituted ore. About four-fifths by bulk and about one half of the values went into the dumps. Because of the excessive transportation costs and the exhaustion of these

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1. Calif. Min. Bur. Tenth Ann. Rpt., p. 211. 1890.

more easily mined rich ores, the smelters were shut down within a few years, prior to the completion of the narrow gauge railroad to Keeler in 1883. After shutdown of the smelters, jigging of the ores came into practice and concentrates obtained from newly mined ore and from the dumps were shipped to smelters at Selby or Salt Lake.

During the eighties and nineties mining and production were sporadic and at times practically dormant due to poor transportation, lack of modern mining facilities, and some litigation. Some leasing and shipping were carried on from 1900 to 1910, but only small activity was reported by Knopf in 1913. In 1915 the Darwin Development Company consolidated the Lucky Jim, Promentory, Lane, and Columbia mines and began the construction of a mill on the Lane property. This company soon gave way to the Darwin Lead-Silver Development Corporation, and finally, in 1917 the Darwin Silver Company consolidated the above properties with the Defiance and Independence mines purchased from the Reddy Estate. Modern equipment, roads, and camps were constructed with the view of mining on a large sdale, and although considerable ore was blocked out and nearly a half million in richer ore was shipped, real mining awaited camp building and surface developments. The camp was financed by E. W. Wagner and development was managed by A. G. Kirby in 1921. During the heighth of the development Wagner committed suicide due to reverses in grain speculation growing out of the grain crash of 1920. Kirby leased the properties from the Wagner Estate during the period of 1922 to 1924 and produced some ore, but because of estate complications was forced to quit.

The Lucky Jim mine, one of the big producers of the district, was mined extensively in the early days. According to J. A. McKenzie, who owned the mine at the time Goodyear reported on the district in 1888, the mine at that time produced about $1,250,000 or $1,500,000, but probably more money had been spent on the mine than had been taken out. At the time of Goodyear's visit the mine had been opened 300 feet by vertical shaft and 180 feet below the bottom level by an inclined winze. Although some mining had been done during the intervening time, no greater depth had been attained at the time of Knopf's work in 1913. The Darwin Development Company working the mine in 1915 had deepened it to 600 feet. The Lucky Jim camp above the mine was built about this time and the Lucky Jim mine continued to be deepened and mined until about 1926 when a depth of about 1000 feet was reached. The Defiance, Independence, and Lane mines were also worked to a considerable extent during the period from the World War to about 1927. The larger ore body in the Independence mine was opened up and worked during this period.

With the straightening out of the Wagner Estate affairs, the American Metals Company under C. H. Lord of Chicago leased the properties and operations again began. Considerable ore was concentrated and shipped during the period 1925 to 1927. But by 1927 the lead industry was becoming depressed and the camp was again shut down. In 1928 an open switch in the Lucky Jim mine caused a fire which burned out much of the shaft and mine timbering. As a consequence this mine, perhaps the largest in the district, is quite inaccessible.

In 1936 with the return of more favorable mining conditions and better prices for lead and silver, the Darwin properties were again opened up in preparation for mining. The Wagner Estate properties were reorganized as the Darwin Lead Company. By the end of 1936 the Lane mill had been rebuilt to 200 ton capacity and early in 1937 the Thompson tunnel was cleaned out in preparation for working the Independence ore body at a lower level. A. A. Rubel in 1936 purchased the Keystone properties in the south end of the hills and constructed a modern camp in preparation for extensive development under the name of Keystone Darwin Limited.

It is evident from the history of the camp that there have been two contrasting periods of production. The first, in the early seventies, was halted because of depletion of the rich surface ores, and because of lack of modern methods of mining and milling and transportation applied to low grade ores. The second began with the World War impetus to mining during which consolidation of properties and large scale operations were effected. This later period faltered during the unprecedented depression, but should now swing into full stride again. With modern methods of mining, ore treatment, and transportation the Darwin district will be rightly proven as a silver-lead producer.

The following table of production from the more important mines in the district is based partly upon figures and estimates made by previous writers and partly upon estimates from information gained during the present survey:

Mine	Estimated Production
Lucky Jim . . .	$2,000,000
Defiance	1,500,000
Christmas Gift . .	550,000
Independence . . .	500,000
Lane	300,000
Custer	250,000
Promentory . . .	200,000
Thompson	100,000
Columbia	100,000
All others . . .	300,000
Total:	$5,800,000

MINES

MINES IN THE NORTH END OF THE DARWIN HILLS

Fairbanks Mine

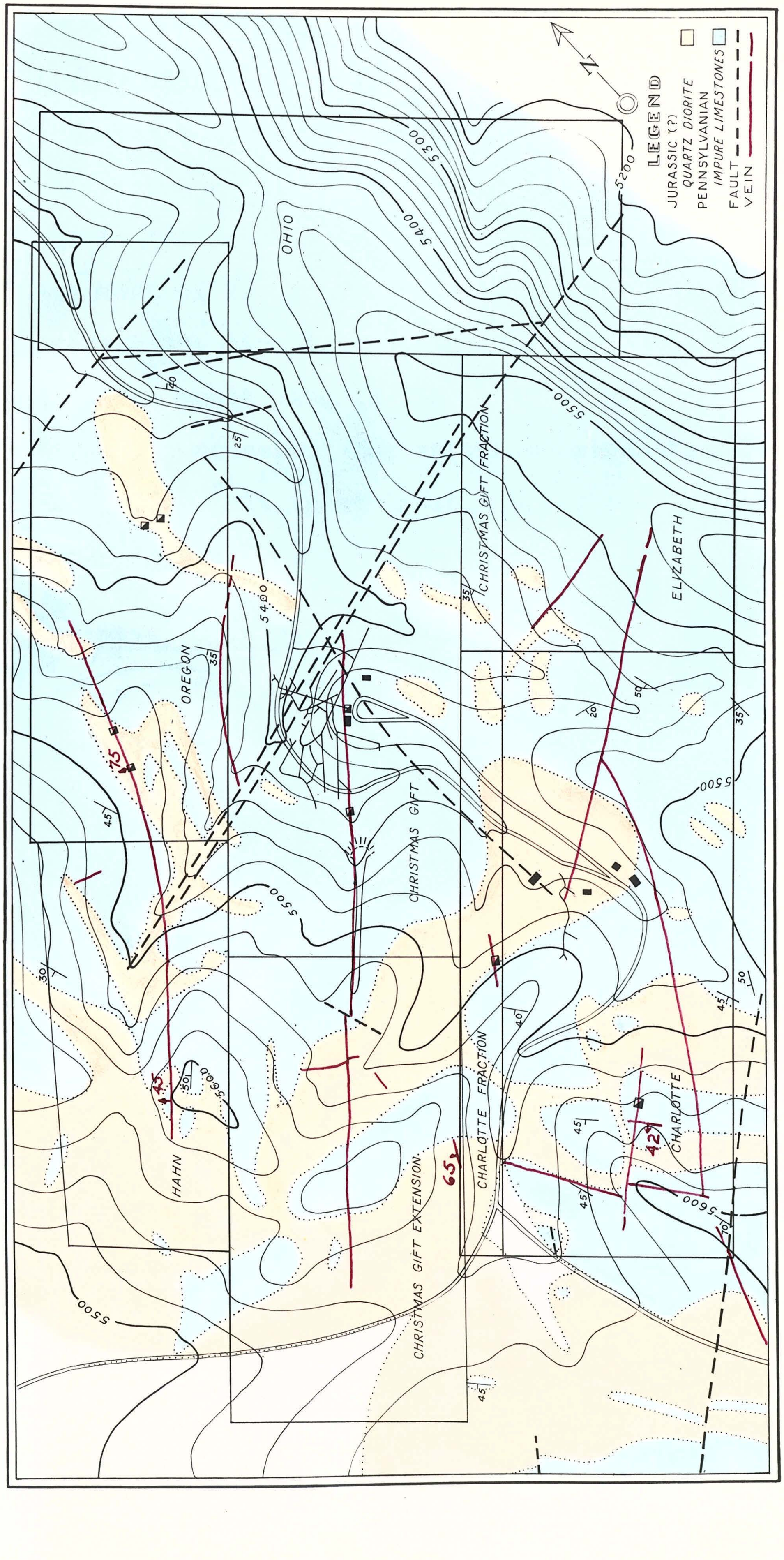
The Fairbanks mine is situated about three miles north of Darwin and about 1700 feet northwest of the Lucky Jim mine at an altitude of 5500 feet. The ore body occurs in a small chimney-like vertical vein which strikes northeasterly within the zone of the Darwin tear fault. The wall rock, composed of impure limestones, strikes S 38° W, a trend considerably at variance with the regional trend due to the drag effect of the large fault. Although the exact relation of the ore vein to the tear fault could not be determined, it is probably subsidiary to the major fault, ore originating from solutions which rose along the fault. The vein matter consists of galena and cerussite in a gangue of quartz, fluorite, calcite, and iron oxides, the latter probably derived as gossany material from jasper and pyrite in the original vein. Some galena occurs in the outcrop.

Equipment consists of an ore bin, hoist-house, 6 h.p. gasoline engine, and a head frame, all of which had been installed within very recent years. A vertical shaft of 150 feet has been sunk on the vein.

Ore shipped is reported to have averaged \$35.00 per ton. The mine and eight claims of the Fairbanks are owned by Alex Rouna of Darwin, California.

Lucky Jim Mine

The Lucky Jim mine is situated about three miles north of Darwin at an elevation of 5000 feet. It is located on a rather persistent vein which strikes N 50° E and dips 80° NW. About 500-600 feet southwest of the shaft the vein is broken by two faults which strike northwest. The dislocation on each of these faults is about 50 feet, and as is the rule in the district the north side has moved westward. The principal ore shoot is inclined to the southwest about 30° and this has been worked downward in a series of tunnels and winzes to about 1000 feet. The vein averages four to six feet in width, but in places is nearly 20 feet. To the northeast the vein cuts less metamorphosed limestones that have been thrown into series of small folds. The ore consists of galena and cerussite occurring in bunches in an oxidized jasper gangue. Only small quantities of calcite, pyrite, and fluorite are found. The ore averaged 1-1½ ounces of silver to each one per cent of lead. The lead percentage of the ore mined varied with the stope, but is reported to have been 8-10 per cent. Also the



GEOLOGIC MAP OF THE CHRISTMAS GIFT CLAIM GROUP

BY VINCENT C. KELLEY

1936

SCALE

0 100 200 400

Feet

CONTOUR INTERVAL 20'

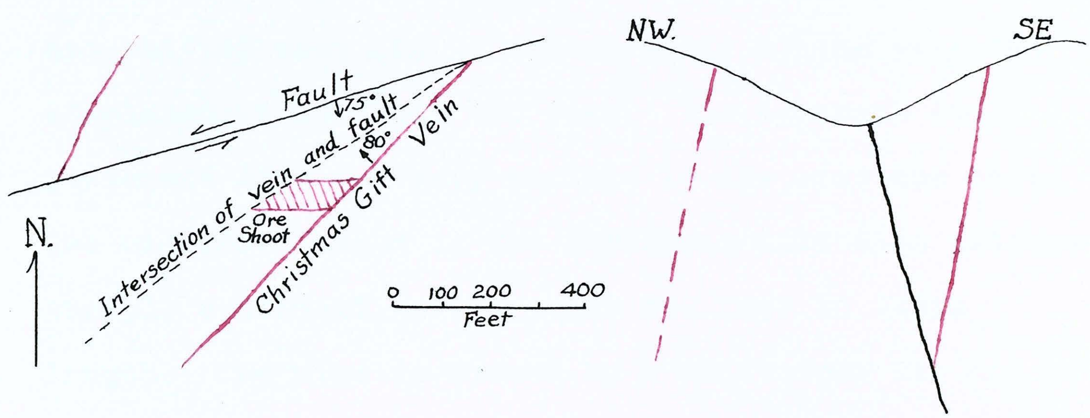
Plate XXIX

silver values mined in the surface cuts are reported to have been much higher than at depth.

The mine was modernized in the twenties, but in 1928 a fire caused by an open switch burned out most of the improvements in the main shaft and at present the mine is shut down and inaccessible. It is the deepest mine in the district and one of the largest producers. The estimated production is $2,000,000. It is at present owned by the Darwin Lead Company.

Christmas Gift Mine

The Christmas Gift mine is located about 2000 feet southeast of the Lucky Jim mine on a vein which strikes N 40° E and dips about 80° NW. The



A. Plan sketch of the Christmas Gift vein and fault showing the rake of the ore shoot.

B. Diagrammatic section across the Christmas Gift vein and fault.

Figure 1.

rock in the vicinity of the mine is stratified tactite which has been pierced by many small dikes and irregular offshoots of the Darwin stock as shown in Plate XXIX. Although the tactites are considerably disturbed by the intrusions they strike generally N 30° W and dip 30-40° W. As can be seen on the geologic map on the Christmas Gift claim group, an intricate system of fissures and faults have been superimposed upon the multiplicity of small intrusions into the tactites. Among the fissures are several parallel to the Christmas Gift vein and these in general have been most mineralized. The Christmas Gift vein is cut off by a compound fault about 200 feet northeast of the shaft. This fault strikes N 70° E and dips 75° S. The north side of this fault has shifted west and in the vicinity of the mine the displacement is about 450 feet. The apparent displacement dies out very rapidly to the east and west. The ore shoot mined in the Christmas Gift mine pitches steeply southwest and is about 300 feet in stope length. The mine is opened by a shaft down the dip of the vein to a depth of 400 feet with drifts along the fault or the vein to intersect the ore shoot. Because of the trough structure formed by the planes of the fault and the vein, the ore shoot ends sharply against the fault on the 250 level. The ore consists of bunches of galena and considerable lead carbonate. The ore is imbedded in earthy iron oxides apparently derived from pyrite and jasper, remnants of which still occur in the vein. According to Mr. Skinner, the owner, the ores ran somewhat higher in silver than the average for the district. He reports that much of the ore carried three ounces of silver to each one per cent of lead and that the best shipments averaged 45 per cent in lead. The mine and nine adjoining claims are owned by W. L. Skinner and Ing C. Boe, Darwin, California.

MINES OF THE ROUNA GROUP

In this group are included the mines and prospects located in the canyon next north of Lane canyon through which the highway passes. All of the deposits are in fissure veins along the east side of the stock directly opposite the Independence mine. Most of the work has been done on two large and persistent northwesterly trending fissures which converge from the west and unite near the development camp in the canyon. In the twenties both branches of the fissure system were explored by tunnels several hundred feet in length but no ore was found. These fissure veins are among the largest in the district attaining 40-50 feet in width. The walls are very indefinite as the result of irregular impregnation of sheared zones on either side of the fissure. Jasper and calcite make up the bulk of the veins, but considerable barite can be found in places. In the tunnels and open cuts small quantities of chalcopyrite, sphalerite, and pyrite are occasionally found. To date, however, practically no production has come from these northwesterly trending veins and it is quite probable that, in spite of the extensive gangue mineralization of jasper and calcite, they were not effectively opened to sulphide mineralization. These veins have been followed by narrow dikes of basalt and aplite in the vicinity of the tunnels. The basaltic material is not like any of the dike rocks definitely related to the major stock and there is some suggestion that these dikes are later than the mineralization of the fissures.

Several northeasterly trending veins have been exploited in this group and, although these are narrower and less persistent, they show mineralization of a more encouraging type. Of these veins the Standard has been most developed and from it considerable lead ore has been mined. It outcrops on the south side of the canyon and lies south of the above-mentioned fissures. The vein is two to six feet in width and contains coarse calcite, much gossany iron oxide, and the favorable ore indicator, fluorite. Large masses of galena were found in the vein in addition to considerable oxidized lead ores.

During the driving of the tunnels on the large fissure veins in the twenties a small camp was built in the canyon. A recent cloudburst destroyed or washed away much of the equipment. That which is left consists of two portable pneumatic compressors of 130 foot capacity, an Ingersoll-Rand drill sharpener, blacksmith shop, mine cars, rails, and air and water pipe.

Considerable electrical exploration work was done by the Radiore Company prior to the development work in an effort to find the best indications of ore. Most of the indications obtained by the electrical work are, however, evident on the surface.

The prospects and mines of this group are all held by Alex Rouna of Darwin, California. No mining had been done for several years at the time of this survey in 1936.

MINES OF THE DEFIANCE INDEPENDENCE MINE GROUP

The mines of this group are located along the east side of the prominent ridge back of the

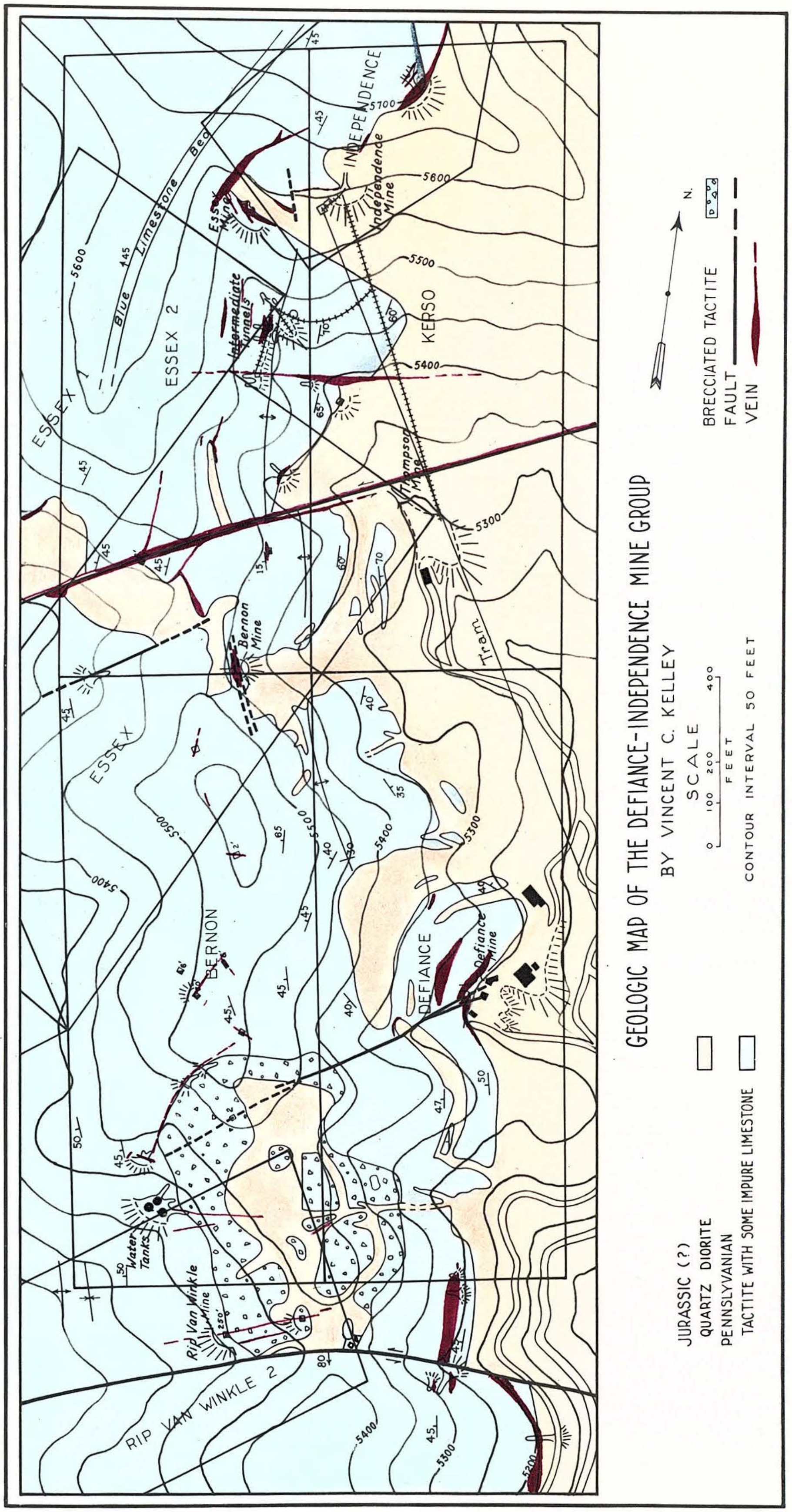

GEOLOGIC MAP OF THE DEFIANCE-INDEPENDENCE MINE GROUP
BY VINCENT C. KELLEY
SCALE
0 100 200 400
FEET
CONTOUR INTERVAL 50 FEET
JURASSIC (?)
QUARTZ DIORITE
PENNSLYVANIAN
TACTITE WITH SOME IMPURE LIMESTONE
BRECCIATED TACTITE
FAULT
VEIN
N.
INDEPENDENCE
Independence Mine
Essex Mine
Blue Limestone Bed
ESSEX 2
Intermediate tunnels
KERSO
ESSEX
Thompson Mine
Bernon Mine
Tram
BERNON
DEFIANCE
Defiance Mine
Water Tanks
Rip Van Winkle Mine
RIP VAN WINKLE 2
5700
5600
5500
5400
5300
5200

Plate XXX

Darwin Lead Company's camp a distance of about one half to one mile from Darwin. The mines are centered about two large tabular ore bodies at or near the west contact of the stock. The southern ore body is worked by the Defiance mine and the northern ore body is opened up by the combined workings of the Independence, Essex, and Thompson mines (Plate XXX). All of the mines of this group are on patented ground owned by the Darwin Lead Company.

Independence Mine

The Independence mine is located one and a half miles north of Darwin at an elevation of 5600 feet near the top of the prominent ridge extending southeasterly from Ophir Mountain. The ore body is poorly exposed at the surface. The initial discovery and entrance to the ore body was made by an inclined shaft located on the crest of the ridge at an eleva-

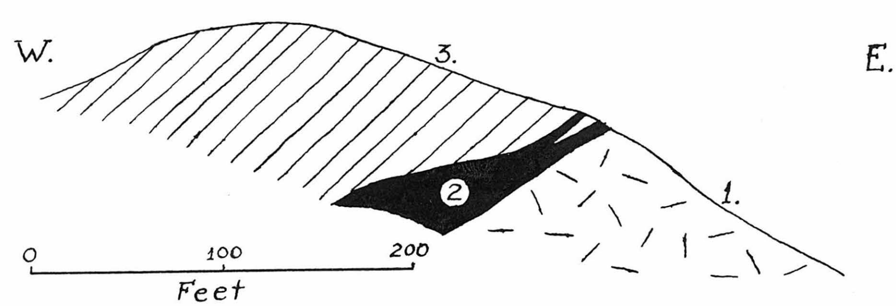


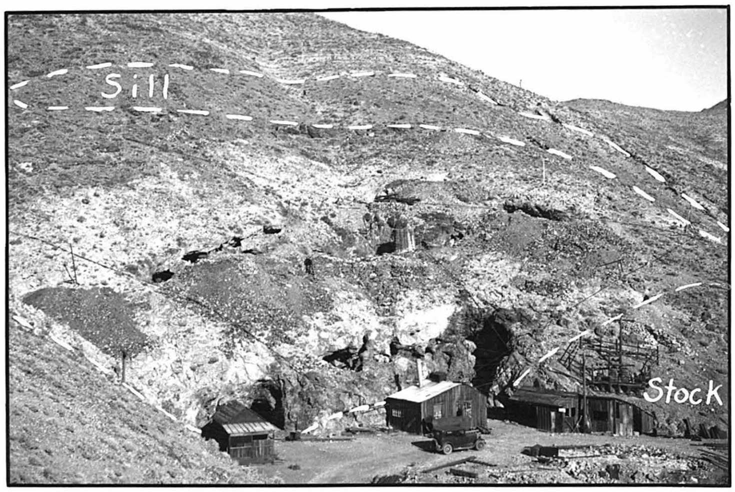
Figure 2. Diagrammatic section through the Independence ore body. 1. Quartz diorite, 2. ore body, 3. stratified tactite.

tion of 5700 feet. At this point there crops out a tabular vein about 20 feet in width lying along the contact. Northward from this entrance the outcrop of the vein can be traced several hundred feet before it pinches out. South of the ridge crest the outcrop of the vein pinches out in about 50 feet. Two smaller parallel veins lie in the beds a few feet above the vein at the contact. Entrance was later made to the ore body by a tunnel on the south side of the ridge through a lobe of quartz diorite near the contact (Plate XXI-B). The ore body within the ridge above the elevation of the tunnel is enormous and stopes in this ridge are the largest in the district. At the tunnel level the ore body is 100 to 150 feet in width and the stope length is about 200 feet. The footwall of the ore body is in most places quartz diorite although sometimes a narrow layer of tactite intervenes. The hanging wall is limestone and tactite. The bulk of the ore body consists of a porous, highly gossanized material which contains many pseudomorphs of limonite after pyrite. Considerable kaolin, calcite, siderite, quartz, and jasper occurs throughout the gossanized vein material, much of which is mined as high-grade milling ore. Small unmined remnants of galena and cerussite which undoubtedly occurred in

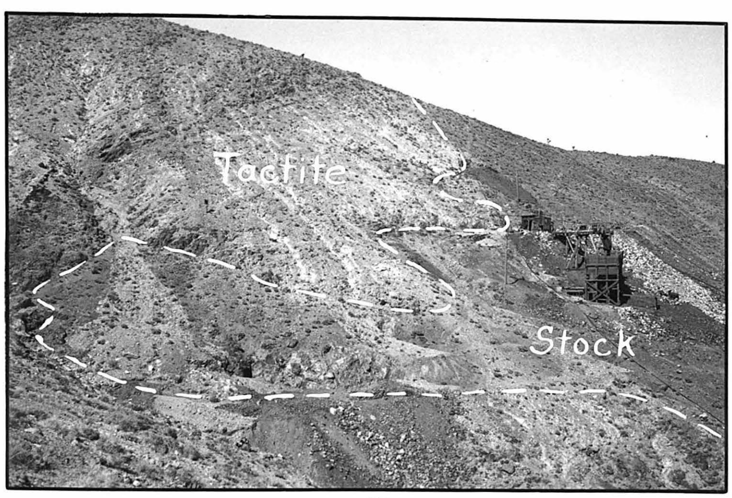
Plate XXXI

A. View of the Defiance mine showing the lower and upper ore bodies lying between the stock in the foreground and the sill above the white tactite wedge in the center of the picture.

B. View of the Independence mine (right of center) and the Essex mine (lower left). The prominent white tactite outcrop in the center of the picture lies as a blanket over the large Independence ore body within the ridge and a part of which may outcrop in the dark area in the extreme left in the picture.



A.



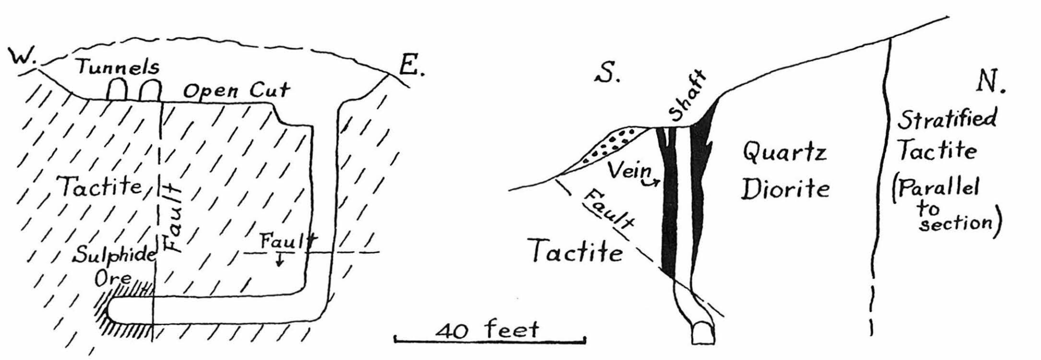
B.

larger masses can be found scattered through the gossanized walls of the stopes. The ore stoped from above the tunnel level probably extends downward along the contact for a considerable distance. The unmined ore in this ore body probably constitutes one of the largest reserves of ore in the district. Because of its elevation it can be readily tapped by tunnels at lower levels. In fact, this is the intention of the Darwin Lead Company in its resumption of mining in 1937.

An aerial tram 2000 feet in length was used to carry the ore to the storage bins at the Defiance mine where it was again trammed to the Lane mill a distance of 6000 feet.

Essex Mine

The Essex mine lies 200 feet southwest of the Independence mine at an elevation of 5500 feet.



A. Parallel to the vein. B. Across the vein.

Figure 3. Diagrammatic sections through the Essex ore body.

The workings consist of an open cut from which are driven two short tunnels each about 100 feet in length and a vertical shaft 40 feet deep. The vertical shaft is sunk on a vein 7-20 feet wide, striking N 65° W and dipping 85° S. The deposit has formed on the south side of a small lobe of the stock. The vein has several small branches into the tactite and intrusive. Near the bottom of the shaft the vein is faulted. A vertical north-south fault is encountered 25 feet west in a drift driven in the footwall of the fault beyond which tactite is impregnated with pyrite, steely galena, and fluorite. The fluorite is purple and darkens upon lying in the open. The sulphides replace the tactite in small veinlets and masses. This is one of the few places in the district where sulphides have impregnated the tactite in quantities sufficient to constitute ore. As it is mined, it runs 15 per cent in lead and seven ounces in silver. Aside from this occurrence west of the fault in the bottom of the mine, most of the material in the Essex vein is the gossany like material similar to that found in the Independence mine. A peculiar vein consisting of white laminated fluorite carrying considerable galena occurs in a small open cut at the west end of the Essex dump. Fifteen or 20 tons of good sulphide ore are piled near the shaft. In some of this material blue radiating crystals of linarite, the double basic sulphate of lead and copper, have been found.

Thompson Mine

The Thompson mine is situated about 1000 feet north of the Defiance mine at an elevation of 5300 feet. Access to the principal workings of the mine is gained by a tunnel 400 feet in length driven N 65° W. The portal is in quartz diorite and the contact of the tactite is about 260 feet in from the portal. A mineralized zone about 60 feet in width is encountered in the tactite about 350 feet in from the portal of the mine, and most of the stopes are in this ground. The presence and extent of the mineralized zone is determined by a prominent cross fracture which bounds it on the north side. This fracture strikes N 75° E and cuts the tactite-quartz diorite contact in the canyon 350 feet northwest of the portal to the Thompson mine at which point the fracture is heavily gossanized for a width of 10-15 feet, both in the tactite and in the quartz diorite.

The ore consisted of galena, cerussite, pyrite, and sphalerite with calcite, quartz, jasper, and iron oxides. That chalcopyrite is a constituent of the ore is shown by numerous chrysocolla veinlets in the outcrop directly over the principal workings. Unusually large masses of galena were encountered in the stopes and considerable native sulphur occurs as an oxidation product of the lead ores. Unusually coarsely crystalline sphalerite, attaining dimensions of several inches, occurs associated with calcite.

Near the end of the Thompson tunnel a 175 foot raise has been driven to the surface along a prominent cross fracture. Ores from small cuts and tunnels are dropped through this raise and hauled out through the Thompson tunnel. From their position between the Thompson and Independence mines these tunnels are known as the Intermediate mine. The entrance to the main Intermediate tunnel was entirely covered by debris from a recent cloudburst at the time of the field work. All of the Intermediate workings lie north of the cross fracture and they are located on bedding plane deposits and smaller cross fractures. Several small tongues of syenite or alaskite intrusives occur near the workings.

Defiance Mine

The Defiance mine is situated one mile north of Darwin at an elevation of 5250 feet. It is one of the oldest mines in the district and as a producer ranks with the Lucky Jim mine, although the ratio of silver to lead in the Defiance mine has not been as high as that at the Lucky Jim. At the Defiance mine two large lens-shaped ore bodies occur parallel to the contact. The principal ore body crops out along the intrusive contact for a distance of 215 feet and has a maximum thickness of about 40 feet. At the mine the contact of the stock roughly parallels the stratification of the tactites which strike N 25° W and dip 35° W. The other ore body lies about 50 feet

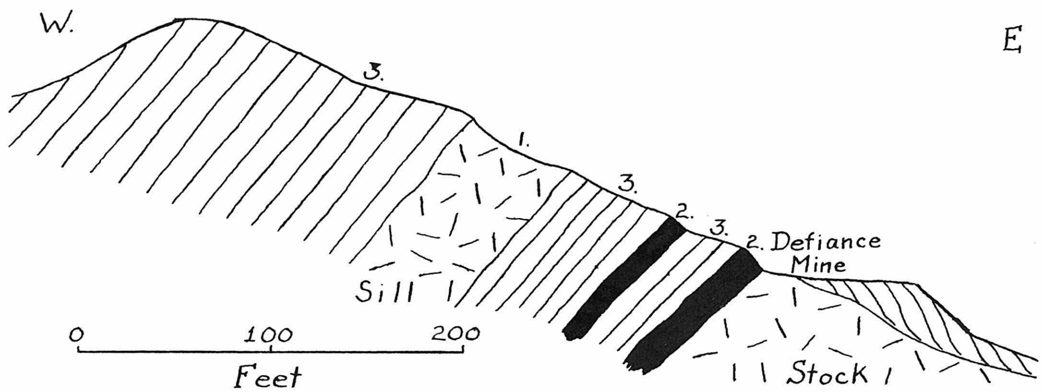


Figure 4. Generalized section through the Defiance ore bodies. 1. Quartz diorite, 2. ore body, 3. stratified tactite.

above the contact ore body along the bedding of the tactites. It is 190 feet in length and 30 feet in its greatest width. About 100 feet above the upper ore body is a sill of quartz diorite 100 feet in thickness which follows the gently arched tactite in a curve to the north where it joins the main stock near the cook house 250 feet north of the mine

(Plate XXXI-A). Thus, the ore bodies lie in a curved wedge of tactite between the stock and a branch sill. The northward extent of the ore bodies is limited by the sill. It is evident from the underground workings that the orebodies are more extensive to the south than the surface outcrops would indicate. The mine is opened by an inclined shaft in the footwall of the ore body to a vertical depth of about 300 feet. In addition a tunnel 550 feet in length has been driven straight into the hill at the surface level of the mine and considerable ore from the upper ore body was stoped by drifts from this level. Drifts north and south from the inclined shaft have been run at various levels from which the bulk of the ore produced has been stoped.

Most of the veins consist of highly gossanized and kaolinitic material within and along which are found masses of calcite, quartz, pyrite, fluorite, and jasper. In addition, large remnants of limestone and tactite are included in the veins. In the early days of mining at the Defiance mine much of the highly oxidized material of the veins was either left unmined or thrown on the dumps. However, under present conditions of mining and milling much of this would undoubtedly form good milling ore.

The calcite of the deposit is exceedingly coarse and cleavage pieces 12-18 inches in diameter are common. Fluorite is also coarse grained and may be white, lavender, or green in color. Galena and cerussite occur in bunches and small shoots in the highly oxidized material or enclosed in calcite or fluorite with pyrite and dark brown sphalerite. Pyrite crystals ranging from a fraction of an inch up to two inches are very abundant and near the outcrop the walls of the stopes are in places lined with pseudomorphs of limonite after pyrite. Chalcopyrite in small quantities is common with the galena, and as a result chrysocolla and melaconite are to be found near the surface. In places the tactite walls are impregnated with pyrite and sphalerite, the latter often in bands following the stratification. In the future, ore found in this mine will most probably lie to the south of the entrance shaft and from a structural standpoint the ground around the breccia tactite south of the drifts on the 215 and 290 levels is the best to explore.

Rip Van Winkle Mine

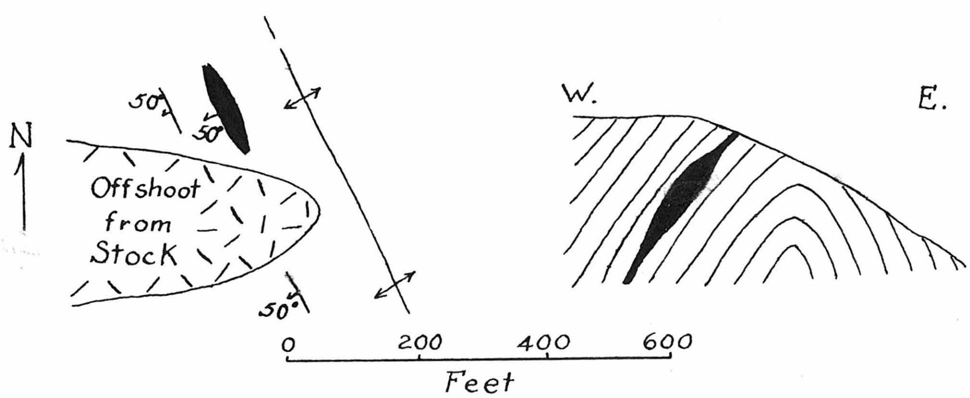
The Rip Van Winkle mine is situated on the west side of the Defiance ridge about 1000 feet south of the Defiance mine. It is opened up by a vertical shaft 250 feet in depth along a cross fracture striking N 45° E. It is one of the few producers from a fissure vein on the west side of the stock. The ore is highly pyritic and is reported to run unusually high in silver. Galena, sphalerite, and pyrite together with considerable calcite and fluorite impregnate the tactite walls adjacent to the fissure. The mine which is owned by the Darwin Lead Company has not been worked for many years and was inaccessible at the time of the field work.

MINES OF THE SOUTH END OF THE DARWIN HILLS

The mines described under this heading all lie south of the highway through the hills.

Custer Mine

The Custer mine is situated one mile east of Darwin in the canyon next south of Lane canyon,



A. Plan sketch of the Custer ore body showing its relationship to the stock and the structure of the tactites.

B. Section through the Custer ore body and associated tactites.

Figure 5. Diagrammatic sketches of the Custer ore body.

the one through which the state highway runs. The elevation is 4700 feet. The deposit occurs near the tip of a very prominent cross-cutting lobe of the quartz diorite protruding from the east side of the Darwin stock. Knopf[1] considered the ore to be formed in the broken arch of a fold. As a matter of fact, however, the deposit is located 150 feet west of the axis of the fold along the bedding of the tactites which strike N 25° W and dip 50° W. The steeply dipping tactites in which the ore chimney has formed are cut off 25 feet south of the inclined shaft in the ore by the lobe of quartz diorite. Thus, the deposit is of the bedding plane type located a short distance from the contact which is in this case approximately normal to the stratification. The inclined shaft is 335 feet in depth with levels at 130, 150, 185, 230 and 310 feet.

The vein minerals in addition to the usual lead ores consist principally of gossany iron oxides, coarse calcite, pyrite, jasper, and fluorite. In addition, garnet appears to be one of the vein minerals and its association with coarse calcite cementing brecciated fragments of the tactite was noted by Knopf.[2]

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1. U. S. G. S. Bull. 580A, p. 15.
2. *Ibid*.

Also, a little specularite hematite is to be found in cavities in the vein. Coarse calcite is remarkably developed on the 200 level where it is at least 50 feet thick and 75 feet along the strike. This represents a local swelling in the vein, for above and below this level the calcite body is not nearly as large. Lead ores were scattered through the calcite body in association with iron oxides.

Production from the mine probably amounts to $250,000, most of which was prior to 1900. It has not been mined for several years, but the character of mineralization is such as to attract attention and it may become a producer again in the near future. It is owned by Theo. Peterson of Darwin.

Fernando Mine

The Fernando mine is situated in the next canyon south of the Custer mine at an elevation of 4600 feet. The deposit occurs at the intersection of a prominent cross fracture and the bedding of the tactite. The mineralization is greater on the cross fracture or fissure vein which is rather persistent and traceable on the surface for about 2000 feet in a direction N 65° E. The tactites strike N 15° W and dip 55° W. An inclined shaft 125 feet in depth has been sunk on the bedding and the deposit opened up therefrom by numerous short tunnels and stopes from several levels. The inclined shaft is intersected by a tunnel driven along the fissure about 30 feet below the shaft entrance. Along this tunnel considerable displacement is evidenced by brecciation, clay and iron oxide gouge, and well preserved slickensides. Striations on the fault plane dip parallel to the bedding, i. e., 50-60° west, the north side having moved down and to the west. The mineralization along the stratification is not confined to one horizon and locally has spread through several closely spaced beds. On the 100 level mineralization paralleling the fissure has affected a width of 30-40 feet. The ore minerals are galena, cerussite, and anglesite and the gangue consists of jasper, hematite, much gossany limonite and a little calcite. Galena found in the stopes is coarse grained and in places imbedded in jasper. Ore shipped from the mine when it was last worked in the late twenties is reported to have carried 30 per cent lead and 30 ounces in silver. The mine is owned by Theo. Peterson of Darwin.

Promentory Mine

The Promentory mine is situated about a mile southeast of Darwin at an elevation of 5000 feet. The deposit is one of the initial discoveries made in the district. Three closely spaced bedding plane veins are exposed in the cut behind the shaft. These are in tactite which strikes north and dips 33° W. It is opened up by an inclined shaft down the dip of the beds to a depth of 320 feet. Drifts not over 100 feet in length lead to extensive stopes north and south of the shaft. The veins range from a fraction of a foot to 6 or 8 feet and locally more in width. The veins have been subjected to considerable slippage which took place largely along the veins themselves causing considerable gouge material and slickensiding. Some of the movements, however, have been at angles to the veins, but the displacements do not appear to be large. Iron oxides and jasper are the most abundant gangue minerals of the vein, but some calcite and siderite are present. Much secondary calcite in flat rhombohedrons occurs throughout the mine. The usual lead ores are present and some argentite is reported to have been found in the mine. The property, which is now idle, is owned by the Darwin Lead Company.

<u>Silver Spoon Mine</u>

The Silver Spoon mine is situated about two miles southeast of Darwin and 3000 feet northwest of the Columbia mine at an elevation of 4500 feet. It is located on a prominent fissure vein which strikes

N 65° E and dips roughly 80° N. The fissure is traceable for about 2500 feet and at the mine it has been opened up to a depth of 250 feet by a shaft at the bottom of which is a drift 125 feet to the west. The ore is mostly carbonate with a little galena in highly oxidized and siliceous vein matter. The vein varies from one to four feet in width. Ore shipped carried 35 per cent lead and 18 ounces of silver per ton. Some of the ore was evidently crudely cleaned and concentrated by screening on the dump. The property is owned by Theo. Peterson of Darwin.

Columbia Mine

The Columbia mine is the southernmost mine in the Darwin Hills and is about two and one half miles from Darwin at an elevation of 4350 feet. It is located on a fissure vein which strikes N 60° E and is about 2000 feet beyond the southern end of the Darwin stock. The vein cuts across blue-gray, unsilicated limestones and the mine is one of two in the district which is located outside of the silicate aureole. The vein, which is vertical, has a maximum width of 15-20 feet. It has been worked along the strike for about 200 feet and to a depth of about 225 feet. The chief feature of this vein is the abundance of dense jasper. The lead ores consist of galena and carbonate. Much of the ore of this vein is reported to have carried gold values up to $12.00 per ton. The Columbia claim is patented and owned by the Darwin Lead Company.

FUTURE EXPLORATION

The immediate future of the Darwin district lies almost entirely in mining to greater depth deposits already discovered. Practically all of the production at Darwin has come from within 300 feet of the surface. Successful mining will have to be carried out on a large scale and it will be necessary to keep ores blocked out in advance of extraction if mining operations are to be more than sporadic. Ore bodies of the contact type are irregular and bunchy and they may terminate suddenly. New bodies, unless exposed at the surface, are difficult to find and hence considerable exploration and proving of new ore should parallel mining at all times.

In regard to future prospecting for deposits it should be borne in mind that only the west side of the stock has revealed ore bodies at the immediate contact. Deposits at the west contact are pod-shaped bodies which are irregularly distributed along the contact surface. They vary considerably in size but the largest generally exceed the dimensions of fissure or bedding plane deposits. The entire unexposed contact surface is potential ground for such deposits. Some deposits, like the Independence body, may be exposed only slightly or hidden entirely. In general, it may be found that irregularities or protuberances of the surface of the stock, especially where paralleled by the stratification of the country rock, are favorable loci for deposits along the contact.

Most of the fissure veins are rather persistent, but only certain stretches of the fissures have been sufficiently mineralized to constitute ore. The ore in such deposits makes in bunches or shoots. In the case of the Lucky Jim and the Christmas Gift deposits the ore shoots rake to the west. This may or may not be true for other such fissure deposits. To date the northeasterly trending fissure veins only have produced ore. In a few cases the fissure veins have been dislocated. Although in most cases the displacements have not been large, it is well to remember that the usual direction of displacement is the north side westward. The fissure veins are more prominently developed in the tactite zone. The portions of such fissures extending into the intrusive as a rule have not constituted desirable ground.

In the past there has been considerable experimentation and money expended for selecting an entree to the ores beneath the Defiance-Independence ridge. The Radiore tunnel driven through hundreds of feet of barren ground is one evidence. Most of the deposits dip westward under this ridge more or less conformable with the bedding or the surface of the contact of the stock.

A considerable amount of geophysical prospecting by electrical methods was carried on during the late twenties in an effort to locate ore. The writer has had access to some of the maps compiled from such work and in only very few instances were electrical indications plotted which were not evident in the outcrop. The electrical indications obtained may be from bodies of pyrite. This type of exploration may be successful in locating a few deposits of hidden ore. From the high jasper content of most of the deposits it seems that a magnetometer survey might also be useful. However, it is felt that a smaller expenditure in geologic advice in connection with active mining and exploration would be more beneficial.