METAMORPHISM AT THE CONTACT
OF THE
CABLE STOCK, MONTANA

Thesis by

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Abstract

A study of metamorphic rocks is integrated with the areal goelogy in the vicinity of the Cable stock, a granodiorite intrusive surrounded by Paleozoic carbonate rocks. Detailed geology of the zones of most intense metamorphism at the intrusive contact is described.

Isochemical thermal metamorphism was followed by metasomatic addition of material and accompanied by various stages of alteration. Silicic magnesian limestones altered to diopside-grossularite marble by the introduction of iron. The addition of iron, little magnesia, and alumina altered the marble to a diopside-grandite tactite. Additional iron was deposited as magnetite and accompanied widespread dedolomitization and alteration. Rocks near the intrusive contact were replaced by epidote, mica, and scapolite.

Areas of intense metamorphism occur at the granodiorite contact. Metamorphism is localized in areas of intense folding, fracturing, and shearing.

The basic border of the stock indicates assimilation of calcareous rocks by the granodiorite; the transfer of calcium across the contact resulted in the development of pargasite, diopside, and scapolite. Deformation of the sediments was preceded and, in part, accompanied by forceful intrusion of the granodiorite.

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INTRODUCTION

This geologic study of an area around the Cable stock, Deer Lodge County, Montana (fig. 1), was initiated as part of a larger and broader research program conducted by Dr. William T. Holser of Columbia University. The purpose of this investigation was to supplement and furnish data for a study already in progress in the Philipsburg area of western Montana. Detailed geologic mapping of the contact zone of the Cable stock, a granodiorite intrusive surrounded by Paleozoic sediments (pl. 1), contributed to a better understanding of the stratigraphy and structure; moreover, the mapping permitted a later petrographic study of the metamorphic rocks to be integrated with the areal geology.

The basic geologic work of this investigation consisted of detailed mapping during August and September, 1947, and a detailed microscopic examination of the metamorphic rocks during 1948-49. Sections were measured at Maywood Ridge, the ridge west of Blodgett Creek, and in cuts along the railroad grade east of Georgetown Lake (pl. 1) in order to provide accurate stratigraphic control. Key marker beds of Paleozoic rocks were carefully traced into zones of most intense metamorphism at the border of the stock. In areas adjacent to the granodiorite, various rock types were examined for reconstitution and replacement of sediments by complex silicates and oxides, for recrystallization and alteration, for joint-controlled silicate mineral deposition, for evidence of metasomatic effects, and for the relation of these various mineralogical changes to local structural and chemical control.

The base map of the Cable stock area (pl. 1) was prepared from U. S. Forestry Service aerial photographs made in 1947 and covers 14 square miles at a scale of 1:22,320. Detailed maps of the granodiorite contact

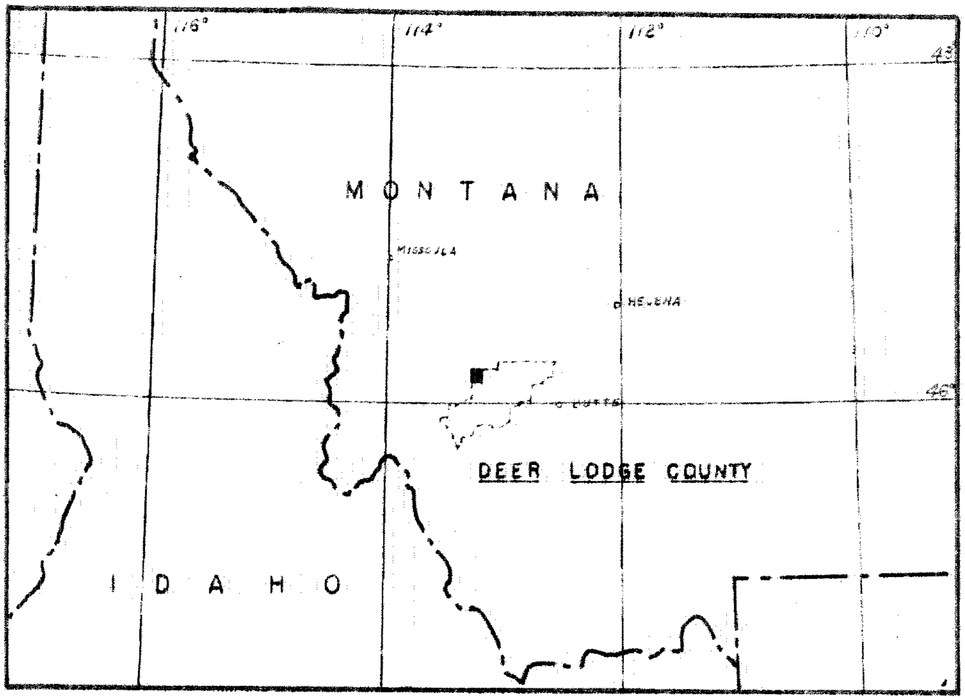

Figure 1. Location of the Cable Stock area (black square), Deer Lodge County, Montana.

were made by plane table and alidade surveys.

The area around the Cable stock is easily accessible by highway, and many small roads and trails furnish local access. The average altitude of the area is about 6,500 feet, and the relief is not in excess of 1,000 feet. This locality is characterized by moderate rainfall; the summers are warm but subject to wide temperature variations. The region presents the rare combination of excellent bedrock exposures and attractive woodlands of firs and pine trees (fig. 2).

Field work during the summer of 1947 was made possible by Columbia University's Special Research Fund in Economic Geology. The Geologic Division of the California Institute of Technology generously furnished sixty rock thin-sections for the petrographic study. William Holser carefully supervised the field work during 1947; grateful recognition of his cooperation is expressed to Dr. Holser. The writer expresses his appreciation to Dr. Ian Campbell and Dr. Richard Jahns of the California Institute of Technology for their guidance and many valuable comments throughout this project and for their review of this thesis.

GENERAL GEOLOGY

The area around the exposed part of the Cable stock is underlain by a stratigraphic thickness of about 4,000 feet of calcitic and dolomitic Paleozoic sediments. These calcareous beds overlie, with regional unconformity, an unknown thickness of Algonkian sediments, mainly quartzites, and are overlain by Tertiary glacial debris and Recent stream gravels.

Regional faulting is dominated by a west-dipping thrust along the Philipsburg Valley. This thrust fault may be an extension of the Lewis overthrust (Willis, 1902). Calkins (Emmons and Calkins, 1913) provides ample evidence that thrusting was followed by major folding. At Georgetown, Algonkian rocks are faulted against Carboniferous rocks, and the fault trace subsequently folded. The sediments have been steeply folded, parallel to the trend of the thrust, and the flanks of the resulting anticlinal structure have been faulted. Compressional forces of the major deformation produced a rupture across the axis of the anticline; this was followed by intrusion of a Tertiary granodiorite into the overlying Paleozoic sediments. Evidence of forceful intrusion is present, as detailed in the discussion of the Cable stock.

Paleozoic sedimentary rocks

Cambrian system

The principal lithologic features of the Cambrian rocks are shown in Table 1, which represents a composite of measurements made by Calkins (Emmons and Calkins, 1913) and the writer near the Cable stock. A detailed description and an accurate measurement of thickness of the Red Lion formation were obtained in a railroad cut between Gold Coin and Georgetown Lake (pl. 1). Other sections were measured west of Blodgett Creek and northwest of Gold Coin mine.

Flathead quartzite

The Flathead quartzite is exposed at Cable Mountain. In outcrop the quartzite is a white to buff, fine-grained and vitreous rock. It is generally thick-bedded and uniform in composition; however, near the intrusive contact the quartzite is iron-stained and shows a faint banding.

Silver Hill formation

The flanks of Cable Mountain provide the best exposures of the Silver Hill formation. For purposes of this study, the formation was subdivided into two mappable units. The lower unit, delimited by Calkins (Emmons and Calkins, 1913), consists of a bright to dark olive-green, thin-bedded shale. Thin lenses of reddish-buff sandstone with maroon shale fragments are interbedded with the shale. Maywood Ridge affords the best section of unmetamorphosed shale. Lochman and Duncan (1944) correlate the shale of the Silver Hill formation with the Wolsey shale, whereas the upper part of the formation is a correlative of the Park shale and Meagher limestone. The green shale is very fissile and weathers into small thin plates.

The limestone of the upper member has wavy siliceous banding. These siliceous laminae are very thick but lack the larger calcareous units found in beds of an overlying formation.

Hasmark dolomite

Three distinct lithologic units make up the Hasmark dolomite. The lower member, which consists largely of blue-gray dolomitic limestone, crops out on a ridge west of Daly Gulch. This rock is finely crystalline and dense. Hard gritty surfaces of the dolomite are caused by differential weathering of the carbonate grains. A partial analysis is given below (Emmons and Calkins, 1913):

Insoluble.	0.45%
CaO.	44.33%
MgO.	6.46%

The shale of the middle member is exposed in a shallow shaft at Gold Coin Gulch. The rock consists of chocolate-brown shale bands, 5-10 mm thick, interlayered with lenticular, gray fossiliferous limestone, which represents about 20% of the entire rock. The layers are uniform in thickness.

From top to bottom, the upper member consists of a massive blue-gray magnesian limestone, a yellow to buff dolomitic limestone that weathers gray, a shaly thin-bedded limestone, and a thinly laminated magnesian limestone. A detailed section of this member is shown in Table 2.

In general, the upper part of the Hasmark dolomite is distinctly more calcareous and thin-bedded than the lower member.

Red Lion formation

In the measured sections (Table 2) the Red Lion formation was found to be consistent in thickness and lithologic characteristics; therefore, this formation provided good stratigraphic control for a detailed study of the metamorphic rocks near the border of the intrusive.

The lower part of the Red Lion formation contains two black shale horizons separated by about 10 feet of dolomitic limestone and highly siliceous limestone. The upper part of the formation is characterized by a blue-gray laminated limestone. The thin, wavy laminae range in thickness from 0.1 to 1.0 mm and consist of a delicate, anastomosing lacework of silica. On weathered surfaces, the laminae stand out in bold relief (fig. 3), and where the silica content is greater, the limestone is enclosed as discrete lenses (fig. 4). The buff laminae on a fresh surface weather to a deep yellow or reddish brown.

In the lower part of the formation, purple or reddish-purple laminae consist of carbonaceous material and siliceous shale. The total insoluble material, largely silica, ranges from 10% to 85% of the total rock by weight and increases downwards in the formation. The upper part of the Red Lion formation is mainly a highly calcareous micrococquina and contains varying amounts of silica (detrital quartz). Micrococquinas occur as small lenticular masses in a sublithographic limestone matrix and are interbedded with siliceous limestone.

Maywood formation

The best exposures of the impure carbonate rocks of the Maywood formation are found on a ridge northwest of Gold Coin (pl. 1) and along the abandoned railroad grade. Gray, buff and olive-green shales interbedded with gray magnesian limestones, buff to maroon calcareous sandstones, and a crystalline dolomitic limestone that contains black chert at its base comprise the Maywood formation.

About 80 feet of massive, red to buff siliceous dolomitic limestone occurs near the top of the formation. The dolomitic limestone is overlain by a massive pink limestone, which is the basal part of the Jefferson formation.

Devonian system

The only rocks of known Devonian age in the vicinity of the Cable stock belong to the Jefferson limestone. However, a bright-yellow calcareous shale, which is believed by the writer to be the overlying Threeforks shale, is exposed near a railroad cut southwest of Georgetown; it is the only known exposure of uppermost Devonian rocks in the Philipsburg quadrangle. The shale is overlain by the Madison limestone.

Jefferson limestone

The Jefferson limestone is well-exposed on a ridge southwest of Georgetown (pl. 1). A pink, crystalline limestone, which weathers to a conspicuous ridge of massive sugary rock, comprises the basal unit. The pink limestone is overlain by a series of gray to black, massive magnesian limestones. Finely divided carbon particles impart a dark color to these limestones. A highly fractured, dark-gray limestone, cut by numerous calcite veinlets, occurs midway in this sequence of carbonate rocks. This brittle limestone is overlain by three limestones characterized by gray mottling, a pale blue color, and fossils, respectively. The uppermost part of the Jefferson limestone is marked by the yellow, calcareous Threeforks shale.

Mississippian system

Madison limestone

The lower unit of the Madison limestone is exposed near Georgetown (pl. 1) and is characterized by black flaggy limestones that weather gray. A tan shaly limestone occurs near the top of the lower unit. The basal shale is missing; however, a black calcareous shale is exposed in the lower part of one measured rock sequence.

The upper member crops out conspicuously on a hill east of Georgetown Lake. This limestone is pale blue-gray, massive, and very fossiliferous. A cherty, gray-blue limestone of the upper unit is exposed in Daly Gulch. Calkins (Emmons and Calkins, 1913) estimated the thickness of the lower member to be about 1,300 feet and found the total thickness of the limestone to be 1,800 feet at nearby Rock Creek.

Igneous rocks

Cable granodiorite

Occurrence and field relations

Granodiorite formed a small stock, roughly circular in plan and about two miles in diameter, at nearly the center of the Cable Mountain anticline (pl. 1). The granodiorite is uniform in composition but has minor variations in the ratio of hornblende to biotite. At its contact with the sediments, the stock becomes more basic; here, the granodiorite has altered the sediments to marble, tactite, and hornfels.

The intrusive contact is best exposed at Daly Gulch, near Georgetown and Pyrenees, and at the Atlantic Cable Extension prospect east of Cable. The border of the granodiorite is sharp and well-defined in these areas (fig. 6). Any local gradation in the contact occurs within a few inches or several feet. In areal extent, the intrusive contact appears to be concordant with the bedding of the sediments, but in detail the contact is irregular or faulted and cuts across the bedding. The granodiorite isolates several sedimentary masses within its borders and breaches the Cable Mountain anticline. Several small dikes extend out from the stock.

Although the age of the granodiorite has been tentatively regarded as Tertiary, the youngest sediments engulfed by the intrusive are Pennsylvanian (Quadrant formation) in age; however, similar adjacent intrusives have been shown to be contemporaneous with the first great deformation of the sediments at the close of Cretaceous or in early Paleocene time (Emmons and Calkins, 1913, p. 83).

Petrography

Sampling and restudy by the writer provide additional data and warrant further description of the intrusive, although the granodiorite has been described by Calkins (Emmons and Calkins, 1913, pp. 94-97).

The pronounced poikilitic texture of the orthoclase and smaller quartz grains is the most striking and persistent microscopic characteristic of the granodiorite (figs. 7 and 8). The poikilitic relationship of plagioclase in large orthoclase or quartz crystals persists to within a few centimeters of the calcareous sediments. This texture is obliterated or noticeably modified in the vicinity of apophyses or in areas of assimilation of the sediments.

Sericite is a common alteration product of the calcic core of the zoned plagioclase. The cores are silicified and epidotized along cleavage planes and zonal boundaries (fig. 9). The bulk of the plagioclase has a composition of An_{45} but tends to become more calcic near the intrusive contact.

Granodiorite sampled from 1,000 feet to 2,000 feet from the border of the stock has a ratio of biotite to hornblende of 3:1. Calkins (Emmons and Calkins, 1913) found the ratio to be 2:3; however, the writer found the central parts of the stock to be richer in biotite than hornblende. Only near the border does the amount of hornblende exceed that of biotite.

The relationships of the various rock samples from the Cable stock are shown in a von Wolff diagram (fig. 5). Sample 1a represents the calculated norm of an analysis of granodiorite from a quarry near the center of the stock (Emmons and Calkins, 1913, p. 96). The rock is a tonalite according to a modified Johannsen classification.

Marginal facies

The igneous rock becomes more basic and more highly altered as the border of the stock is approached; quartz diminishes, the biotite-hornblende ratio decreases, and the poikilitic texture of the orthoclase and quartz disappears. The basic facies is indicated by samples 7 and 11 (fig. 5). Biotite gradually decreases in the border zone and is absent where pyroxene begins to appear. Depletion of biotite at the outer edge of the stock probably made available considerable iron, alumina, potassium, and silica for reactions with the carbonate rocks. An appreciable amount of pyroxene occurs within two feet of the intrusive contact. The pyroxene is locally accompanied by abundant sphene, epidote, and a little scapolite.

Border rocks are rich in hornblende, whereas the amount of quartz decreases. Plagioclase is more calcic. A typical border rock (sample 7, fig. 5) shows that (a) the hornblende is more sodic; (b) part of the plagioclase has a composition in the range of An_{93-97}; (c) cores of zoned plagioclase are sericitized and zoisitized; and (d) the amount of sphene, ilmenite, rutile, and apatite has increased.

Border rock from the Pomeroy mine at Southern Cross (pl. 5) shows sericitized, silicified, and epidotized plagioclase. Small sphene crystals

Figure 5. Modal analyses of intrusive rocks

Location in stock	Distance from contact	Nearest sediment fm.
1. center	3000 ft.	Hasmark
2. S. Hill	25	Maywodd
3. Daly Gul.	2000	Maywood
4. Pyrenees	1000	Jefferson
5. N. Hill	½	Maywood
6. N. Hill	0.1	Maywood
7. N. Hill	5	Red Lion
8. Pyrenees	200	Maywood
9. N. Hill	0.1	Maywood
10. S. Hill	2	Red Lion
11. S. Hill	½	Red Lion
12.	1	Madison
13.	5	Madison
14. Pyrenees	2	Maywood
15. S. Hill	7	Red Lion
16. N. Hill	25	Red Lion
17. N. Hill	25	Red Lion

Samples 16 and 17 are altered feldspathic quartzite.

accompany the epidote. Phlogopite replaces parts of the earlier minerals. In the Cable mine (pl. 7) altered granodiorite contains orthoclase with a spotty texture, a result of replacement of the orthoclase by epidote and calcic plagioclase. Rutile and ilmenite are present. Phlogopite is a late replacement mineral. Many of the mineral grains are fragmented or distorted and show the effect of shearing stress near the contact.

At the border of the stock, iron, titanium, magnesium, calcium, sodium, potassium, and chlorine increase, whereas free silica (quartz) disappears.

Granophyric inclusions and streaking

Small flattened or ellipsoidal granophyric inclusions occur in the Daly Gulch area, at Granite Hill, and they also are scattered irregularly throughout the stock. The inclusions have about the same composition as their host rock, except the inclusions are richer in biotite and orthoclase. Biotite grains give the rock a distinct planar structure. Some of the inclusions are partly resorbed and drawn out as schlieren. Bands of biotite, zircon, rutile and sphene in these quartz-rich inclusions, arranged as heavy minerals in a sedimentary rock, suggest that the original rock was probably a feldspathic sandstone. The high quartz content also suggested a sedimentary origin of the original rock.

Locally a perceptible planar structure is developed in the granodiorite within a few inches of the intrusive parallel to its contact with the sediments. Distinct linear and planar structures have been developed only in the area of altered feldspathic quartzite at Daly Gulch (figs. 10 and 11).

Sills and dikes

Several small sills occur in the vicinity of the stock; the best exposure of a sill is at South Hill (pl. 2). This sill of massive, fine-grained granite is 7 feet thick and crops out for a distance of about 350 feet. Rock from the sill shows a pseudocataclastic texture. In comparison with the normal granodiorite, hornblende content in the sill rock (sample 5, fig. 5) decreased, whereas quartz increased. Assimilation of an adjacent shaly siltstone, now a biotite hornfels, may account for the increase in silica. Several of the inner zones of the plagioclase crystals are rimmed with magnetite and chlorite.

A small pegmatite dike, exposed near the dolomite contact in the Cable mine, has a graphic texture that results from an intergrowth of albite and quartz. Microcline is present. Albitization of some feldspars has been followed by sericitization and saussuritization. A thin, highly albitic pegmatite dike of unknown extent occurs on a ridge east of Cable.

The trace of a dike of hornblende felsite porphyry is marked by float between Georgetown Lake and Gold Coin. Large porphyritic hornblende crystals are held in a fine-grained feldspar matrix (fig. 12). In this dike rock the hornblende has undergone uralitization and partial propyliitization. The feldspars are almost completely sericitized. A similar dike rock occurs in an adit at North Hill, about 200 feet east of the contact with the Maywood formation. Hornblende is partly altered. Feldspar cores are epidotized and almost completely sericitized. The rock has a compositon of 73.9% feldspar, 23.7% hornblende, 2% magnetite, and 0.4% accessories, largely apatite.

At Southern Cross (pl. 1) a large dike extends westward to the Montana mine and is exposed at the millsite. Near the stock the dike appears to be normal granodiorite, whereas at the mine the dike rock is epidotized and has a spotty texture due to pyroxene.

Near Cable, a large dike appears to have been intruded partly along the contact of the Maywood formation and the Jefferson limestone but has also cut across part of the Jefferson limestone. Near Pyrenees several small apophyses extend several hundred feet from the Cable stock. Granodiorite in the apophyses weathers to a sandy, granular mass similar to the weathered rock at Cable.

Mode of emplacement

The various processes by which the granodiorite might have been emplaced can be reduced in number by examination of the field data. Spatially, the contacts are discordant; their steeply dipping walls cut across the sediments. The shape of the intrusive mass appears to be related to the structure of the anticline, the fold axis and plunge (pl. 1).

Stoping and inclusions:- The large sedimentary inclusions have a peripheral arrangement in the stock; similar inclusions are absent from the center of the intrusive. An elliptical inclusion of Pennsylvanian Quadrant formation, about 400 feet in the long dimension, is located near the contact with the Madison limestone northeast of Gold Coin (pl. 1). Its bedding dips into the stock. According to its spatial relation, the inclusion may be a roof pendant where the granodiorite has risen along the contact between the Quadrant formation and the Madison limestone, isolating a block of the Quadrant formation.

At Daly Gulch, an altered quartzite inclusion appears to have been moved into its present position by the granodiorite during intrusion. The orientation of biotite grains preserves the original silty bedding. The underground contact of the inclusion with the granodiorite is marked by a six-inch clay zone, which indicates the inclusion may have been partly faulted into its present position. However, planar structures in the inclusion are partly parallel to and partly normal to the intrusive contact.

Bedding of the Maywood inclusion at Pyrenees (pl. 4) is essentially undisturbed, although the strike and dip of the bedding indicates the inclusion has been rotated. The dolomite inclusion at Cable (pls. 1 and 7) is faulted on part of its western contact with the granodiorite and is sheared throughout a large area underground. Relationships of the rocks in the mine and on the surface are not sufficiently detailed to determine the spatial position of the inclusion, but dips of bedding and crumpling of the rocks indicate severe compression of the inclusion and possible rotation.

Evidence of forceful instrusion:- The Paleozoic sediments appear to have yielded to the forces of intrusion as well as to compressional forces exerted during periods of major deformation. Along the western contact, the beds dip steeply into the stock and twist around as if they had been "squeezed" into position (pl. 1); this "squeezing" is particularly noticeable north of Pyrenees, at Southern Cross, and at South Hill where the beds are nearly overturned. At North Hill, beds in the Red Lion formation are isoclinally folded and faulted parallel to the granodiorite contact. No major dislocations occur in the wall rock of the stock.

Assimilation:- The basic border of the stock indicates some assimilation of calcareous sediments by the granodiorite in addition to the transfer of calcium across the contact into the stock that resulted in the endometamorphic development of hornblende, diopside, and scapolite. The transitional contact and composition of the altered feldspathic quartzite at Daly Gulch also indicate partial assimilation by the host rock. Many reentrants in the contact contain altered rock.

Absence of a chilled border indicates that the granodiorite may have heated the sediments to about the temperature of the intrusive, a condition conducive to migration of constituents, and may have lost its heat slowly. Deformation that precedes and accompanies intrusion, faulting, brecciation, and folding of the wall rock, create areas of dilatancy (Mead, 1925), which provide space and a differential pressure for the concentration of early and late residual mineralizers. The mineralizers in turn establish favorable conditions for further stoping and assimilation. Deuteric effects found at the contact partly substantiate the accumulation of the late residual magmatic solutions.

The continual mixing of crystals and diffusion of constituents within the granodiorite at the close of intrusion and the attendant assimilation of calcareous sediments may partly account for the lack of linear structures in the stock as well as a narrow basic border.

STRUCTURE

The most prominent structural feature of the mapped area is the Cable Mountain anticline. The trend of the anticline is nearly north-northeast and parallels a large thrust fault to the west. The south-plunging anticline is asymmetric, as the beds dip more steeply on the east flank of the anticline.

The faults on the flanks of the anticline are normal or of the gravity type and trend parallel to the fold axis. Small transverse faults across the anticline are tensional features associated with the major deformation.

Folding

The southward pitching axis of the Cable Mountain anticline is partly cut off by the Cable stock, but the anticline continues southward with an undulating crest towards the Anaconda Range. Compressional forces from the west and tensional forces operating along the anticlinal axis appear to have squeezed and pulled this structure until rupture occurred somewhere north of Granite Hill. The beds dip toward the stock.

Local folding and overturned dips near the contact may be due to the force of intrusion. At South Hill the beds are nearly vertical at the contact; near Cable similar beds in the Red Lion formation are overturned.

North of Pyrenees, strata of the Jefferson limestone are sharply folded and overturned (fig. 13); nearby a small dike of granodiorite has squeezed and folded dolomitic marble. At North Hill, laminae in the Red Lion formation are isoclinally folded to the extent of rupture (fig. 14).

Faulting

Thrusting in the west is probably a continuation of the Lewis overthrust described by Willis (1902, pp. 305-352); however, a local thrust fault at North Hill is believed by the writer to be caused by intrusive forces rather than regional tectonism. The thrust dips northeastward, and its strike is normal to the regional thrusts.

The anticline is faulted parallel to its axis; for example, at Daly Gulch the Madison limestone is faulted against the Red Lion formation (pl. 1). Two wide mineralized breccia zones mark the traces of the normal faults. Farther east two large normal faults have cut out parts of the sedimentary rocks; their downthrown sides are nearest the stock. At Cable the Hasmark dolomite is faulted against lower formations by a transverse fault.

A postulated transverse fracture, now partly occupied by a long dike of altered granodiorite that cuts across the sediments and extends westward from Southern Cross, may have provided initial access for the intrusion of granodiorite. This same dislocation also allowed the force of intrusion to shift the southern part of the Cable Mountain anticline to its present position.

Transverse faulting occurs at the south end of Cable Mountain, at Daly Gulch, and west of Blodgett Creek. Mineralized fault zones near Gold Coin strike nearly west-northwest and dip steeply toward the stock (fig. 15).

Jointing

Two prominent sets of joints are recognized in the Cable area. They trend N. 40° W. and N. 55° E. According to this joint pattern developed locally in the sediments, the forces responsible for their origin seem to have been operating in an easterly direction and are probably directly related to the forces responsible for the regional deformation. A second set of joints is formed near the border of the stock. They coincide in direction with the joints in the granodiorite and are related to post-intrusive adjustments. These joints follow irregularities in the contact and may have been caused by contraction and cooling phenomena.

RELATIONSHIPS IN THE AREA OF METAMORPHIC ROCKS

Sedimentary rocks surrounding the Cable stock show the results of metamorphism in the simple marbles and complex tactites. The intensity of metamorphism is governed, to some extent, by the nature of the intruded sediment. Locally a limestone, such as the Jefferson or Madison limestones, is simply recrystallized, whereas siliceous beds of the Red Lion formation are transformed into tactites.

The following descriptive names of rock types, commonly found in the literature and characteristic of metamorphism in the vicinity of the Cable stock, are briefly defined for reason of clarity:

Marble - granular crystalline rock containing carbonate.

Reaction marble - a marble in which the original constituents or introduced constituents react under thermal conditions to form additional minerals.

Tactite - granular aggregates of silicate and oxide minerals (pyroxene, hornblende, garnet, magnetite, etc.) containing only a minor amount of carbonate (Hess, 1919).

Hornfels - very fine-grained aggregate of silicate minerals (biotite, feldspar, quartz, etc.)

Grandite - garnet rock containing a homogeneous mixture of grossularite and andradite (Winchell, 1951).

Mineral names of the important constituents are prefixed to these names in order to describe a particular rock type. Textural adjectives, such as "banded" (applied to a fine visual banding similar to the siliceous laminae of the Red Lion formation), are also prefixed to the rock-type name.

Daly Gulch area

Contact at South Hill

The contact of granodiorite cuts across the Red Lion formation and forms a thin sill between this formation and the Hasmark dolomite (pl. 2). Two shallow shafts penetrate the intrusive rock at a depth of about 20 feet on the south slope. Northward, the contact crosses Daly Gulch and marks a small reentrant. At this point the contact becomes indefinite; a zone of "transition" rock intervenes between the normal granodiorite and tactite. An inclusion of cross-bedded quartzite crops out to the northeast. Rock from the inclusion shows affinities to the indurated sandstones of the Spokane formation.

At South Hill, the Hasmark dolomite has been changed to a white crystalline dolomite marble with a maximum grain size of about 1.5 mm. Impure shaly laminae, which are generally thin and discontinuous, form large brown nodules in a bleached crystalline matrix (fig. 16). At the north end of the sill, the dolomite contains a small body of magnetite associated with a hard, bright green, brittle mica.

The basal shale bed of the Red Lion formation has been altered to a spotted biotite hornfels. The beds directly above the sill have been metamorphosed to an epidotized grandite-diopside tactite. The tactite nearby is probably fractured but is completely surrounded by a zone of diopside-grossularite marble and diopside-calcite marble. Bands of porphyroblastic grossularite are in a matrix of diopside-calcite marble (fig. 17).

Partially scapolitized zoned-garnet-epidote tactite occurs near the granodiorite with the following relations:

```
            Ca, Mg -->
diopside               scapolite         phlogopite
grandite     ----      epidote      ---- granodiorite---granodiorite
magnetite              plagioclase       hornblende
                                 <-- Fe, Al, Si, Fl, K
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Along much of the contact, the Red Lion formation is recrystallized and locally has small amounts of diopside in the siliceous banded laminae of the marble. Near the upper reentrant, a large mass of zoned garnet is exposed. It is bordered on one side by scapolitized-epidotized granodiorite and on the other side it lies in contact with a grandite-diopside tactite.

Contact at North Hill

The contact is irregular but well exposed along parts of the Maywood formation. At the top of the hill, a small apophysis cuts across the bedding of the Maywood and Red Lion formations and parallels part of their contact (pl. 3). As at South Hill, most of the beds of the Red Lion formation are a recrystallized siliceous limestone. Several elongate areas, parallel to the intrusive contact and sheared, are underlain by coarsely crystalline marble. Most of the marble contains some diopside, especially near the contact. The siliceous laminae have been folded and have partly flowed into irregular blebs near the granodiorite contact; compressional forces were normal to the contact.

Several elongate areas of garnet-diopside tactite, partly enclosed by an intense green border of diopside-epidote rock, are exposed on the hill. A band of tactite parallels the folded bedding on the ridge and is probably controlled by bedding-plane fractures. Another mass of tactite appears to be faulted against a banded diopside-grossularite marble; however, the sharp contact may be the result of the metamorphic effects actually having crossed the marble and bedding and localized by fractures. The exact nature of the contact is difficult to ascertain as the rock is sheared.

Zoned garnet tactite crops out adjacent to the apophysis at the top of North Hill. The garnet is partly bordered by garnet-diopside tactite, which contains a moderate amount of magnetite parallel to the bedding. A narrow band of radiating sheaves of scapolite lies between the zoned garnet and the granodiorite. The zoned-garnet tactite is characterized by large crystalline masses of garnet with concentric color banding (fig. 18).

Rock of the Maywood formation bordering the apophysis has altered to a diopside-rich rock or pyroxenite. Elsewhere the same beds are changed to a diopside-calcite marble that contain bands of black chert. Near the contact of the stock, the chert has altered to a complex tactite by reaction of silica with dolomite and introduced iron, alumina, titanium, potassium and chlorine. The marble was changed to a garnet-diopside tactite where the intrusive cut the Maywood beds. The upper part of the formation is changed to a diopside hornfels that contains bands of garnet and tremolite; its contact with the granodiorite is well-defined to within a fraction of an inch (fig. 29). Here the original texture of the granodiorite is retained in even the smallest apophyses cutting the rocks.

At the south end of the area, a small mass of forsterite dolomite marble is isolated by the granodiorite. The forsterite is altered to serpentine, which contains some chrysotile, antigorite and brucite. An area of altered feldspathic quartzite is located between the inclusion of marble and the Maywood formation. The quartzite contains many small inclusions and show planar structure (fig. 19).

The basal member of the Red Lion formation exhibits the effects of intense metamorphism. The black shale marker bed, which is a biotite hornfels elsewhere, is transformed into a spotted chiastolite hornfels that contains sillimanite and knots of partly replaced cordierite (fig. 20). Although no intrusive contact was observed because of the soil cover, abundant granodiorite float adjacent to the hornfels indicates the presence of a nearby intrusive.

Pyrenees area

Over most of the area, the Jefferson limestone is a partly recrystallized rock; however, near the intrusive, the beds become a coarse, white to light-gray marble (pl. 4). The marble crops out near Georgetown. Most of the carbonaceous matter has been expelled from the original limestone. Nearby, iron gossan is exposed at the contact in an area of highly fractured marble. The cherty beds of the Maywood formation at the Joker prospect contain masses of actinolite and forsterite.

Beds of the Maywood formation on the west limb of the anticline consist of siliceous and argillaceous dolomitic limestone with intercalated silty and shaly layers. The east limb of the anticline is in contact with a small sill-like mass of granodiorite. Here, the silty limestone is altered to a diopside-calcite marble, and as at North Hill, the black chert is partly changed to a complex tactite. In places the shaly layers are metamorphosed to a tremolite hornfels. Gossan is common near the contact.

At Pyrenees, a small inclusion of Maywood has been altered to a dolomitic marble. Correlation was made on the basis of lithology, including a faint banding, distinctive of the Maywood formation exposed near the Joker prospect. Characteristic of other apophyses, sills, and reentrants at the border of the stock, a small apophysis in the inclusion is surrounded by an area of intense metamorphism, which consists largely of an epidotized diopside-garnet tactite. Gossan is common at the surface; at depth, a sulfide ore body was mined. At the nose of the anticline, the Red Lion formation crops out as a banded silica-calcite marble.

Southern Cross area

Typical of its occurrence in other areas, the Hasmark dolomite crops out as a fine-grained dolomite with a distinctive rough sugary texture. Altered dolomite marble is exposed in numerous small pits at the Holdfast mine (pl. 5). Forsterite, serpentine, and phlogopite are the main constituents of the marble (fig. 21). Magnetite replacement of the dolomite is common as exemplified by exposures in open cuts near the Oro Fino mine.

At the Pomeroy mine, the Hasmark beds are massive and recrystallized. Magnetite occurs as massive replacement bodies or as disseminated mineral in bands of dolomite and with much serpentine. Surface exposures over the caved stopes only show gross relationships. The serpentine is an alteration of large masses of olivine, which were altered probably by iron-bearing solutions.

Along the western flank of the anticline near the intrusive, the Silver Hill formation crops out as a series of tactites. Farther away the beds are represented by a biotite-calcite marble. The granodiorite projects into beds of the Silver Hill formation in an area of tactites. The garnet-diopside tactite at the border, which is in the upper part of the Silver Hill formation, changes to a calcite marble that contains biotite and pyroxene at a distance of 300 to 500 feet from the contact. The lower part of the formation contains magnetite.

Near the Southern Cross shaft, the Red Lion formation crops out as siliceous banded marble. Red Lion beds have been changed to a mixture of tactite and marble in the vicinity of the Trinity prospect. The writer believes that these local areas of intense metamorphism are due to unexposed apophyses or dikes, as epidotized granodiorite is exposed in several shallow prospect pits at Southern Cross.

A geologic map of a part of the Trilby tunnel (pl. 6) shows part of the complexity of the metamorphism near the granodiorite contact. In several places the contact is indefinite or transitional. Parts of the limestone, beyond the zone of actinolite at the contact, are essentially unmetamorphosed.

Distinctive of its occurrence in other mines of adjacent areas, mica replaces part of the fractured granodiorite near its contact in the Trilby tunnel. The mica is brown to green, slightly brittle, and platy. Locally the marble has been replaced by biotite, and the open spaces partly filled with clear calcite rhombs (fig. 22). Chlorite and antigorite replaced the mica in fracture zones.

In summary, the introduction of large amounts of K, Na, Al, and Si were necessary for large-scale replacement of marble by mica. According to the pattern of replacement, the mineralizing solutions followed the fractures in major shear zones and spread through the marble along intergranular boundaries of crystals, and perhaps by ionic diffusion through crystal lattices. The contemporaneous removal of carbonate constituents at the time of biotite replacement resulted in a concentration of argillaceous material into shaly bands.

Large crystals are peculiar to several tactites, in particular, the actinolite-magnetite tactite in the Trilby tunnel (fig. 23). A diopside-grossularite tactite near the granodiorite is replaced locally by epidote, phlogopite, and scapolite. A similar alteration rock was found within a few inches of the intrusive contact at South Hill. At the end of the tunnel, bedding of the original banded sediments is preserved by bands of grossularite, epidote and calcite (fig. 24). Magnetite bodies are small and closely associated with actinolite or marble. In the coarse white marble of the Hasmark dolomite, the magnetite is largely disseminated.

Cable area

The Hasmark formation at Cable has been faulted against the Algonkian Spokane quartzite and bent around the nose of the Cable Mountain anticline, both east and west of the trend of the anticline (pl. 7). On the east flank of the anticline, the Silver Hill formation appears to be cut out by a downthrown block of dolomite.

The Hasmark dolomite at the Union prospect and the Stirton mine is a typical recrystallized marble. At the Stirton mine, the rock in the contact zone is sheared and largely replaced by mica. Actinolite-magnetite tactite, similar to an occurrence in the Trilby tunnel, is found at the Stirton mine. Vein quartz and gossan occur in exposures of dolomite at the Uncle Billy shaft. A dolomite outcrop near the shaft has numerous magnetite-filled fractures.

At the Cable mine, dolomite exposed at the surface directly above the caved stopes is sheared and contains several small zones of magnetite. Near the caved stopes as well as at the southwest end of the inclusion, the Hasmark dolomite is marmorized (bleached and recrystallized) to a coarse white marble. Quartz and hematite fill the fractures. The dolomite crystals as large as ten inches are remarkably free of impurities or organic inclusions. The glide lamellae have a discontinuous characteristic showing the effect of shearing; twin planes are sheared.

Underground at the Cable mine, alteration and mineralization have intensified areas of faulting, which might otherwise be concealed by rehealing of the dolomite. Altered granodiorite retains the relic poikilitic texture of orthoclase and quartz even in zones of shearing and brecciation. The western contact is characterized by areas of coarse breccia (fig. 25) in zones of extensive faulting and serpentine alteration. The southwest part of the inclusion has been severely faulted in wide shear zones.

As on the surface, the Hasmark dolomite in the Cable mine is a bleached white marble. Biotite replacement veinlets, especially in areas of magnetite mineralization, are prominent; their boundaries are sharp but irregular. Phlogopite and white chlorite (leuchtenbergite) are common constituents of micaceous marble. Individual plates of mica show the effect of shearing through bending, distortion, and fracture. A pink mica related to manganophyllite occurs in the micaceous marble. In the southeastern stopes, magnetite is disseminated through the altered mica. This bright green chloritic micaceous rock is refractured and contains many calcite veinlets (fig. 26). Plagioclase, fluor-apatite, and quartz are present in micaceous areas.

Magnetite is earlier than biotite and calcite. Generally the magnetite bodies are tabular (fig. 27) but are fractured and cut by later carbonate rock. The magnetite is disseminated or has formed coarse breccias in sheared areas (fig. 28). In the area of sulfide mineralization, largely pyrite, partial dedolomitization has resulted in the formation of forsterite, which is partly altered. Near the contact of the magnetite, sphene is very abundant.

Near the Atlantic Cable Extension prospect (pl. 7), the Hasmark formation has been pressed into a semi-rounded mass; it is cut off at both ends by granodiorite. As at Cable, the dolomite is marmorized and contains several small replacement bodies of magnetite, which are locallized by shear zones. Near the south end of the prospect the magnetite continues across the contact into the Red Lion formation and is disseminated in a garnet-hornblende tactite. At the southern extremity of the Red Lion formation a magnetite-garnet tactite is rimmed by a dark-green zone of diopside and epidote and bears a marked similarity to the occurrence of magnetite at Cable.

Granodiorite at the contact of the Maywood and Red Lion formations is epidotized and contains pyroxene. Several areas of garnet-diopside tactite are exposed in trenches and outcrop; these areas are bordered by steeply folded calcite-silica banded marble, charcteristic of the Red Lion beds. The impure siliceous marble shows a seriate texture, in part, and also shows a cataclastic texture where the grains of calcite are elongate or partly crushed. The maximum grain size of the marble is 0.6 mm. Poikiloblastic phlogopite and feldspar contain grains of calcite, pyroxene, and quartz and are scattered through the marble. A shaft in the Maywood formation near the granodiorite contact penetrates a diopside hornfels similar to that at North Hill.

In summary, the changes across an area of metamorphosed sediments are as follows: (a) from siliceous banded marble to diopside-calcite banded marble, Si and CO_2 remain essentially constant, whereas Fe and Mg increased slightly; (b) from diopside-calcite banded marble to diopside-grossularite marble, Fe and Mg increased moderately and CO_2 decreased; and (c) diopside-grossularite marble to epidotized grandite-diopside tactite, Fe and Mg increased considerably, whereas CO_2 is very low or absent. From the siliceous marble to the tactite, alumina increased slightly, whereas Si remains about constant. Tactite generally borders the intrusive.

ISOCHEMICAL THERMAL METAMORPHISM

Marmorization

Theory concerning the relation of recrystallization and macrocrystallization in this area is summarized by Holser (1950, pp. 1068-1069); however, several points are sufficiently important to bear repetition. Elastic strain energy stored within crystals as a result of deformation is released upon heating and results in crystal growth (Buerger and Washken, 1947; Buckley, 1951). Inasmuch as deformation almost always precedes the thermal effects of intrusion, regardless of its origin (pre-intrusive regional deformation or deformation by forceful intrusion), crystalline limestones or dolomites have stored sufficient elastic strain (potential) energy to have aided recrystallization and macrocrystallization under thermal effects accompanying intrusion; with restricted pore space and openings, diffusion becomes a dominant process (Bugge, 1946; Holser, 1947).

Heat of intrusion and the accompanying water (magmatic liquids and the pore fluids of sediments) are conditions conducive to recrystallization and macrocrystallization in permeable zones (Verhoogen, 1948), generally fractured areas or bedding planes (Bain, 1934, 1936) on highly deformed anticlines or synclines; such areas were found at Pyrenees, Daly Gulch, and Cable.

In these areas the coarse-grained marble coincides with zones of shearing along which repeated adjustments have taken place. Most of these areas are within two hundred feet of the granodiorite contact. The grain size of a marble within a single exposure is uniform, although the grain size diminishes, abruptly in places, away from zones of shearing. The Madison limestone at the southeast contact of the granodiorite changed to a highly sheared marble. The marble contains individual crystals as large as 6 mm. Subsequent shearing has given the marble a "sheeted" or layered appearance.

Bleaching

The phenomenon of bleaching in the Jefferson formation is generally accompanied by the expulsion of foreign particles from the calcite grains. Locally the marble may contain graphite and biotite. At Pyrenees the Jefferson limestone is gray, as only part of the carbonaceous material has been expelled from the calcite grains; yet, the grain size has increased appreciably over that of normal calcitic limestone.

Near the inclusion of Quadrant formation (pl. 1) at the south border of the stock, bleaching has accompanied macrocrystallization in the Madison limestone. Similarly at Cable, very large crystal surfaces are developed at the south end of the inclusion of Hasmark dolomite. At Daly Gulch, aureoles of bleaching surround areas of macrocrystallization; the grain size decreases rapidly away from the coarse crystalline mass and yet remains within the bleached area.

Calcium deficient rocks

The basal black marker bed of the Red Lion formation at South Hill is changed to a spotted biotite hornfels. Some of the biotite grains are purple, characteristic of manganian mica. A few grains of zircon and sphene occur in a mosaic of quartz and feldspar. At North Hill, the same bed is highly altered and contains several distinctive minerals; andalusite (var. chiastolite) associated with magnetite and rutile; sillimanite in mesh of acicular needles; tourmaline (var. schorlite). The matrix of feldspar, quartz, and biotite contains large ellipsoidal "knots", which are composed of cordierite intergrown with micas. Biotite has altered to sillimanite; sericite has partly altered to andulusite. A coarse granitic dike of quartz, orthoclase, and plagioclase cuts the hornfels and is bordered by poikiloblastic phlogopite and tourmaline. The introduction of constituents is evidenced by tourmalinization of this aluminous rock (Fe, B), phlogopite (K, Fl), and rutile (Ti, Fe).

Diopside hornfels is distinctive of part of the Maywood formation at North Hill and Cable. Locally the rock is a pyroxenite. A mosaic of embayed or corroded quartz grains and sericitized feldspars is held in a matrix of intergranular diopside (fig. 29). The Maywood beds are also characterized by a tremolite hornfels. The rock is composed of fine bands of prismatic tremolite, idocrase, iron-poor epidote (clinozoisite) and clusters of tiny sphene crystals. Other layers are micaceous and contain chlorite, biotite, pistacite, and quartz. Magnetite, epidote and sphene are late minerals. Locally, this hornfels contains bands of garnet with poikiloblastic phlogopite replacing feldspar and diopside. A few bands are rich in hedenbergite.

At Daly Gulch, the brown shale member of the Hasmark dolomite is altered to a sericite-chlorite hornfels that contains minor forsterite, magnetite, epidote and relic flakes of biotite. The rock is largely quartz.

Variations in the mineralogy of the hornfels indicate a movement of original materials and the introduction of new constituents; however, reconstitution is the dominant process. The most important constituents introduced into these rocks are iron, titanium, boron, and potassium.

Impure limestones

Isochemical reaction marbles

Most of the reaction marbles occur within 50 feet of the intrusive contact. In the vicinity of the Joker prospect, silica-rich areas or cherty zones in the upper part of the Maywood formation, are rimmed by amphiboles. The host rock is a slightly altered forsterite marble that contains a minor amount of leuchtenbergite and rutile. The siliceous area is surrounded successively by a fine-grained border of magnetite, a band of fibrous tremolite and coarse magnetite, white chlorite and, finally, coarse actinolite and magnetite. These same relationships were observed in the Trilby tunnel (pl. 6).

The black chert at the base of the Maywood formation has a complex reaction rim; diopside-calcite marble is the host rock. The chert contains quartz, biotite, and elongate blebs of magnetite. A zone of pistacite surrounds the chert. Pargasite (magnesium hornblende) encloses isolated calcite grains. Garnet is silicified, feldspathized, and rimmed by diopside.

Large poikiloblastic crystals of phlogopite replace parts of the entire mass. Magnetite is pseudomorphous after garnet; in the quartz matrix, it has a cellular texture, which resembles an exploding bomb and is typical as well as characteristic of its occurrence in large deposits.

The introduction of iron, titanium, alumina, potassium and sodium probably adds to the complexity of the original simple reaction. The most important metasomatic constituents are iron and alumina.

Dedolomitization

Forsterite marbles are widespread in the Hasmark formation. Forsterite and antigorite constitute as much as 30% of these fine-grained marbles. Brucite is commonly associated with large masses of antigorite-serpophite mixtures, as may be expected because of similarity in their crystal structures (Selfridge, 1936; Bowen, 1949). In coarse-grained sections, spinel and magnetite are common. The spinel cuts forsterite and is in turn rimmed by magnetite. Veinlets of phlogopite, commonly distorted or sheared, cut across the marble adjacent to calcite-filled fractures. Pennine and leuchtenbergite are moderately abundant in the micaceous marbles.

Large-scale dedolomitization is distinctive of the Hasmark formation near the intrusive. Phlogopite is characteristic of late alkaline hydrothermal action. Forsterite fixes silica and magnetite, whereas the excess alumina is fixed by spinel.

In general the regional pattern of isochemical thermal metamorphism is controlled by the granodiorite. Areas of dilatancy, marked by intense folding, fracturing and shearing, control the local metamorphism; crystal growth is controlled, in part, by thermal and stress effects. Metasomatism is important in the formation of complex silicates; iron and alumina are most important in this role.

ALLOCHEMICAL SILICATE METAMORPHISM

Much of our present knowledge concerning isochemical thermal (contact) metamorphism and allochemical (metasomatic) metamorphism is discussed and summarized by Turner and Verhoogen (1951), Eskola (1939), Turner (1948) and Harker (1939).

Grossularite marble

In the grossularite marble, the garnet and the marble correspond to the original siliceous laminae and limestone of the unmetamorphosed equivalents in the Red Lion formation, respectively (samples 13.1283-84, Table 2). The garnet, a mixture of light grossularite partly rimmed by darker andradite (sometimes homogeneous), occurs as large dodecahedral porphyroblasts between the siliceous laminae and the marble (fig. 17). Individual garnet crystals exceed a diameter of one centimeter. Zoned crystals are partly replaced by epidote, calcite and calcic plagioclase, which leave skeletal or dodecahedral shells of garnet, an example of retrograde metamorphism according to Osborne (1932) and Harker (1939).

Diopside is disseminated throughout the marble but is largely concentrated inside the border of the silica zone. Garnet appears to be a reaction product of diopside and marble. Pargasite occurs between the garnet and the marble as a reaction product (fig. 30).

An iron-poor epidote, resembling the non-ferrian variety of zoisite, with almost parallel extinction (2^0) and anomalous blue interference colors, is called clinozoisite. It occurs in the silica zone as large poikiloblastic crystals that contain pargasite and diopside. Clinozoisite, together with calcite, replaces the amphiboles. Magnetite also occurs at the border of the silica zone and partly replaces diopside and epidote. Pistacite generally replaces garnet. The siliceous zone contains minor amounts of sphene, allanite, twinned anorthite, and hedenbergite.

Relationships indicate that diopside and silica react with the marble to form garnet, with an introduction of iron in the formation of andradite-rich garnet; nevertheless, these minerals are controlled locally by the original siliceous laminae. Pargasite fixes Mg and Si and indicates the introduction of Na and Al. Introduced alumina is essential for the formation of garnet. Minor amounts of titanium, iron, and alumina are fixed by epidote and sphene.

Diopside marble

Various diopsidic marbles are closely related to the grossularite marbles but usually show only a skeletal form of garnet. These garnetiferous areas are devoid of diopside; it is the writer's opinion that the diopside entered into the formation of the garnet. The siliceous parts of the diopside marble are characterized by a concentration of magnetite. In the unmetamorphosed Red Lion beds, the magnetite is confined to the siliceous laminae and has increased in amount near the calcitic parts of the rock (sample 13.1285, Table 2).

The concentration of minerals in the siliceous laminae may be attributable to the permeability of the silica grains and interconnected lacework. Calcic plagioclase (anorthite-bytownite range), clinozoisite, and large poikiloblastic hornblende, which contains diopside, are common in the silica zone.

Near the intrusive contact, the marble is scapolitized. Poikiloblastic scapolite contains many unreplaced inclusions of diopside and clinozoisite; scapolite is localized in the silica zone. Large phlogopite crystals are also scapolitized.

Silicate tactites

Diopside rock

A rock rich in diopside borders more complex tactites in many places. Diopside is commonly associated with clinozoisite. Pistacite and abundant sphene replace diopside. The replacement is selective along particular layers, generally the fine-grained beds. Sericite, allanite, and magnetite occur in minor amounts.

At North Hill, the Maywood beds at the border of the small apophysis have been metamorphosed to an almost pure diopside rock or pyroxenite. The fine-grained parts show a granoblastic structure and are non-pleochroic. Indices of the diopside are $N_\gamma = 1.687$, $N_\alpha = 1.657$, and $N_\beta = 1.660$, which corresponds to about 25% clinoenstatite ($MgMgSi_2O_6$) member. In coarse-grained areas, slightly pleochroic diopside occurs as radial sheaves, characteristic of hedenbergite, and is intergrown with fibrous actinolite. N_β exceeds 1.68, equivalent to about 20% hedenbergite. Scattered grains of corroded quartz and sericitized feldspar occur as relic crystals and probably represent the original sediments. Borders of the pyroxenite are gradational into a diopside hornfels and a cherty diopside marble. The diopside rock represents the altered basal sand member of the Maywood formation, which is generally not well exposed.

Garnet-diopside tactite

Tactite rich in garnet is commonly localized around reentrants, apophyses, and sills. Brown massive garnet at North and South Hills shows a zonal structure. In its growth against calcite, garnet is idiomorphic and occurs as crystals as large as 2 cm. Blue-green pargasite generally rims the calcite (fig. 30). In weathered zones, leaching of the calcite leaves a vuggy rock; however, its vuggy character also may be due to a decrease in volume resulting from a loss in CO_2. As in the marbles, garnet is replaced by late minerals such as pistacite, calcite, and calcic plagioclase.

Fractures act as feeders for garnet forming constituents, which are carried from a garnet-rich zone and redeposited in a diopside marble. Similarly, deposition of abundant magnetite and sphene followed by epidote occurs in fractures; the solutions move out from the fractures into the intergranular spaces, between crystal faces, and perhaps by diffusion for short distances.

Diopside is generally disseminated in the marble, poikiloblastically included in phlogopite, or concentrated in bands parallel to the siliceous laminae. In some of the tactites, magnetite is disseminated along the bedding; its replacement is controlled by open spaces, fractures or the zonal pattern of the garnet (fig. 31).

The late solutions are rich in alkalies and iron as shown below in an example of replacement;

phlogopite } replaces both { epidote replaces { garnet
magnetite } -------------- { epidote ---------- { diopside

Three varieties of epidote occur in the tactite. Clinozoisite is associated with diopside and garnet in the silica zone. Allanite is zonally rimmed by pistacite. The intergrowth of allanite with pistacite indicates instability or non-equilibrium in the replacing solutions; they are decreasing in Mg and Fe content. The enclosure of some epidote by bands of diopside may result from retrograde effects, the late formation of diopside, or the forceful growth of late epidote crystals.

The sequence of replacement and the poikiloblastic texture of cordierite, pistacite, phlogopite, and scapolite indicate the replacement nature of these late minerals. Scapolite is the latest mineral and replaces the other minerals.

Amphibole-rich rocks

Tactites in the Tribly tunnel contain considerable amounts of actinolite and pargasite. Radiating crystals and fibrous clusters of actinolite contain 30% to 50% tremolite member. Calcite has replaced the amphiboles along cleavages; chlorite is a common alteration mineral of the amphiboles. Intergranular magnetite, sphene, and apatite are moderately abundant.

According to the average optical characteristics and indices of clinozoisite, it contains 10% to 15% pistacite.

Transitional facies

The contact of the stock is generally sharp; all transitional zones are relatively narrow or nonexistant. An entire sequence of mineralogical changes, from normal granodiorite to diopside tactite, can occur within a few inches. The sequence given below involves about two inches of rock:

Fe, Al, Ti, K, Na ⟶

normal grano-diorite	phlogopite sphene chlorite	hedenbergite tremolite-actinolite pargasite (allanite)	actinolite pyroxene pistacite plagioclase (ghosts)	diopside pistacite

⟵ Mg, Ca

Pyroxene is probably a mixture of diopside and hedenbergite. The prominent zones are marked by the introduction of phlogopite (fig. 32); pargasite layers; radiating fibrous tremolite (fig. 33); and diopside. Plagioclase "ghosts" are epidotized at the center and almost completely sericitized. Allanite is associated with hedenbergite.

The transition from normal granodiorite to garnet tactite is not as well defined as the previous sequence. This sequence occurs within a distance of two feet and is divided into three zones as follows: (a) pistacite zone, (b) intermediate zone, and (c) garnet zone. The granodiorite is replaced by epidote, which is represented by the first zone. Apatite and actinolite are poikiloblastically included in the epidote. Almost without exception, a profusion of tiny crystals of sphene accompanies pistacite at the contact zone. Plagioclase is epidotized and sericitized. Magnetite, fibrous actinolite, pargasite, phlogopite, and less abundant sphene and apatite occur in the intermediate zone. In the garnet zone, quartz and plagioclase partly replace the garnet and leave remnants of zoned garnet.

Diopside is moderately abundant in the garnet zone.

The transition from garnet tactite to diopside rock is marked by sharp boundaries (fig. 34). The diopside zone contains fibrous actinolite, magnetite, and minor amounts of quartz and feldspar. Magnetite is disseminated between the two zones. A thin band of pargasite marks the boundary between the zones (fig. 35). The pargasite is optically positive, pleochroic (X yellow-green, Y emerald-green, Z blue-green), $Z \wedge c = 19^{\circ}$ maximum, N_{β}=1.633 and N_{α}=1.657. The blades of pargasite are normal to the contact of the two zones.

ZONED GARNET TACTITE

In the vicinity of the Cable stock, zoned garnet only occurs in the Red Lion formation. At North Hill, large crystals of peripherally zoned garnet occur in a narrow band parallel to the intrusive contact (pl. 3). The garnet transects the bedding of the siliceous calcite marble and is bordered by a zone of scapolite. At South Hill zoned garnet occurs within several inches of the granodiorite.

The tactite consists of dodecahedrons of pale-brown to red-brown garnet, as large as three inches. In the pale-brown garnet, the zones are continuous from crystal to crystal, as well as concentric to the individual crystal (figs. 18, 36). Zones in the red-brown garnet are composed alternately of pistacite and garnet. The individual cores of the garnet consist largely of pistacite, some diopside, quartz, feldspar, and calcite as replacement or poikiloblastically included minerals. The dark-red garnet contains considerable andradite ($n>1.78$).

Replacement of the garnet is mainly along radial fractures, zonal boundaries, and crystal faces. Fractures provided easy access to the zonal boundaries along which the diffusion of replacing constituents took place. The presence of anorthite indicates that zoned garnet at Daly Gulch was probably formed by a reaction of an unstable calcium silicate, such as wollastonite, of an early tactite, anorthite, and introduced iron.

Zoning may represent periods of non-equilibrium during the formation of garnet, and periods of equilibrium during which no constituents, such as iron were added to an early tactite. In addition, the intermittant metasomatic introduction of iron at a late stage followed by crystallization of iron-free grossularite under thermal conditions may account for the zoned grandite. Small traces of impurities at the zonal boundaries may have impeded deposition or may represent a period of non-deposition.

MAGNETITE MINERALIZATION

Magnetite-carbonate marble

Magnetite-rich marbles are characterized by large-scale dedolomitization and widespread alteration. Most of these rocks are exposed at the Pomeroy mine near Southern Cross (pl. 5). Alteration in the banded magnetite-forsterite-carbonate marbles indicates that most of the serpentine minerals are derived from the alteration of olivine.

Deposition of the magnetite was controlled by fractures and bedding planes. The magnetite cut across or replaced minerals along the bedding. In an ophicalcite, magnetite deposition was initially controlled by cleavage and twin planes of the dolomite host rock.

At North Hill, a small inclusion of serpentine marble is exposed; here, forsterite has altered to antigorite. Fibrous chrysotile occurs in small veinlets accompanied by antigorite and finely disseminated magnetite. Brucite is associated with antigorite. In addition, phlogopite and spinel occur in the marble.

Magnetite tactite

In most of the tactite, the magnetite replaces dolomite or calcite, quartz, and feldspar. It embays and corrodes the quartz and feldspar but generally replaces an entire carbonate grain. In an amphibole-rich tactite, the magnetite bends and shatters the fibrous actinolite and chlorite (fig. 36). It replaces parts of the garnet crystals and is controlled by the zonal structure of the garnet. Some magnetite grains are rimmed by leuchtenbergite, probably the result of hydrothermal action.

In the Trilby tunnel large crystals of fibrous actinolite and calcite are replaced by magnetite. Veinlets of magnetite cut and are cut by epidote-filled fractures and veinlets of secondary calcite, indicating contemporaneous deposition or redeposition of these minerals.

SCAPOLITIZATION

Scapolite occurs as gray to white prismatic or radiating crystals at the contact of the intrusive. Sphene, apatite, clinozoisite, pargasite, pyroxene, and calcite are poikiloblastically included in scapolite. Small dodechedral garnets are scattered through the scapolite, whereas scapolite partly replaces the large massive garnet.

Under the microscope, most of the zoned scapolite is rich in meionite member, whereas the marialite-rich scapolite occurs in a mosaic pattern and has wavy extinction. The average indices are $N_o = 1.567$ and $N_\epsilon = 1.544$, which correspond to 40%-44% meionite, variety diapyre.

The zoned varieties occur nearest the limestone at the contact. The soda-rich scapolite replaces parts of the granodiorite and adjacent tactites. The variation in composition of the scapolite indicates the direction in which the exchange of constituents occurred, namely, chlorine and sodium from the granodiorite and calcium carbonate from the limestone.

SUMMARY AND CONCULUSIONS

The composition of the granodiorite is uniform over the entire stock, with the exception of local variations in biotite and hornblende. In places the composition and texture of the granodiorite are the same a few feet from the contact as they are at the center of the intrusive. The contact of the stock is sharp; all transitional zones are narrow or absent.

The basic border of the stock indicates some assimilation of calcareous rocks by the granodiorite; the transfer of calcium across the contact resulted in the endometamorphic development of hornblende, diopside, and scapolite. Border rocks are rich in sodic hornblende (pargasite) and very calcic plagioclase. Many reentrants in the contact contain epidotized intrusive rock. Deformation of the sediments accompanied forceful intrusion of the granodiorite.

Reconstitution is the dominant process in the basal hornfels of the Red Lion beds and the massive Hasmark dolomite; however, iron, titanium, boron, and postassium have been introduced into these rocks. Depletion of biotite at the edge of the stock made available considerable amounts of iron, alumina, potassium, and silica for reaction with carbonate rocks; large-scale replacement of marble by mica utilized these same constituents.

Iron is the most important metasomatic constituent in the vicinity of the Cable stock. Fe, Al, Si, Fl, Cl, K, B, Na, and Ti from the stock have been exchanged with Ca, Mg, and CO_2 from the carbonate sediments. Tactites consist chiefly of grandite, pargasite, and magnetite. The late exchange of sodium chloride from the stock and calcium carbonate from the sediments provided constituents for scapolitization at the intrusive contact.

Large-scale dedolomitization precedes and accompanies deposition of magnetite. Garnet tactites contain considerable magnetite. Magnetite occurs as massive replacement bodies and as disseminated mineral in dolomite and serpentine-rich marbles.

Poikiloblastic texture is common in the prominent replacement minerals. Solutions that provide constituents for the formation of common replacement minerals were rich in iron, alkalies, and some halogens.

In addition to impurities at the crystal faces impeding alternate deposition of andradite and grossularite, intermittant metasomatic introduction of iron followed by crystallization of iron-free garnet under thermal conditions may account for the formation of zoned garnet.

Areas of dilatancy and stress, marked by intense folding, fracturing, and shearing, control metamorphism. Mineralizing solutions followed fractures in sheared areas and spread out into the sediments along intergranular spaces, crystal faces, and perhaps by diffusion for short distances.

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Table 1 - Characteristics of the Paleozoic rocks

Period	Age[1]	Formation[1]	Thickness (feet)	Character
Mississippian	Kinderhookian-Osagian	Madison limestone	1300	Limestone, black, dense, compact brown; flaggy to shaly at base; gray, massive, fossiliferous in upper part; calcitic, cherty, and petroliferous at base.
Devonian	Senecan	Jefferson limestone	600-900	Limestone, white, to gray-black, sugary, dense, granular, mottled, massive, marked by yellow shale at top; slightly dolomitic; fractured, carbonaceous.
Upper Cambrian	Trempaleauan	Maywood formation	200-300	Limestones, gray to red and siliceous; interbedded, gray, buff shales, maroon sandstone with interbeds of dolomitic; calcarous; buff to maroon, fine-grained, dolomitic; black chert at base; basal part is sandy.
	Franconian	Red Lion formation	270-280	Limestone, light to dark blue-gray; sublithographic to fine-grained, calcitic and siliceous; calcareous portion fossiliferous, very low silica; microcoquinas; laminae buff to reddish brown, 0.1 to 0.8 inch thick, wavy, thin, anastomosing, siliceous and carbonaceous; 10 to 85% SiO_2; basal portion is shaly, dolomitic and sandy.
	Dresbachian	Hasmark dolomite	ca. 1000	Limestone, bluish gray to white sublithographic to crystalline dolomite; middle member shaly, chocolate brown, dense; upper member yellow-buff to gray, dense, dolomitic.

Table 1

	Age[1]	Formation[1]	Thickness (feet)	Character
Middle Cambrian	(cf. Park shale-Meagher limestone)	Silver Hill[2] formation upper part	150-250	Limestone, with siliceous and shaly laminae similar to Red Lion formation.
	(cf. Wolsey shale)	Silver Hill[2] formation lower part	60-120	Shale, dark olive-green; thin interbeds of white to maroon sandstone.
		Flathead quartzite	135-150	Quartzite, white to buff, fine- to medium-grained.

1/ Stratigraphy according to Calkins (Emmons and Calkins, 1913) as modified by Lochman and Duncan (1944) p. 12-16.
2/ after Holser (1951).

Table 2. Section of Paleozoic rocks in railroad cut west of Daly Gulch.

	Thickness (feet)
MAYWOOD FORMATION (LOWER PART)	
Sandstone, light buff, calcareous, very fine-grained, thin-bedded. 1% iron.[1] (13.1303)[2]	40
Limestone, buff to brown, dolomitic highly siliceous massive and fine-grained. 60% SiO_2, 0.4% iron (13.1302)	35
Sandstone, maroon to buff, cross-bedded, very fine-grained, calcareous, silty partings and thin-bedded, lower part; 89% SiO_2; 2.3% iron (13.1301)	22
Limestone, dolomitic, buff, fine-grained to granular, siliceous, 58% SiO_2; 1.2% iron.	5
Shale, drab, thin-bedded, slightly calcareous.	2
Limestone, dolomitic, buff, very fine-grained, siliceous; (65% SiO_2 ; 0.3% iron).	7
Covered	76
RED LION FORMATION	
Limestone, gray with brown wavy laminae about 1-8mm thick 69% SiO_2; 0.6% iron; calcareous; iron in siliceous laminae, coarse-calcite filled fractures and along stylolites; calcite recrystallized, 1.0 mm (twinned); iron as sulfide and oxide cement in siliceous part and give-banding buff color (13.1298)	49
Limestone, bluish gray and drab-gray, thin laminae weathering reddish brown, wavy laminae encloses coarse gray limestone 48% SiO_2; 0.3% iron; highly calcareous (13.1297)	53
Limestone, blue gray, calcite partially recrystallized, 0.5 mm, contains few grains of dolomite, feldspar; and hematite; siliceous portion contains quartz about 0.02 mm;49% SiO_2; 0.3% iron; highly calcareous; beds 2 feet thick alternate with: (13.1286)	
Limestone, drab, brown siliceous laminae, weather to bright reddish-brown; calcite grains 0.02-.04mm; iron as hematite and magnetite restricted to the siliceous part at the calcite-quartz border; iron partially replaces or coats the rhombs of calcite;86% SiO_2; 2.1% iron; highly calcareous beds are 5-6 feet thick (13.1285)	53

Table 2 - continued

	Thickness (feet)
Limestone, blue-gray, fossilferous, contains recrystallized calcite up to 0.5 mm; calcareous part contain grains of feldspar and quartz; iron occurs as pyrite altering to hematite; 52% SiO_2; 1.2% iron; (13.1283) alternates with limestone, blue-gray, brown wavy siliceous laminae; 74% SiO_3; 1% iron; siliceous laminae contain quartz, feldspar, mica and most of the iron content; zircon, sphene also occur in the laminae; iron mineralization fills some fractures and spreads out into siliceous layers. (13.1282).	45
Limestone, buff, thin purple siliceous laminae; purple banding (20% of rock, by area) bituminous or carbonaceous material and quartz grains; borders of quartz and felspar grains corroded; calcite 0.2 mm, with white mica and quartz; iron oxide coats calcite; few pyrite cubes; several rhombs of dolomite; 87% SiO_2; 2.2% iron (13.1281)	8
Limestone, buff dark brown siliceous laminae; 66% SiO_2; 1.1% iron, calcareous (13.1280)	14
Limestone, drab, purple siliceous laminae; 83% SiO_2; 1.6% iron (13.1259)	3
Limestone, gray, buff wavy siliceous laminae, fossiliferous, few scattered grains of quartz, quartz grains filling veinlets; hematite and pyrite along stylolites; 20% SiO_2; 0.4% iron (13.1258)	21
Limestone, buff, thin purple laminae (arenaceous spergenite) with thin bed of siliceous magnesian limestone at base; 67% SiO_2, 1.3% iron; (13.1257)	7
Shale, black to dark gray, graded bedding from clay size to 0.02mm (quartz grains); siliceous portions are lenticular; shale characteristic varved appearance. Detrital quartz in cross-cutting veinlets to bedding. (13.1255)	3
Limestone, drab, dolomitic, thin calcareous silty partings, thin-bedded siliceous (13.1256)	4
Sandstone, buff, thin-bedded, calcareous, some silt.	10
Shale, black (same as 13.1255)	1
	267

HASMARK FORMATION
Upper magnesium limestone member

Limestone, purple and white, very thinly bedded with contorted laminae, dolomitic, shaly near the base; 0.4% iron, 18% SiO_2. (13.1254)	21

Table 2 - continued

	Thickness (feet)
Dolomite, yellow to buff, thin-bedded to massive at base, beds 1 to 6 inches thick, siliceous; 10% SiO_2; 0.3% iron (13.1251)	52
Dolomite, pale yellow to gray, massive (2 ft. beds), locally calcareous (26% to 11% SiO_2; 0.1% iron.	76
	149

1/ SiO_2 determined by weight after initially treating sample with HCl and aqua regia, and ignition determined colorimetrically (electrophotometer) with an accuracy of 10% due to sampling errors. Residues examined microscopically.

2/ the numbers refer to samples and thin-section

Figure 2. Daly Gulch from Gold Coin looking north toward South Hill, Granite Hill, and Cable Mountain.

Figure 3. Laminae in beds of the Red Lion formation near Gold Coin Gulch. Pencil gives scale.

Figure 4. Laminae in beds of the Red Lion formation near Gold Coin Gulch. Dark siliceous laminae encloses the white marble.

Figure 2

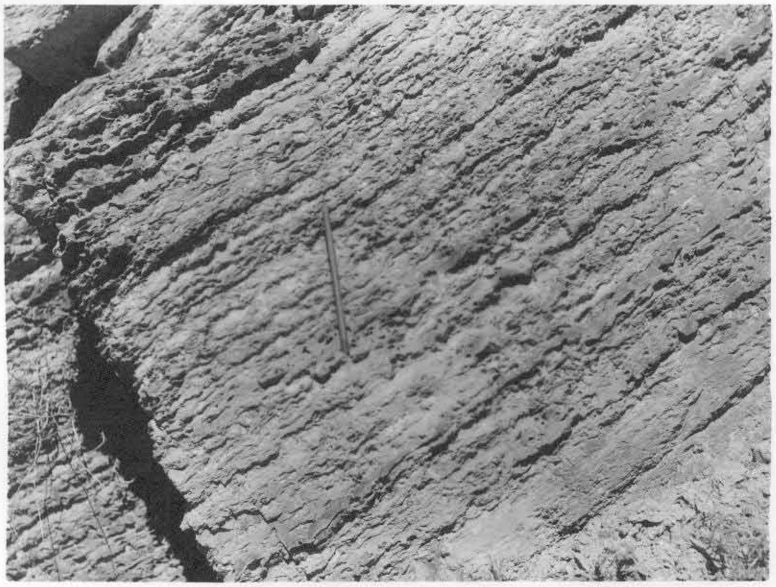


Figure 3

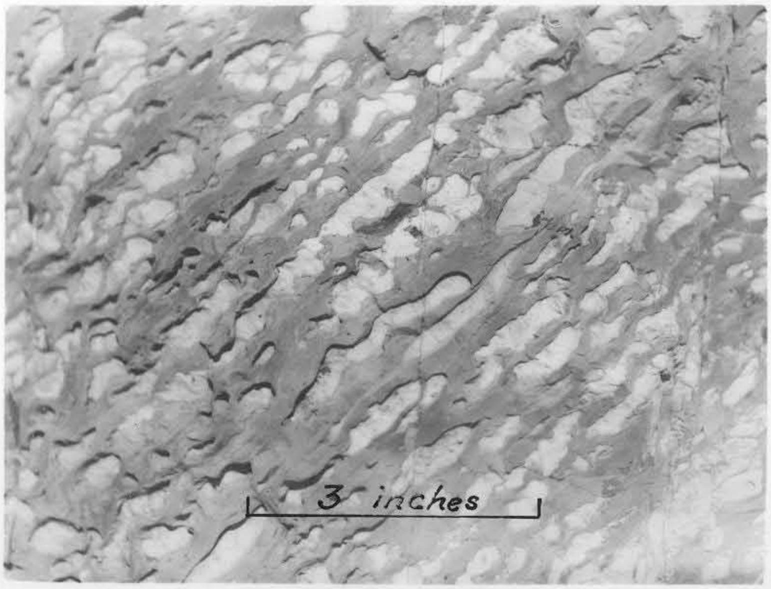


Figure 4

Figure 6. The sharp contact of granodiorite (gd) against a bed in the Maywood formation (diopside hornfels). Two inclusions (i) occur in the granodiorite. The hornfels is cut by a small apophysis of granodiorite. The rock section is five inches wide.

Figure 10. Streaking in altered feldspathic rock that contains granophyric inclusions. Near North Hill, Daly Gulch. Lower part of the exposure is normal granodiorite. Pencil gives scale.

Figure 16. Nodules in the Hasmark dolomite at South Hill, Daly Gulch. Nodules of brown siliceous dolomite generally occur as discrete lenticular masses in the white marble.

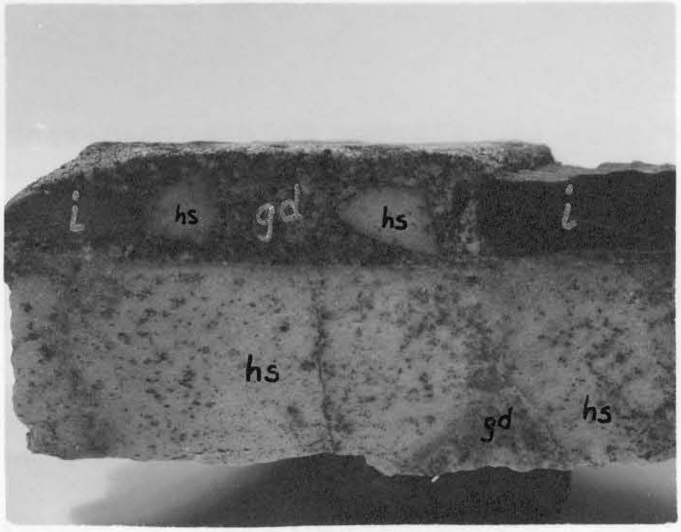


Figure 6

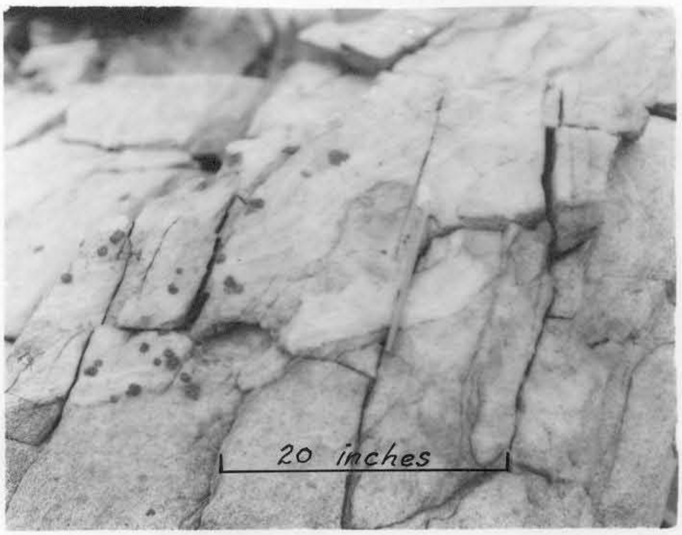


Figure 10

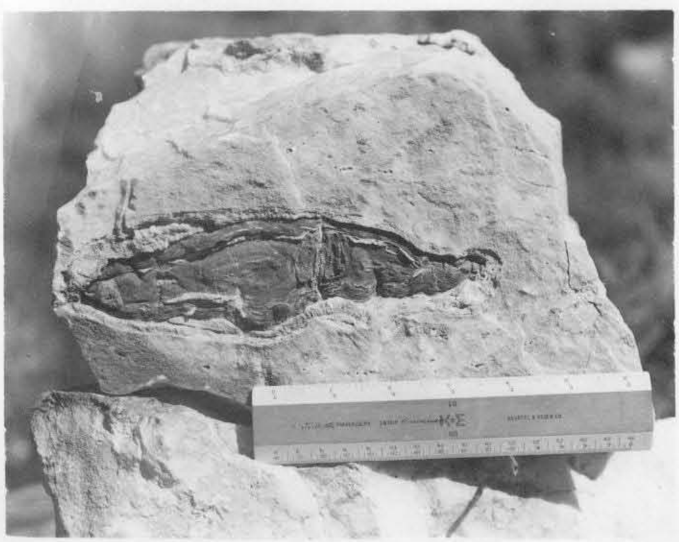


Figure 16

Figure 11. Altered feldspathic rock as in figure 10. Pencil gives scale.

Figure 13. Folded beds in the Jefferson limestone near Georgetown. Locally the beds are overturned. Width of the exposure is about twenty feet.

Figure 14. Isoclinal folding in beds of the Red Lion formation. North Hill about fifteen feet east of reverse fault. At left a small fault was produced in folded laminae.

Figure 15. Mineralized fault zone, looking west into Gold Coin Gulch. Stoped area dips about 60° north and is an extension of the Gold Coin mine.

Figure 11

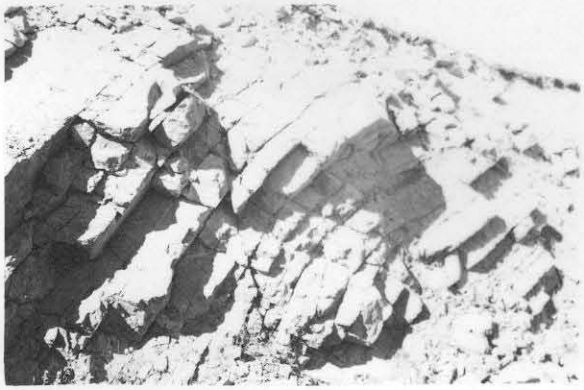


Figure 13

Figure 14

Figure 15

Figure 7. Poikilitic texture of the Cable granodiorite. Plagioclase (p) is poikilitically included in large crystals of orthoclase (or) and quartz (qz). X 82, crossed-nicols.

Figure 8. Poikilitic texture of the Cable granodiorite. X 26, crossed-nicols.

Figure 9. Altered Cable granodiorite. Cores of calcic plagioclase (p) are epidotized (ep) and sericitized (s). Chlorite (c) occurs as large discrete masses. X 82, plain-polarized light.

Figure 12. Hornblende felsite porphyry. Large crystals of hornblende (hb) are held in a matrix of feldspars (fd). cores of plagioclase are partly altered to sericite. From dike near Georgetown Lake. X 26, crossed nicols.

Figure 20. Spotted chiastolite hornfels in the Red Lion formation at North Hill, Daly Gulch area. Chiastolite (a) and cordierite (c) occur in a quartz-biotite matrix (qz). Tourmaline borders a small dike cutting the hornfels. X 26, plain-polarized light.

Figure 21. Forsterite-dolomite marble in the Hasmark dolomite from the Southern Cross area. Intergranular magnetite (m) has replaced forsterite (f) and dolomite (dol). Spinel (sp) is common. Phlogopite, a late mineral, has replaced parts of the marble. X 26, plain-polarized light.

Figure 8

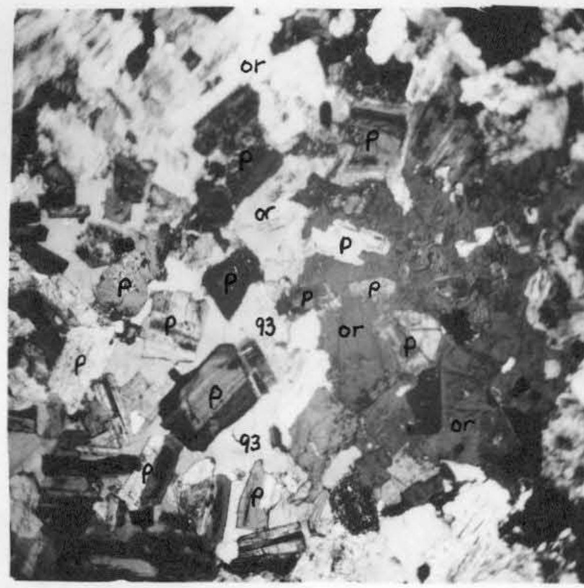


Figure 7

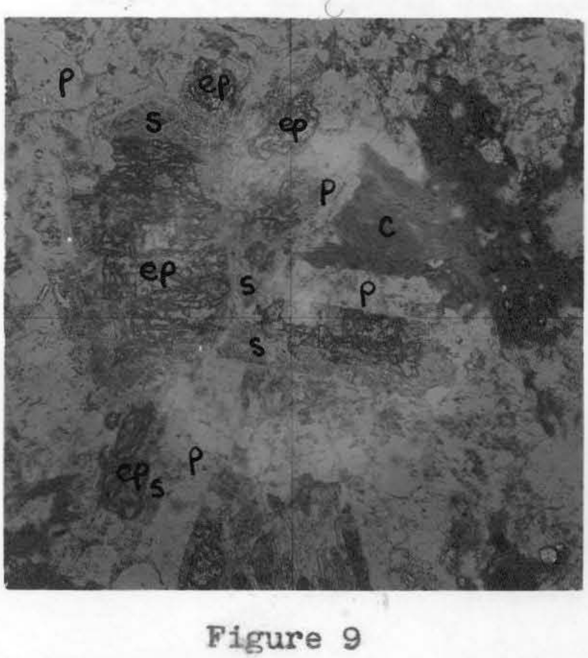


Figure 9

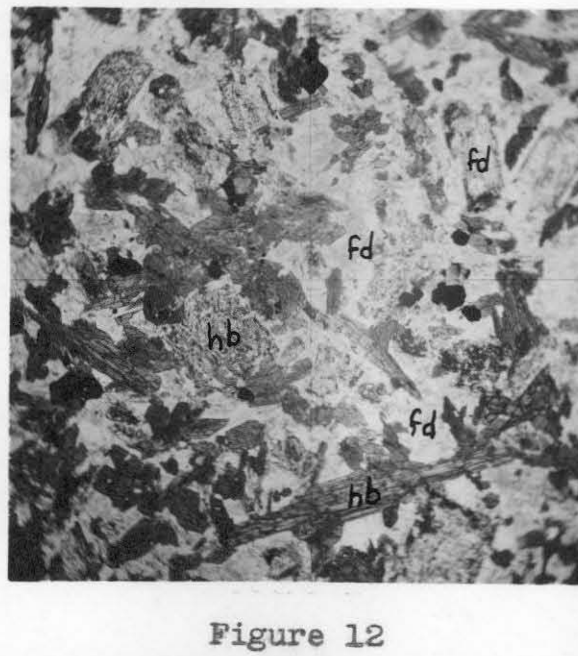
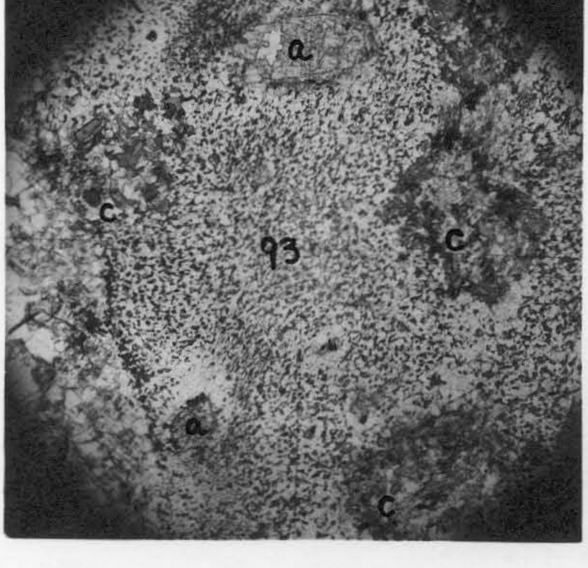


Figure 12



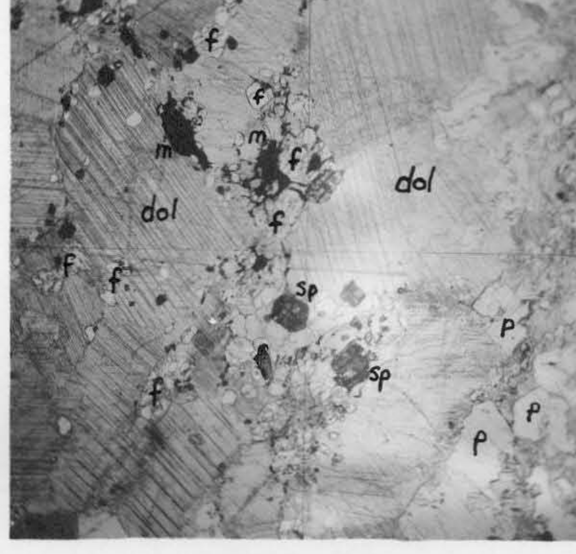


Figure 21

Figure 1 7. Grossularite-diopside-calcite marble at South Hill, Daly Gulch. Garnet preserves the bedding (the original siliceous laminae) of the Red Lion formation. The area is about three feet wide.

Figure 18. Zoned-garnet tactite in the Red Lion formation at South Hill, Daly Gulch area. Alternating light and dark zones of grossularite and grandite are concentric to individual crystals and groups of crystals.

Figure 19. Altered feldspathic quartzite near North Hill, Daly Gulch area. The original bedding is preserved by biotite layers.

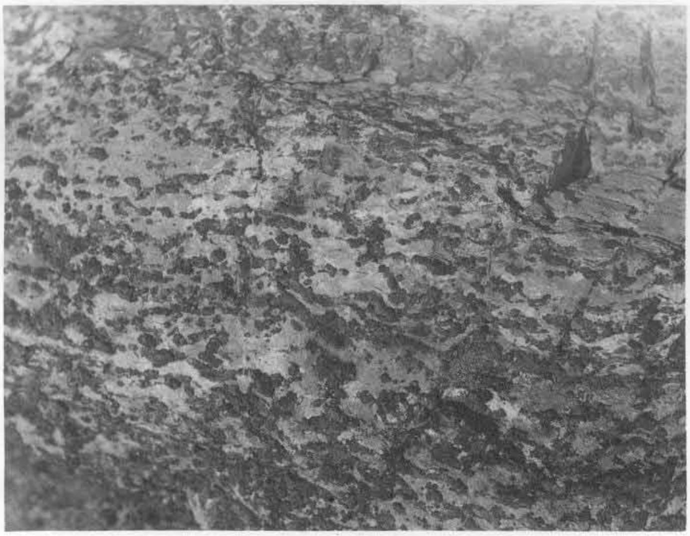


Figure 17

Figure 18

Figure 19

Figure 22. Biotite replacement of marble in the Trilby tunnel, Southern Cross area. Veinlets of biotite and calcite have replaced the sheared marble. Width of the exposure is about three feet.

Figure 23. Actinolite-magnetite tactite and calcite marble from the Red Lion formation in the Trilby tunnel, Southern Cross area. The marble contains large prisms of actinolite; below, magnetite and serpentine occur in coarsely crystalline bands. The rock is eight inches wide.

Figure 24. Grossularite tactite from the Trilby tunnel, Southern Cross area. Bands of grossularite (g), epidote (ep), and calcite preserve the bedding of the banded sediments of the Red Lion formation. The end of a one-inch eraser gives scale.

Figure 22

Figure 23

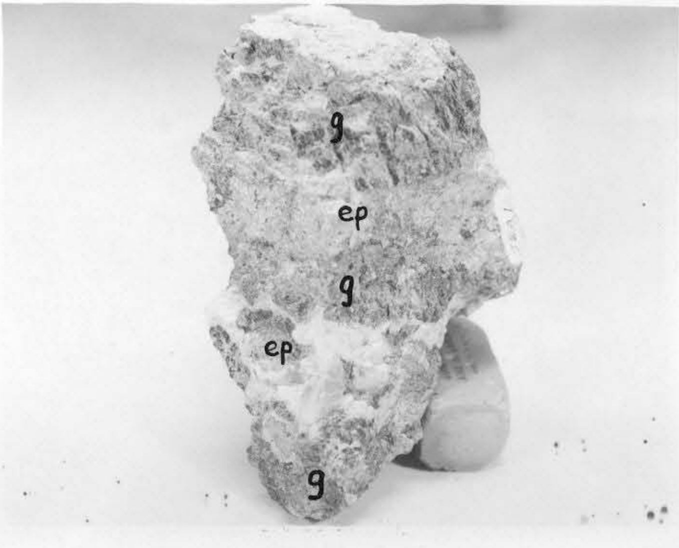


Figure 24

Figure 25. Block breccia of dark-brown marble in light marble near the Nowlan raise, Cable mine. Pencil gives scale.

Figure 26. Biotite and chlorite replacing marble in the Cable mine. Westernmost stope, 6800-foot level. Biotite has replaced the marble; later the biotite was almost completely chloritized. Veinlets of late calcite cut the altered mica. The entire mass has been sheared repeatedly. Slickensides are visible in many directions. Width of the exposed rock is about three feet.

Figure 27. Magnetite ore in the Cable mine. Back of main drift, near main winze, 6800-foot level. Bands of magnetite replaced dolomite along parallel and transverse fractures. Carbide lamp gives scale.

Figure 25

Figure 26

Figure 27

Figure 28. Magnetite and marble breccia in the Cable mine near the Nowlan raise. Magnetite and marble are cemented by late calcite. Width of area is about two feet.

Figure 30. Garnet-pargasite-magnetite tactite from the Red Lion formation, South Hill, Daly Gulch area. Pargasite (p) borders grandite (g) and encloses isolated masses of calcite. Note zoning in garnet. Pencil eraser gives scale.

Figure 36. Zoned-garnet tactite at North Hill, Daly Gulch area. Note alternating dark and light zones of andradite and grossularite, and the concentric banding around groups of crystals. Width of the exposure is about two feet.

Figure 28

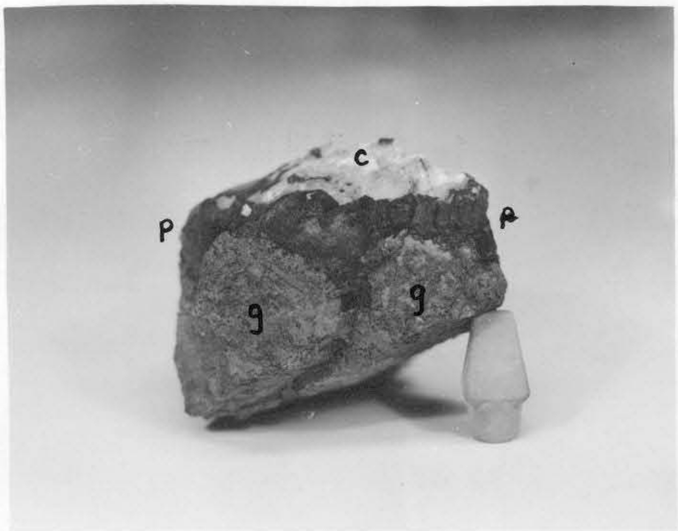


Figure 30

Figure 36

Figure 29. Diopside hornfels in granodiorite. From section of rock shown in figure 6. Small apophysis of granodiorite (gd) isolates diopside hornfels (hf) and granophyric inclusion (i). Note corroded quartz grains (clear) in dark matrix of diopside. X 26, plain-polarized light.

Figure 31. Garnet-diopside tactite from the Red Lion formation in the Trilby tunnel, Southern Cross area. Magnetite (m) has filled and partly replaced grossularite (g) and diopside (d). The garnet is partly feldspathized and silicified (f). Note zonal boundaries in garnet. X 82, plain-polarized light.

Figure 32. Phlogopite replacement of granodiorite at the intrusive contact. Phlogopite (p) has partly replaced feldspars of the granodiorite. Transition zone between normal granodiorite and garnet-diopside tactite at South Hill, Daly Gulch. X 82, crossed nicols.

Figure 33. Sheaves of radiating tremolite in transition zone at intrusive contact (adjacent to area shown in figure 32). Partly altered granodiorite (gd) is shown at right. X 26, crossed nicols.

Figure 35. Boundary between garnet tactite (g) and diopside rock (d). From rock section shown in figure 34. Sheaves of pargasite (p) are perpendicular to boundary. Note calcite-filled fractures normal to zoning in garnet. X 26, plain-polarized light.

Figure 37. Actinolite-magnetite tactite from Trilby tunnel. Actinolite (a) bends around magnetite (m): pennine (p) at boundary. X 82, plain-polarized light.

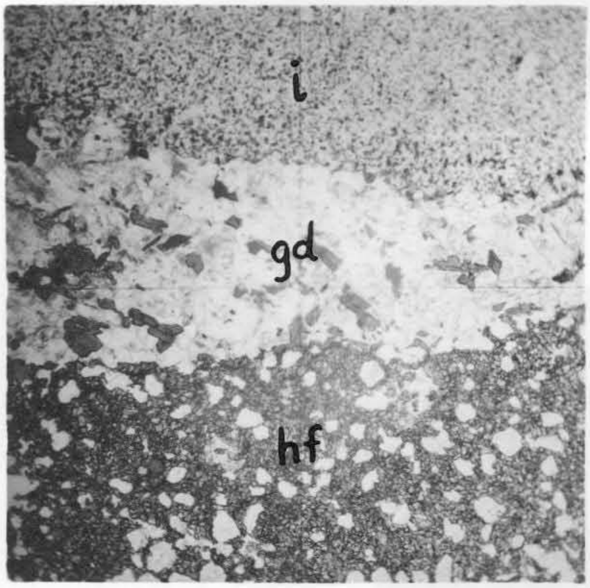


Figure 29

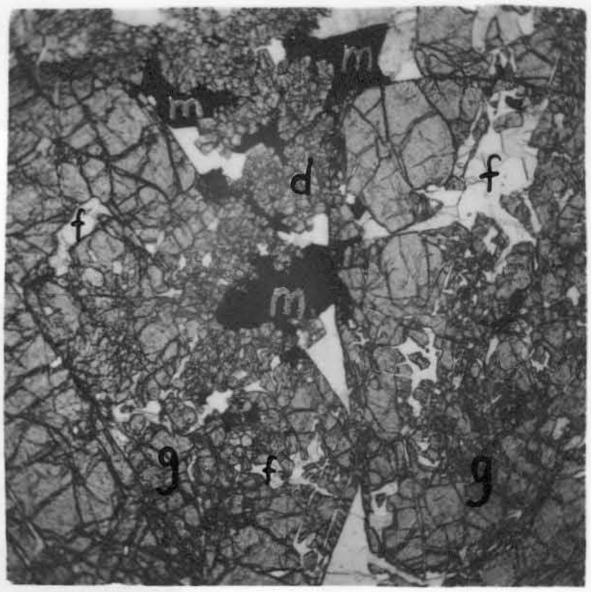


Figure 31

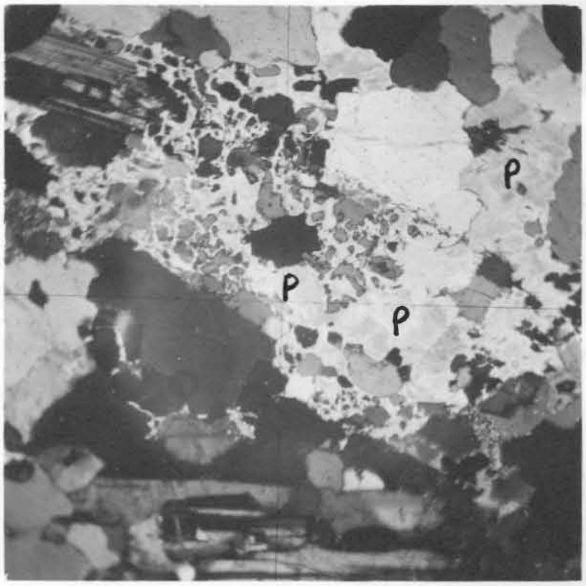


Figure 32

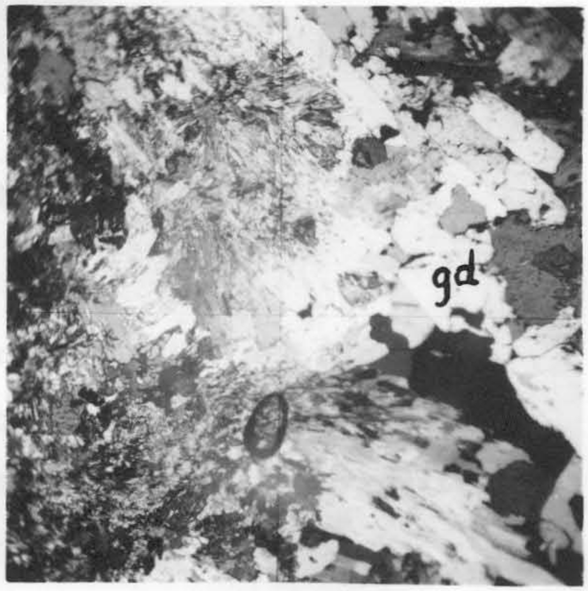


Figure 33

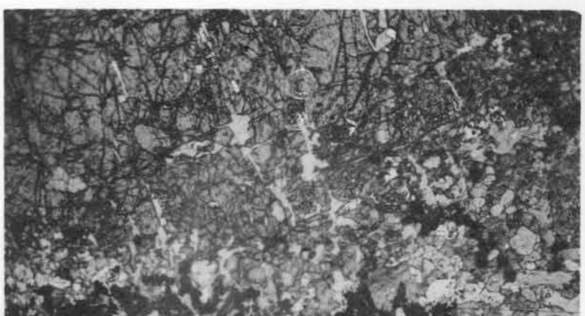


Figure 35

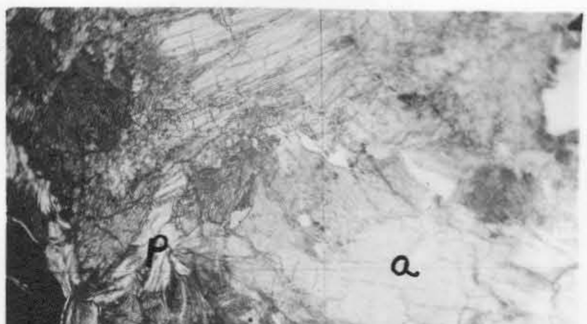
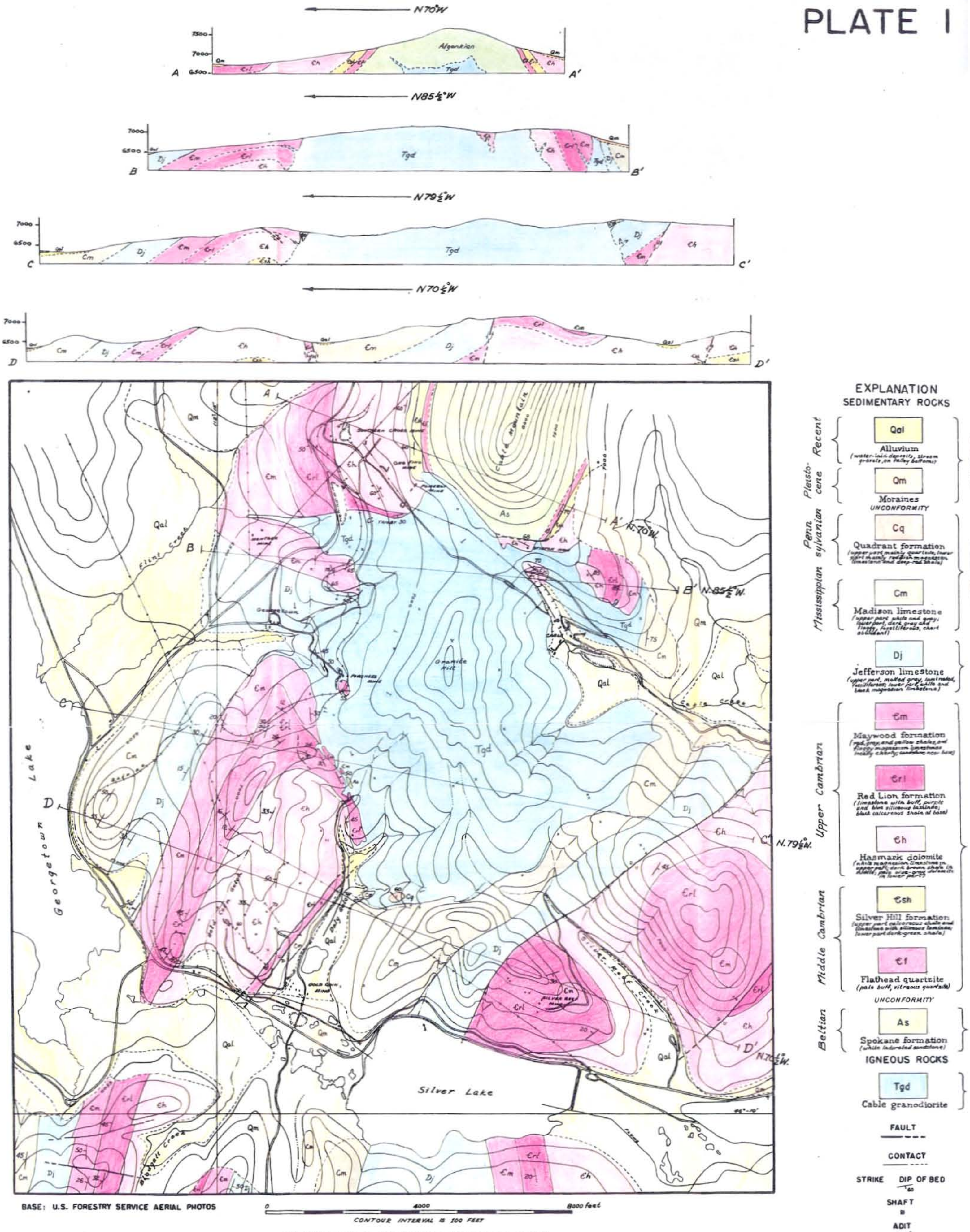


Figure 37

Figure 34

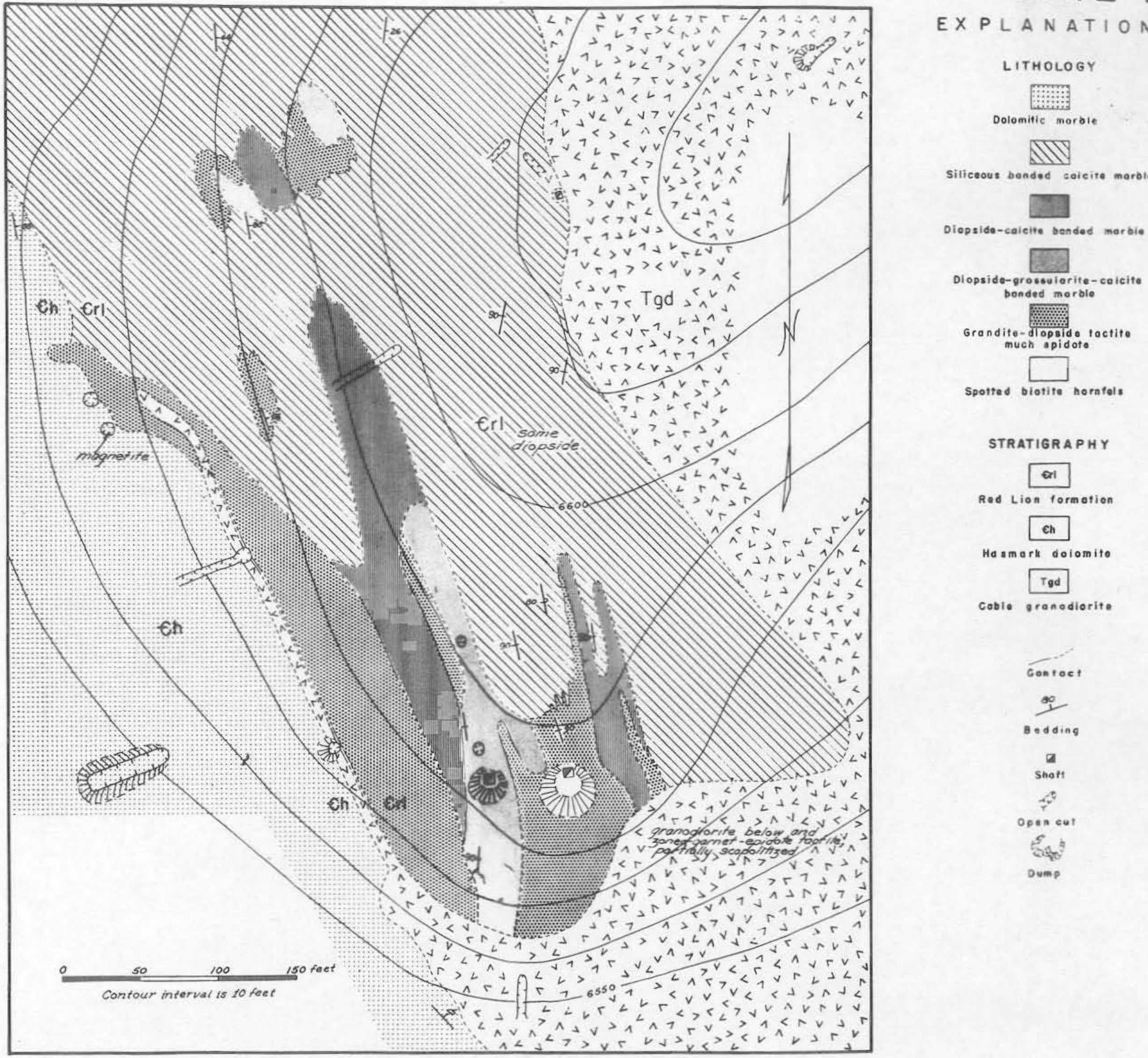
Figure 34. Boundary between garnet tactite and diopside rock of the Red Lion formation, South Hill, Daly Gulch area. Note sharpness of boundary marked by pargasite. Diopside contains clots of white calcite. 2-inch eraser gives scale.

PLATE I



GEOLOGIC MAP OF THE CABLE STOCK AREA
DEER LODGE COUNTY, MONTANA.

PLATE 2

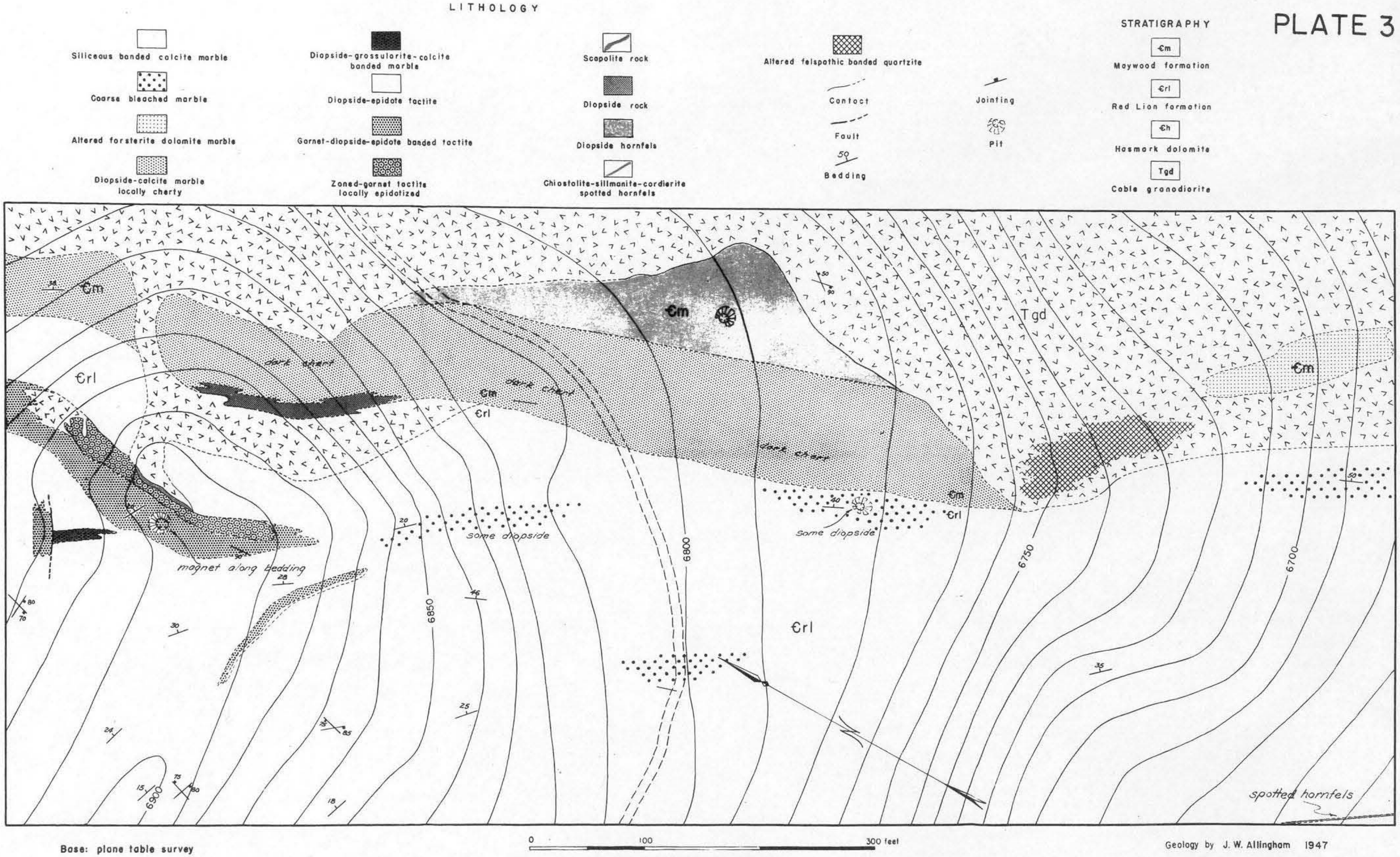


Base: plane table survey

CONTACT OF THE CABLE STOCK AT SOUTH HILL, DALY GULCH

Geology by J. W. Allingham 1947
W. T. Holser 1948

PLATE 3

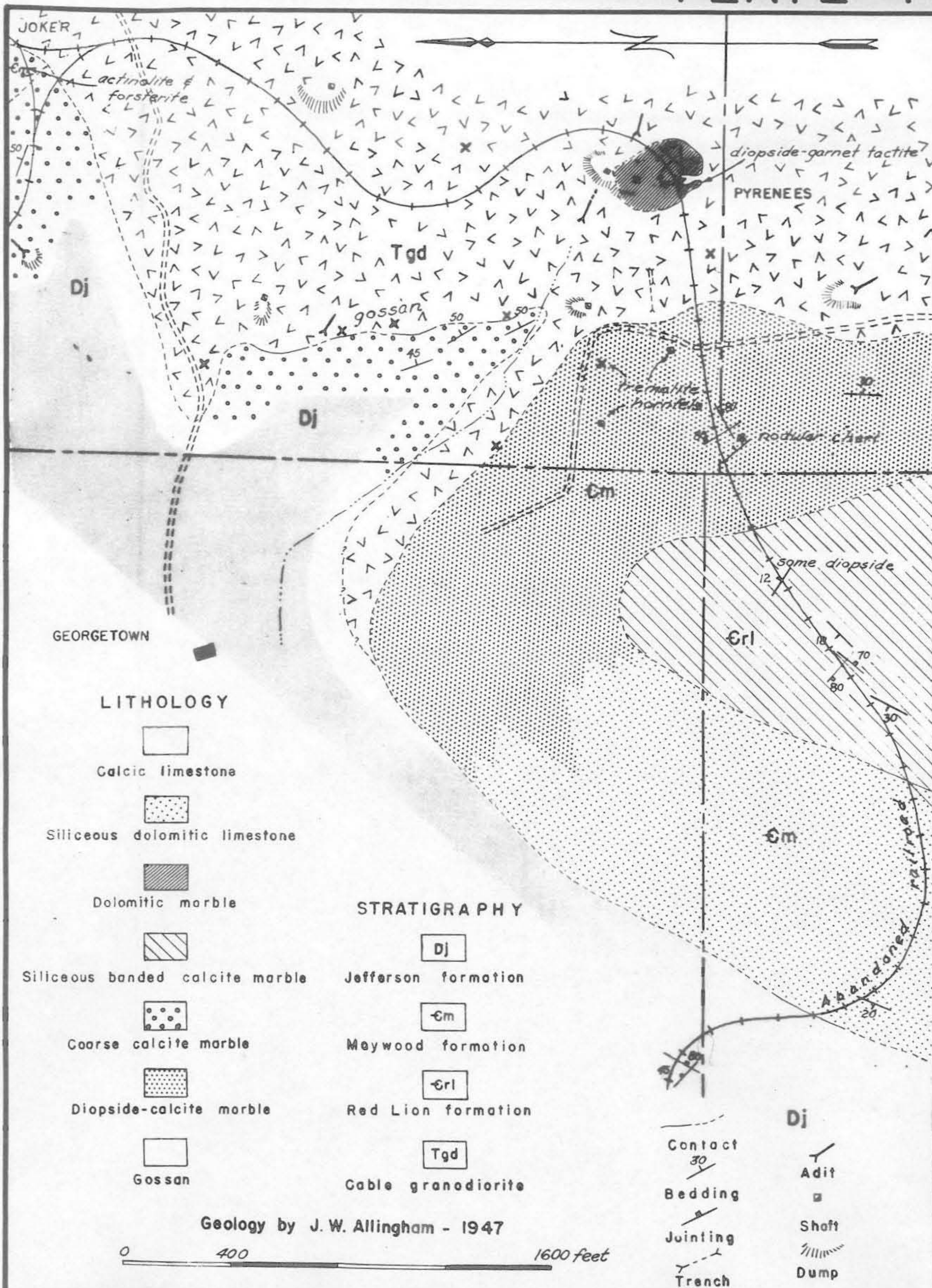


Base: plane table survey

Geology by J. W. Allingham 1947

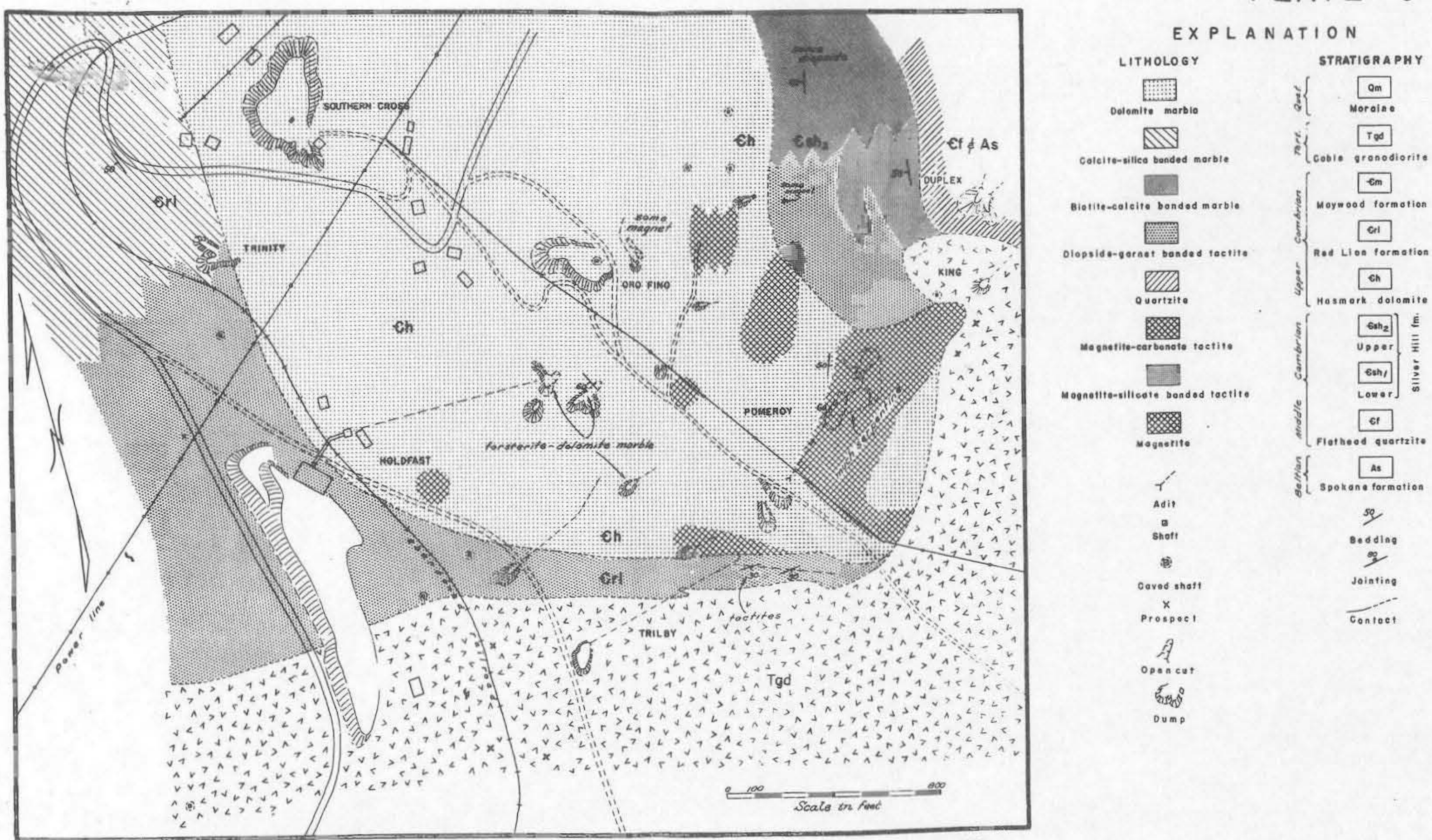
CONTACT OF THE CABLE STOCK AT NORTH HILL, DALY GULCH

PLATE 4



CONTACT OF THE CABLE STOCK
PYRENEES AREA

PLATE 5

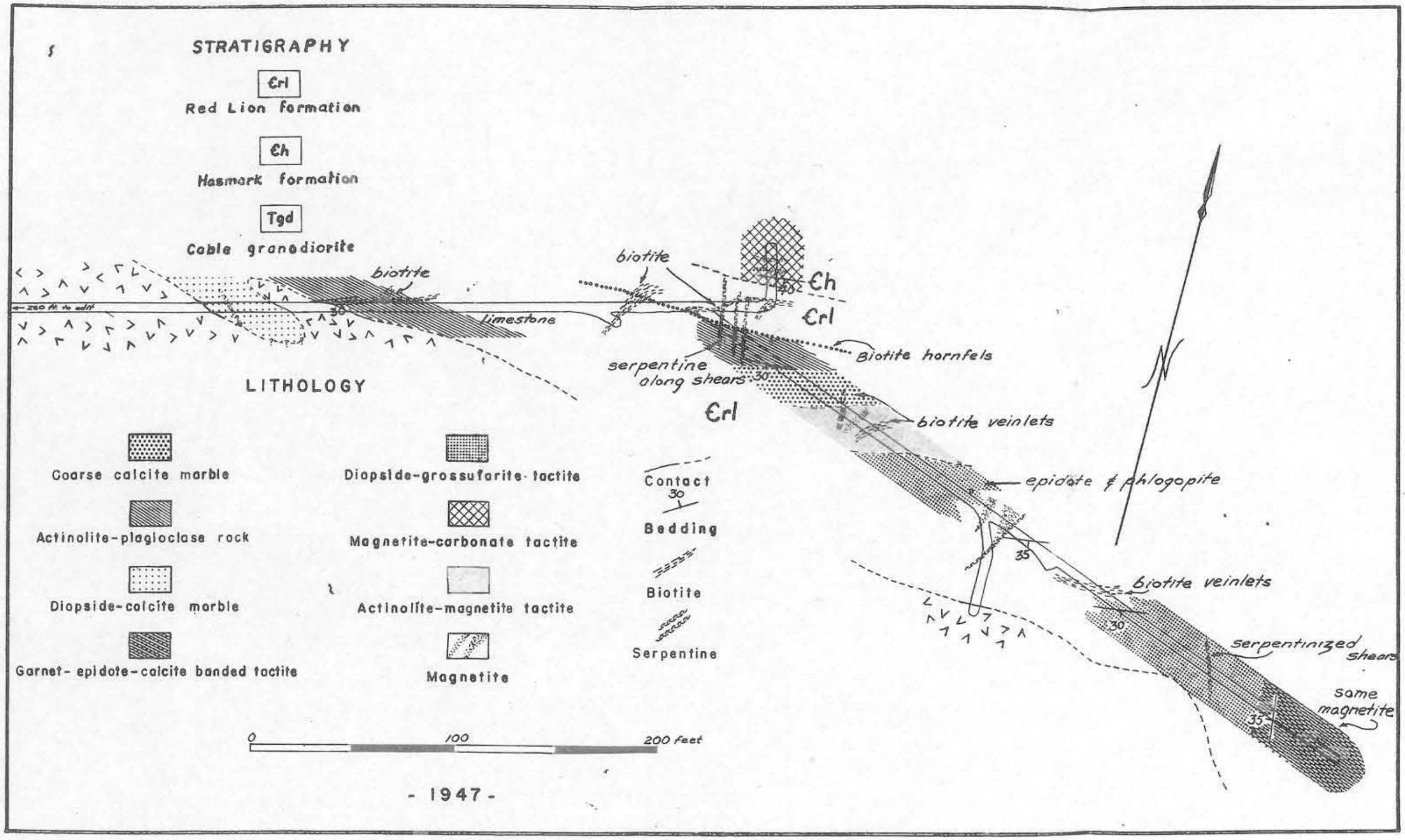


Base compiled from: U.S. Bur. Min. map 1944
U.S. Land Office mineral surveys
U.S. Forestry Service aerial photos
B.A.&P. Ry. map

METAMORPHISM IN THE SOUTHERN CROSS AREA

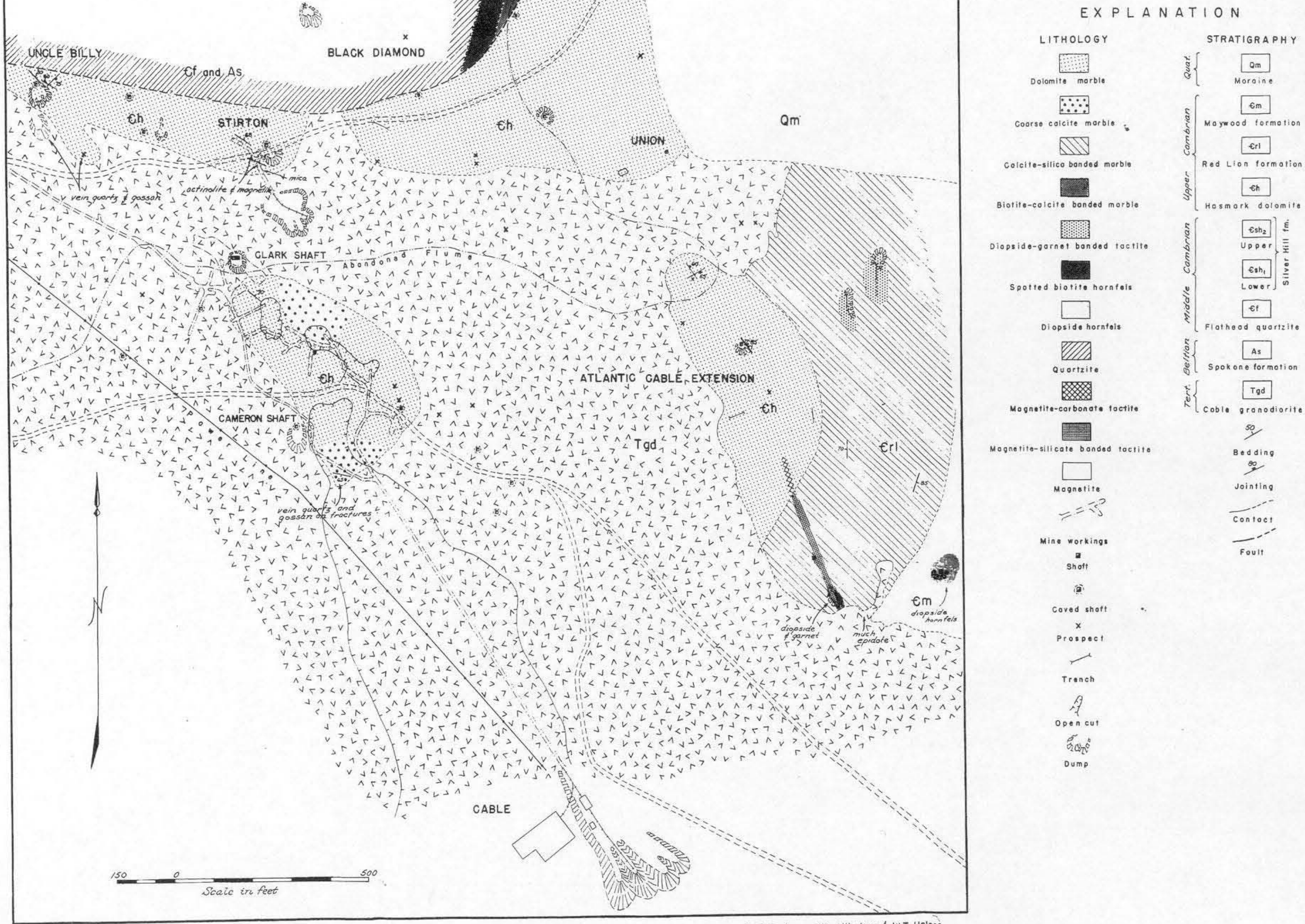
Geology by J. W. Allingham 1947
W. T. Holser 1947-48

PLATE 6



Portion of the Trilby Tunnel – Southern Cross area

PLATE 7



Base compiled from U.S. Land Office mineral surveys
U.S. Forestry Service aerial photos

METAMORPHISM IN THE CABLE AREA

Geology by J.W. Allingham & W.T. Holser
1947