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THE GOSSAN OF A LEAD DEPOSIT IN LIMESTONE
YUKON TERRITORY

by
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P R E F A C E

This thesis is based on the field occurrence and laboratory investigations of numerous mineral, rock, and limonite specimens from the Star Group of claims in south central Yukon. The writer supervised the prospecting, staking, and exploration of the claims, and assisted Dr. D.R. Derry in compiling the geological map. The writer wishes to thank the management of Western Ranges Prospecting Syndicate for permission to make full use of the information and material obtained during this time, and in particular to thank Dr. Derry for making available copies of his geological map.

Thanks and appreciation are also extended to Dr. H.C. Gunning, under whose direction this study was carried out, for his suggestions and assistance. Dr. V.J. Okulitch advised in the matter of taking photographs and Dr. K. deP. Watson assisted in petrography. Acknowledgement is due to J.A. Donan, laboratory technician in the Dept. of Geology, U.B.C., for his interest and experimentation in devising a satisfactory method of preparing thin and polished sections of weathered specimens, and for his assistance in making them.

The results obtained in this study could not have been achieved without the co-operation of these people.

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A B S T R A C T

The interpretation of leached outcrops as guides to the specific minerals from which they were formed has been developed to a rather high degree by earlier workers, among whom Boswell and Blanchard deserve particular mention. In the present work, a gossan that led to the discovery of a lead deposit is described. Since many hand specimens of the limonite from this gossan lack the characteristic boxwork structures described by the authors above, microscopic investigations of thin and polished sections were carried out. However, the gossan is classified into six types mainly on the basis of its physical properties. At least three of these are correlated with types described by Boswell and Blanchard, one of pyrite derivation and the others from galena.

The relative solubility of different limonite types in dilute HCl was not found to be of as much value as some writers have indicated.

The mineral deposits to which the limonite pointed the way have not been sufficiently exposed to allow detailed study, but the presence of tremolite and phlogopite in an area of disseminated mineralization indicates that this portion at least may be of contact metamorphic origin.

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I N T R O D U C T I O N

STATEMENT OF THE PROBLEM

During the 1945-46 term at the University of British Columbia, the writer was introduced to the subject of "Leached Outcrops" in a course in Economic Geology. While prospecting in the summer of 1946, a practical field example was encountered, which illustrates some of the problems of this subject, as well as the benefit which might be derived from its further study.

A typical piece of "limonite float" from the surface of a leached outcrop of a mineral deposit is shown in Plate 1. A typical specimen of the partially oxidized or leached mineral deposit, which was found about 4 feet below, is shown in Plate 2. The former appears to give no indications as to its origin, while the latter contains abundant fresh galena as well as a boxwork structure reminiscent of the cubic cleavage of galena.

It was therefore decided to carry out a laboratory investigation of numerous mineral specimens from this deposit in an attempt to arrive at some definite conclusions as to their origin, and the possible significance of the various limonite types.

To do so, it was deemed advisable to describe first the environment of the limonite, and the known mineral deposits to which some of the limonite pointed the way. Accordingly, the first part of this report covers the geology and mineralogy of the area, while the latter portion deals with the study of the various types of limonite.

LOCATION

The Star Group of claims is situated in the Dawson mining district of Yukon Territory, about five miles north of the B.C. - Yukon boundary, and about $2\frac{1}{2}$ miles south of Mile Post 702 on the Alaska highway. (See Map No. 1, in pocket.)

The claims cover a group of low-lying hills on the eastern contact of the Cassiar batholith. These hills reach elevations of about 4400 feet, while the immediately adjacent valley floor has an elevation of about 3600 feet. The elevation of the Rancheria River, which flows easterly through the Cassiar Mountains, is about 2900 feet at mile 702.

PROSPECTING

These claims were staked in the summer of 1946 by prospectors working for the Western Ranges Prospecting Syndicate.

The first indications of mineralization found by the prospectors consisted of numerous patches of "limonite float" scattered over a number of the bare hills in a restricted area of about 6,000 feet long and 600 feet wide close to the intrusive contact. On closer examination, some of this was found to contain occasional grains of fresh galena. After examination by the author, it was decided to explore the ground more thoroughly to attempt to find the source of the limonite. The following points favored this decision:

(1) Occasional specks of fresh residual galena were found in some pieces of limonite.

(2) A small amount of near surface, loose, rock debris was found to contain a small percentage of galena in tiny veinlets or as disseminated grains.

(3) The source of the limonite appeared to be local. None of this float was found on the surface of the bare intrusive mass immediately to the west, and it was considered that if the limonite had been transported and deposited by ice, some of the limonite should also have been found on the surrounding area. Further, a local source was postulated by Lord (9).

(4) Some of the limonite "looked" similar to certain types described by Bateman (2) as having been derived from metallic sulphides. The author was not sufficiently

familiar with these limonite boxworks to state definitely their derivation.

(5) The district was apparently favorable for the location of lead-zinc deposits. Mineralization along the eastern edge of the Cassiar-Omineca batholith has been known for some years near such localities as Manson Creek, Ingenika River, and McDame Creek. In the vicinity of the Alaska highway, Lord (9, p. 16-18) reports galena and sphalerite at three localities, one about twelve miles north of the highway and two others at five and seven miles south of the highway, all close to the intrusive.

(6) Limestone and dolomite, which underlie the limonite float, form favorable host rocks for numerous important lead-zinc deposits in many parts of the world.

GENERAL GEOLOGY

The following is a summary from Lord's report (9) of the regional geology covering a narrow strip along the eastern edge of the Cassiar-Omineca batholith extending several miles north and south of the Alaska Highway.

The sedimentary rocks consist mainly of light gray limestone and buff-weathering dolomite, but include some argillite, slate, phyllite, quartzite, and schist. Fossil corals indicate that some of this group is probably of Carboniferous age.

Schistose limestone and dolomite are prominent north of the highway, but were not noted south of the highway.

Locally, along the granitic contact, some of the rocks of this group have been conspicuously altered by contact metamorphism across a zone which is generally less than 200 feet wide.

Most of these formations have a strike nearly parallel to the edge of the batholith and dip about 45 degrees away from it. However, near the highway the beds strike in many directions and some are nearly flat-lying.

The Cassiar-Omineca batholith is about 14 miles wide in this region, and has a north-northwest trend. It is light gray, massive, medium to coarse-grained granite to granodiorite, but the common variety is probably biotite-quartz monzonite. Numerous aplite dykes, and a

few pegmatite and lamprophyre dykes cut the intrusive. Gneissic phases with foliation and banding striking parallel to the border were noted along the western edge of the intrusive. Locally along the eastern edge, the rock within several feet of the contact is fine-grained, and contains very little dark minerals.

Under the heading of "Metallic Mineral Deposits", Lord (9, p.17) reports:

"Botryoidal limonite float is abundant about 2 miles south of the highway at mile 702. It occurs in drift overlying dense, white, buff-weathering dolomite or limestone, or both, within a few hundred feet of the edge of the granitic batholith and has probably not been transported more than a few feet. The area of limonite float parallels the granite contact for more than 1,000 feet. One specimen of nearly solid, dark brown limonite assayed; gold, 0.005 ounce a ton; silver, 0.79 ounce a ton; tungsten, nil."

No mention was made of the presence of galena here, but on p. 19 Lord (9) further states:

"Most known mineral deposits in the map area lie within the limestones, dolomites, and associated rocks of Group C close to the eastern edge of the Cassiar batholith, that is north and south of the highway at about mile 701. This section contains gold, silver, copper, lead, zinc, tungsten, and tin, and clearly warrants further prospecting."

GEOLOGY OF THE STAR GROUP

In the area covered by the Star claims, Paleozoic sediments of clastic and chemical deposition are folded or domed to form a southerly-plunging anticlinal structure. (Map No. 1) These are intruded by the Cassiar-Omineca batholith which is considered by Lord(9) to be of Jurassic or later age. An irregular mass of quartz-feldspar porphyry also intrudes some of the sediments, but the relation of this to the main batholithic intrusion is not known. It is assumed by the writer, however, that this may be a later off-shoot genetically related to the main intrusive.

The contact of the batholith with the sedimentary strata, coincides fairly closely with, and is locally defined by a continuous depression or valley. Several summits in this trench direct the local drainage in the two opposite directions. Since the sediments dip towards the batholith, and contact metamorphic minerals were not noted in this vicinity, Dr. Derry considered that the contact trench might be the surface expression of a fault between the batholith and the sediments, along which mineralizing solutions may have penetrated or deposited. The color and taste of the water, and the brown rust on plants in the upper reaches of Iron Creek, are further evidence that a mineral deposit may be located in a

possible fault zone below the pond from which the creek is fed.

Outcrops are numerous above the tree line, which is at an elevation of about 3900-4000 feet in this area. The overburden consists of soil and grass in places, but mainly of residual rock fragments and particles broken and weathered from the underlying strata. Glacial erratics consisting principally of granitic boulders, which were probably transported from the Cassiar batholith, are present to the tops of the hills. However, there is no general mantle of glacial debris, and most of these erratic boulders are above the size of pebbles. Apparently, the smaller particles of glacial drift, which may have been spread over the area at one time, have been washed off these hills into the valley.

Short veins of pure, white to transparent calcite are exposed in some of the limestone outcrops. In two localities near the tree line, narrow barren quartz veins cut a lower sandstone member.

TABLE OF FORMATIONS (1)

Jurassic or later.	{	Quartz Feldspar Porphyry
	{	Cassiar Batholith
Carboniferous or Devonian	{	Charity Hill Limestone
		Cal Gray Limestone
		Faith Limestone
		Shale
		Gray Limestone
	{	Banded Argillaceous Sandstone.

In the valley of the Rancheria River, outcrops of mica schist are widespread, and these strata presumably underlie the series listed above.

(1) Mapped and compiled by D.R. Derry, Geologist for Ventures Limited..

DESCRIPTION OF FORMATIONS

BANDED ARGILLACEOUS SANDSTONE

These strata were originally mapped as limestone, but further examination of the single representative sample available, collected from Claim 4, point Y, proves it to be an impure sandstone. The rock is dark gray in color and exposed surfaces show bands or laminae that weather differentially to produce ridges up to $\frac{1}{4}$ in. thick. The finely laminated nature of this rock is quite distinctive even in freshly broken specimens.

In some places where the contact between this and the Gray limestone above is exposed, the sandstone member is seen to be locally folded and twisted whereas the Gray limestone is not. Such a relationship suggests a local nonconformity. However, since their attitudes are generally similar throughout the mapped area, it may be that no unconformity exists here. Possibly the Gray limestone was less competent at the time of folding, and was deformed by flowage.

In thin section, the laminated structure is seen to be due to the variation in composition of the different laminae, as well as grain size variations. Anhedral quartz grains about .1 mm. diameter predominate, but some are as large as .5 mm. These have been highly recrystallized, as proven by their compaction and

interpenetrating contacts.

An unknown mineral (Cordierite? or Anorthoclase?) which appears very similar to quartz and also forms tight interpenetrating contacts with it, forms possibly 10% of this specimen. It has a pale pinkish tinge, is slightly sericitized, and apparently lacks good cleavage. Other optical properties are: $n=1.53$; $2V=40^\circ$; negative; $B=.006$; Occasional grains resemble Carlsbad twins, and in these the optic plane is normal to the twinning plane. Most grains are slightly larger than the quartz grains, some are rimmed with quartz, and some contain tiny inclusions of actinolite?

Brown biotite and green actinolite make up about 20% of the rock, and diopside is present in smaller amounts. Since these minerals would not normally be found to such an extent in a fine-grained sandstone or quartzite, it is likely that locally, at least, this member has been highly altered during the intrusion of either the Cassiar batholith, or the quartz feldspar porphyry stock, or both, and that the introduction of most of these minerals was due to metasomatic replacement at fairly high temperatures.

Pyrite and magnetite form more than 3% of the thin section, and a slight amount of brown iron stain may be attributed to them. Irregular grains of pyrite are more or less concentrated along certain bands or veinlets, and

This also contributes to the lamination. Apatite, titanite and chlorite are present in minor amounts, the latter near areas of pyrite.

GRAY LIMESTONE

This is a light gray rock which weathers to a darker gray. When freshly broken it has a mottled appearance. Occasional coarse calcite grains, sometimes resembling phenocrysts in an igneous rock, may be seen in the fine-grained dense "groundmass" which shows vague bedding or foliation.

In thin section, fine-grained (less than .1mm) compact calcite grains form a matrix for larger crystal grains or oolitic-appearing areas of coarser grained calcite. A Planar structure is apparent in the "groundmass" as well as in the elliptical shapes and lineal arrangements of the larger grains. This may be due to foliation, or it may represent bedding since the lineation tends to flow around some of the larger grains. A minor amount of clastic quartz is present as small irregular grains.

FAITH LIMESTONE

This is a dense, fine-grained grayish-white rock that weathers on all exposed surfaces to a buff or rusty color. The rock appears massive, with a lack of bedding or

foliation in the hand specimen. Even in well exposed outcrops, it is often difficult to distinguish between bedding and fracture systems.

A thin section showed fine-grained (less than .1 mm.) compact carbonate grains, with an occasional veinlet of later (?) coarser (.5 mm.) calcite.

These strata underlie most of the hills covered by the claims, and form the host rock for all the known mineralization. While outcrops are numerous, most of this area is covered with a foot or two of loose fragments and particles consisting mainly of the underlying Faith limestone.

In view of the possibility that the composition of this member may have been more favorable than the underlying Gray limestone for the precipitation of the ore minerals, comparative tests were made to determine what differences did exist. In HCl, and HNO₃, the Gray limestone effervesced freely and dissolved readily, while the Faith limestone effervesced slowly and dissolved with difficulty. An equal amount of each was dissolved in acid, and after filtering off the precipitates caused by the addition of ammonia, the filtrates were tested under similar conditions for the presence of calcium and magnesium. Ammonium oxalate gave two successive precipitates in the Gray limestone,

and only one in the Faith limestone, proving the presence of more calcium in the former. Sodium ammonium phosphate gave no precipitate in the former, but did in the latter, which proves the absence of magnesium in the Gray limestone and its presence in the Faith limestone. Three specific gravity tests on each gave consistent values of 2.70 for the former and 2.82 for the latter. These results, combined with the typical buff weathering color of the Faith limestone, would seem to indicate that it is fairly pure dolomite, while the Gray limestone is fairly pure calcite.

Associated with some of the surface patches of limonite float, and in some cases without any limonite, are patches of light brown pieces of Faith limestone debris. This material is highly fractured, and criss-crossed with tiny dark brown veinlets. (See Plate 3). This rock has been designated "Fractured Faith limestone." Thin and polished sections prove that the veinlets are due to euhedral grains of pyrite disseminated along tiny fractures. The pyrite has been almost wholly altered to metallic limonite, and a brown iron stain permeates the carbonate along the fractures. Very slight movement along some of the fractures is indicated by offsets of cross veinlets. No quartz was found in the thin section of this material.

Another rock type included here has been termed "Brecciated Faith limestone". It consists of angular fragments of normal grayish-white Faith limestone up to about $\frac{1}{2}$ inch in maximum dimension, embedded in a fine-grained matrix which is stained slightly yellowish but also contains small, more or less circular areas of white calcite. (See Plate 4). On exposed surfaces, differential weathering has caused greater erosion of the matrix so that the breccia fragments stand out in relief. This rock occurs in loose debris as well as in place, and was found to be generally closely associated with areas of limonite float, or adjacent to calcite veins. In thin section, the breccia fragments are seen to consist of a large number of tiny, closely packed grains, which are actually considerably smaller on the average than those in the groundmass. The borders of the fragments are quite definite, and a slight concentration of a light brown stain may be seen just outside their boundaries. No quartz was seen in this rock.

CAL GRAY LIMESTONE

This is a dark gray rock which is cut by fairly numerous calcite veinlets. No specimen was available for further study.

CHARITY HILL LIMESTONE

This is a gray crystalline limestone or dolomite that weathers pinkish buff. It contains at least two fossiliferous bands that weather to a rusty red-brown color. Thin sections of the fossiliferous material contain fine- to medium-grained carbonate mixed with quartz, black carbonaceous and kaolinic material, and smaller amounts of tiny mica flakes. The quartz forms about 5% of the rock and consists of angular to rounded clastic grains between .1mm. and .3mm. diameter. The rusty weathering is confined to a fairly sharply defined surface layer less than 2 mm. thick.

After examination of the thin section, Dr. Okulitch of this University stated that the structure was too greatly altered by recrystallization to determine the genus. Dr. M.A. Fritz of the Royal Ontario Museum tentatively classified other specimens from this band as Ordovician corals.

CASSIAR/OMINECA BATHOLITH

In the vicinity of the Star Group, the batholith is a medium- to coarse-grained grayish rock, and is cut by numerous small, white to pinkish aplite dykes. No specimen of this material was available for thin section examination, but Lord (9, p.13) states that it varies from a granite to granodiorite, and is predominantly a

biotite-quartz monzonite.

Trench 3-13 (See Map 1) was dug in an attempt to expose the contact of the batholith and the Faith limestone, but the drift-filled depression proved too deep. However, a small specimen of loose rock, which showed a contact between two rock types, was collected here and studied in thin section. It appears to be the contact between a fine-grained aplite dyke, and a border phase of the batholith which contains very little dark minerals. The dyke contains extremely fine-grained quartz, albite, and microcline, with occasional albite and microcline phenocrysts less than 1 mm. across. At the contact there is a sudden change in texture to medium- to coarse-grained albite, orthoclase, microcline, and quartz. Much of the feldspar is clouded with kaolin, and a small amount of sericite is present. Muscovite forms about 2% of this portion, and a very minor quantity of magnetite was noted. It is likely that this loose specimen had been transported only a few feet from the batholith.

QUARTZ FELDSPAR PORPHYRY

This is a grayish-white rock containing prominent quartz phenocrysts from about $1\frac{1}{2}$ to 3 mm. diameter in a fine-grained groundmass. Numerous smaller feldspar phenocrysts, up to about $1\frac{1}{2}$ mm. long, show up readily in thin section, but are rather difficult to discern in hand specimens.

Thin sections show two main sizes of quartz phenocrysts, the largest group varying between about $1\frac{1}{2}$ to 3 mms., while another group seems to be about .3 mms. diameter. There appears to be very little gradation between these two main sizes, and it is possible therefore that following the first quiescent period during which the larger phenocrysts formed, there was a further upward intrusion of this material, followed by another possibly shorter period of quiescence during which the smaller quartz phenocrysts formed.

The feldspar phenocrysts are predominantly albite but a small number are orthoclase. Kaolinization is quite pronounced in these feldspar phenocrysts, especially near their borders, while the feldspar in the fine-grained groundmass is relatively clear. However, the reverse is true of sericite, which is much more fully developed in the groundmass.

A colorless mineral that may be hydromuscovite (damourite) forms about 2% of the slide. It occurs in tabular to lath-shaped crystals from about .1mm. to $1\frac{1}{2}$ mm. long. Other optical properties are: uniaxial; negative; $n=1.58$; $B=.033$; one cleavage; parallel extinction; length-slow. Euhedral pyrite crystals make up less than 1% of the rock, and are always contained inside the damourite? The pyrite is partially oxidized to a red

semi-transparent limonite, and a light yellow stain invariably extends outwards to color part of the otherwise colorless damourite? These light yellow areas are then slightly pleochroic, and the addition of iron has apparently changed the composition to another unknown mineral with a slightly higher index and a more twisted mat appearance.

MINERAL DEPOSITS

Surface trenching exposed three widely separated veins or mineralized shears containing massive, coarsely crystalline galena.

VEIN NO. 1 (See Map No. 1)

The largest vein was exposed by trench 6-3 on the N.E. side of Faith Hill. Here, fresh massive galena was found in places within 3 feet of the surface. The vein zone was traced for a length of 160 feet along its strike of N 25°W that more or less parallels the batholith contact. The average dip is about 70° easterly, i.e. away from the contact. The vein zone itself pinches and swells, and the galena occurs in lens-like bodies, up to about 12 inches thick. Where the galena lenses out, the vein zone continues and is readily traced by a soft sooty, brownish, or bluish-black material that crumbles like a soft soil in the central portion of the zone. In some cases this soil-like material contains a few tiny specks and grains of

fresh galena. The walls on either side of the narrow zones are relatively solid but are more or less completely permeated with the black mineral.

Blowpipe and chemical analyses confirmed the presence of manganese, iron, CO_2 , and water in this black material. It is probably a mixture of hydrated manganese and iron oxides replacing the original Faith limestone.

Continuing outwards from the vein, the country rock passes from this black rock to a brownish rock and grades into normal Faith limestone. The manganiferous material is considerably less evident in the walls adjacent to the galena lenses.

Thin sections were successfully made that show the black opaque material replacing the carbonate.

Trenching at this locality was suggested because of the presence of surface limonite float. No residual galena was seen in any of this float, nor was there a very large quantity or patch of it in evidence. However, when the first test pit showed the black soil-like material, this was followed and the whole mineralized vein zone exposed. The overburden here, as over most of the treeless hills consists principally of residual products of weathering of the immediately underlying strata, which produces a certain amount of soil mixed with loose country rock fragments. Occasional granitic boulders greater than

six inches in diameter seem to be all that remains of any earlier glacial debris.

VEIN NO. 2

This vein, striking N 13°W and dipping 68°W, was exposed in trench 1-1 near the top of Guy Hill about 2,000 feet north-west of Vein No. 1. The vein zone is traceable over a length of 65 feet by the same black manganiferous material as exposed in Vein No. 1. This trench was again prompted by the presence of surface limonite float, which in this case showed an occasional speck of residual fresh galena. When the top 1½ feet had been removed, the black manganiferous material showed up, and further digging exposed galena in place about 3 feet below the surface. The transition from surface limonite through limonite in place to galena in place was quite evident here.

VEIN NO. 3

In trench 1-6 near the bottom of Guy Hill on its N.W. corner, a short vein, containing a 2-4 inch width of fresh to oxidized galena along a 4-6 inch band of limonite, dips flatly to the south-west. The surface limonite here showed only a very occasional speck of galena, and the galena in place was found about 3 feet below the surface.

AREA OF DISSEMINATED MINERALIZATION

Limonite float containing a few grains of fresh galena, directed attention to the area between trenches 3-6 to 3-8 near the bottom of Faith Hill on its north-west corner. Trenching exposed poorly-defined areas containing disseminated galena in fairly fresh country rocks. In some cases a small amount of sphalerite accompanies the galena, as well as minor amounts of pyrite. Some of this galena occurs as small grains in fracture cleavage joints in the Faith limestone, and it is also common in tiny veinlets.

In trench 3-6, fresh, disseminated pyrite with no other metallics forms up to about 10% of the rock in a small area. Specimens were obtained about 7 feet below the original surface where the host rock was also quite fresh. In hand specimens, this rock is more coarsely crystalline and lighter colored than the normal buff-weathering Faith limestone. Thin sections of this material consist predominantly of medium-grained (about .3mm.) carbonate, but also contain appreciable amounts (possibly 10%) of very pale phlogopite and almost colorless tremolite, and smaller amounts of almost colorless chlorite. Quartz is a minor constituent, but since some grains are long (about .2mm.) and narrow and have irregular outlines, it is probably hypogene.

The pyrite is euhedral to anhedral, and is uniformly disseminated throughout. Phlogopite contains numerous

carbonate inclusions, indicating replacement. Kaolinic material is sometimes associated with phlogopite and chlorite, indicating that the original rock was somewhat argillaceous. The apparent lack of typical contact metamorphic silicates along the batholith contact (See page 7) is not surprising, since the tremolite and phlogopite are about the same color as the carbonate and are not recognized in an ordinary hand specimen. They do show, however, on a flattened or ground surface. These minerals were probably formed by contact metasomatism when heated solutions or vapors reacted with the host dolomite during or following the intrusion of the Cassiar batholith. Possibly the pyrite and quartz were also introduced at this time.

Probably this whole area of disseminated mineralization represents an ill-defined contact metamorphic deposit. It is about 500 feet from the closest exposure of the batholith.

No definite mineralized zone could be outlined in this area, and no gradation from the limonite to mineralization in place could be noted. Within a foot or two of the surface, in the loose weathered mantle, fresh country rock fragments were found to contain small percentages of disseminated fresh galena.

LIMONITIC AREAS

Numerous trenches and pits were dug on or near other areas of limonite float, but no further mineralization in place was found. In some of these, such as trenches 3-10 and 3-11, a small amount of the black manganese oxide material was found in place with limonite in vein zones with relatively solid walls. About 50 feet east of trench 3-10 an occasional piece of country rock float contains a minor amount of disseminated fresh galena.

MINERALOGY

Assays of the massive galena, from the three veins indicated values in silver averaging about one-third of an ounce per unit of lead. Polished sections were prepared in an attempt to determine the source of this silver, since it is unlikely that this amount of silver could be held in the galena in solid solution. A mineral that may be a silver sulpho-salt was found in very minor amounts and in such small areas that it could not be dug out for micro-chemical tests. (Plate 5.) It is light gray in color, is slightly harder (about C-) than galena, and is isotropic or very weakly anisotropic. Oblique illumination did not show any internal reflection, but the small size of the mineral renders such tests unreliable. The following etch tests were obtained:

HNO ₃	HCL	KCN	FeCL ₃	KOH	HgCL ₂
Pos.	Neg.	Pos.	Neg.	Neg.	Pos.

No other sulphides or primary minerals were found with the fresh massive galena from No. 1 Vein. There was not a great deal of limonite here, but a polished section containing a small amount of weathered material in contact with fresh galena shows the alteration in this case to have been first anglesite, and then a brown, powdery limonitic material (Plate 6.) The band of anglesite is about $\frac{1}{8}$ inch wide and was proven by blowpipe tests for lead and sulphur. The limonitic material gave positive iron and sulphate tests, but no lead. It may be that this is Jarosite.

In the partially weathered galena from Vein No. 2 a small amount of pyrite was found in polished section. The galena here is also surrounded by anglesite.

Sphalerite has been found in small amounts in fresh rock only, from the area of disseminated mineralization. It is associated with galena in tiny veinlets or fractures. (Plate 7.)

Pyrite could also be detected in hand specimens in the fresh Faith limestone only, where it occurs as disseminated grains and euhedral crystals up to about $\frac{3}{16}$ inch across. Some of these crystals have been almost completely altered to metallic limonite, while the rock is only very slightly iron stained. (Plates 8 & 9). Polished sections of numerous specimens of limonite revealed occasional small residual areas of pyrite, but these could not be seen with a hand lens.

Quartz was conspicuous by its absence in all of the mineral deposits as far as explored in the field. However, thin sections of specimens from the area of disseminated mineralization proved the presence of a small amount of hypogene quartz. Some of the limonite from the gossans of the deposits also contain hypogene quartz. Polished sections of the black manganiferous material from Vein No. 1, revealed a white metallic mineral forming narrow, irregular veinlets in the soft, black, non-metallic wad. (Plate 10). The metallic mineral is also widely disseminated throughout the wad in microscopic grains. Under the binoculars, it is seen to be a coherent, powdery mixture of metallic grains. It may represent more than one mineral, since positive tests were obtained for iron, manganese, and sulphur.

DESCRIPTION OF LIMONITE

The discovery of mineralization in place beneath or very close to four separate areas of surface limonite float indicates that the majority of the other widely scattered areas of limonite were also formed very close to their present position from pre-existing metallic sulphides.

It is not the purpose of this work to hazard an opinion as to whether this limonite indicates a commercial orebody, but it is felt that further mineralization could be reasonably expected beneath some of the other areas.

In examining the limonite, both in the field and in the laboratory, it became evident that the limonite was not all of one kind. Therefore it was felt that laboratory investigations of the various types, coupled with their occurrences in the field, might form a worthwhile study. The remainder of this report is directed to that end.

TYPE NO. 1. BLUE-BLACK BOTRYOIDAL LIMONITE

This is a dull, bluish-black material, which has a burned or clinkery appearance. (See Plate 11 A, & Plate 1). Smooth, shiny, black botryoidal surfaces are generally small in extent and often restricted to holes or pockets in the surface, so that they may not be seen readily without close examination. The protruberances are in most cases quite small, and are formed on thin encrusting bands, but one specimen contains protruberances almost $\frac{1}{2}$ inch across on an encrusting band about $\frac{1}{8}$ inch thick. When larger pieces are broken, botryoidal layers encrusting cavities are often present, but these are usually dull unless connected through an opening to the surface. This material, when pure, does not stain the hands, but it is often partially contaminated with other types of softer limonite.

All occurrences of this type were restricted to strictly surface exposures, although this is not the only type to be found on the surface. Residual specks of galena seem to be entirely lacking when this type is relatively pure.

The bands have a fibrous radiating structure with the fibres perpendicular to the surface. It has a yellowish-brown streak, a hardness of about $4\frac{1}{2}$ -5, and a uniform specific gravity of 3.93. It gives off water in the

closed tube, becomes magnetic on heating, and gives blowpipe and chemical tests for iron.

Since no relict sulphides or boxwork structure were evident in the hand specimens, polished and thin sections were prepared. Plate 12 is a photomicrograph of a polished section, which shows the typical limonite veinlets forming an irregular and indefinite pattern. A small amount of pyrite was detected in the polished sections, and some of this is shown in the photo. It is quite evident that this pyrite is being replaced or altered to limonite. Another small area of residual pyrite was seen that appears quite similar to that seen in Plate 8. Therefore, it is thought that this type of limonite has been derived largely from pyrite.

In polished sections, the encrusting layers of limonite are seen to form colloform bands on the outside edges of other limonitic areas. This material appears white, has a very smooth surface, and shows a fibrous radiating structure perpendicular to the banding. It is isotropic and has a hardness of about E. Aqua regia stains it light brown, but all the other reagents, as used by Short (11), give a negative etch test.

On the inside of the smooth surfaced banded limonite, the limonite has a pitted white surface, is slightly softer, and is negative to all etch reagents. Under

crossed Nicols it shows red internal reflections, anisotropism from light blue-gray to black, and appears as irregular jagged plates with one cleavage.

Thin sections of this material are largely opaque when pure, but most specimens contain other minerals. Authigenic albite was noted in one of these in very small amounts and in grains about .1mm. long. Angular to rounded quartz grains up to about .1mm. diameter are also present in some sections. This quartz appears to be of hydrothermal origin since some grains show euhedral shapes. Carbonate is present in greater quantity and this probably represents material from the original host rock. A minor amount of phlogopite was also noted in one thin section.

The non-opaque limonite varies from brown to orange to orange-red to bright-red, and forms irregular patterns in the opaque limonite. Some of these colors are a function of the thickness, varying from orange near the thin edges to orange-red in the thicker portions. A small amount of residual pyrite was seen in certain sections, and one area showed definite alteration from fresh pyrite to red semi-transparent limonite. Other areas of similar limonite had square outlines and were probably derived from euhedral pyrite cubes. A very minor amount of tiny grains of fresh galena was seen in one thin section.

TYPE 1 A

A slightly modified form of this botryoidal type was found in small quantity only, near the surface in Trench 1-1 where Vein No. 2 was exposed. It is hard, heavy, and tough, and appears to be almost pure metallic iron oxide. Flat, thick bands intersect each other at angles of about 75° , leaving spaces or cavities which are rounded or filleted at their corners. Colloform banding and botryoidal structure is quite apparent. (See Plates 13 A, and 13 B.) The botryoidal surfaces are not smooth and shiny as in the main type, but are rough, and dull brownish-black. No residual sulphides were found in this material, and as it appears to be of minor importance, little study was given to it.

TYPE NO. 2 REDDISH-BROWN HARD LIMONITE

This is a dull, dark reddish-brown, hard and heavy massive material, which contains numerous irregular cavities, some of which are filled or partly coated with soft powdery material. (See plate 11 C.) Most of the cavities are smaller than those shown in the photograph. The powdery material is principally yellow, but some is a very definite brick red. This latter powdery material forms a thin dull coating on parts of the surface.

Many of the cavities that are filled with the yellow material show a fragile boxwork structure formed of very fine narrow walled partitions. Some of the smaller unfilled cavities have a few thick walled partitions formed of the main hard material, and these appear to be pseudo or relict boxworks. The brick red powder is generally lacking in boxworks.

This material is also restricted to surface occurrences and was found mainly on Hope Hill. (See Map #1). It has a dark brown streak and a hardness of about $4\frac{1}{2}$ to 5. The average of four specific gravity tests was 3.71, but these varied from 3.65 to 3.77 probably as a result of impurities of the yellow powdery limonite.

In polished sections, white, smooth surfaced, metallic limonite may form most of the field, or may occur as irregular areas or tiny veinlets in a background of

light gray limonite. (See Plate 14, & 14 A). This latter material appears non-metallic, and gives orange to red internal reflections under crossed Nicols. This is the yellow powdery material mentioned above as filling some of the cavities. The fragile boxwork structures were found to be formed by very narrow veinlets of the white metallic limonite, but do not seem to have any definite pattern. A small amount of pyrite was also detected, none of which could be noted in hand specimens.

Thin sections contain only a very minor amount of carbonate, and no quartz. Semi-transparent orange-colored veinlets form indefinite boxwork patterns in the black opaque to reddish semi-opaque metallic limonite. (See Plates 15, and 16.) The red limonite appears similar to that noted as forming after pyrite in a thin section of Type 1 limonite, and many of these red areas again show square outlines. One fresh pyrite cube was seen in one section, and a minor amount in other sections. It appears that Type 2 limonite has also been largely of pyrite derivation.

TYPE NO. 3 YELLOW BROWN SOFT LIMONITE

This is a soft, rusty or light yellowish-brown material, with a smooth or velvety feel. Usually it does not form large masses alone, but is often associated with one of the previous types. When scratched with a knife this fine powdery material is readily grooved.

In two localities, hard limonite containing this powdery material also has a small amount of malachite as an encrusting coating, and also disseminated in tiny areas throughout the limonite. Malachite was proven by its green color, adamantine luster, hardness of about 3.5, encrusting form with botryoidal surface and divergent fibrous rosettes, and also by chemical and blowpipe tests that proved the presence of copper, carbon dioxide and water.

This limonite type, when pure, seems to occur in small pieces only and boxwork structure appears to be lacking in these hand specimens. However, when associated with Type No. 2 hard limonite, a very fine-walled cellular boxwork of this powdery material may be preserved.

In polished sections this material does not present a smooth flat surface under the microscope, but shows a cellular boxwork of grayish-white metallic-appearing veinlets surrounding small irregular polygonal cells that may be empty or filled with a non-metallic powdery

limonite. (See Plates 17 and 18.) Some of these polygonal cells have double walls.(See Plate 19.) The metallic veinlets are not the same hard limonite previously described, but have a hardness of about C . The whole field as seen in the microscope has an orange to dark red internal reflection under crossed Nicols.

A considerable quantity of malachite is present in one polished section, and its fibrous radiating structure is readily seen. (See Plate 18.)

The thin section of the limonite containing malachite shows the typical cellular pattern (Plate 20) of this type. Most of the cells are empty, but some contain powdery limonite and others contain malachite.

TYPE NO. 4 POROUS BROWN CRUMBLY LIMONITE

This is a dull, dark brown, porous, light-weight limonite that has a frothy appearance due to its fine cellular boxwork structure. (See Plate 11B.) On surfaces exposed to weathering the detail of the boxworks is not usually well preserved, but it may readily be observed by breaking the specimen. The full detail of this boxwork however, is best obtained by sawing or rough grinding to a flat surface, and examining with a hand lens or 20 power binoculars. (See Plates 21, and 22.)

Small areas of shiny black botryoidal surfaces (similar to those described in Type No. 1) may be seen occasionally in more or less protected hollows or cavities.

Weathered surfaces are somewhat darker brown, while fresh surfaces show numerous brownish yellow and occasional brick red areas of soft powdery limonite (similar to that described in Type No. 3) which fill some of the boxwork cells. In this case, however, neither of these powdery limonites form cell walls or show any boxwork structure in themselves.

This material contains appreciable percentages of quartz, some as irregular grains, but most of it in slender, well-formed, euhedral, doubly-terminated crystals up to $\frac{1}{4}$ in. long.

Occurrences of this type were not restricted entirely to the surface, but were found down to depths of about one

foot, on the northwest side of Hope Hill.

Polished sections reveal a fairly definite cellular pattern formed by white, metallic limonite veinlets. The pattern consists of one strong set of fairly long, straight, parallel cell walls, with one or more other minor sets at 90° or about 45° to the first. Many of the individual veinlets are seen to consist of two narrow limonitic walls separated by a space about twice their thickness which results in a "double-walled" cell partition. (Plate 23.) No pyrite was found in this type, although all the limonite is the hard, white, metallic variety.

In thin sections, the limonite varies from light to dark brown opaque and orange red. A small amount of carbonate was noted, and one thin section contains a small amount of albite which is slightly sericitized. This same section contained only very minor quartz in tiny grains, but another thin section, that was cut from the specimen shown in Plate 21, contains^a considerable quantity of coarse-grained vein quartz with some euhedral crystals up to 2 mm. long. The boxwork in this section consists predominately of limonite veinlets forming fairly straight walls inclosing square, rectangular, and polygonal cells. This boxwork resembles somewhat the galena "cleavage boxwork" described by Blanchard and Boswell, (8, p.675.) However, in this thin section, there is considerable evidence of the limonite growing and eating its way along the quartz

grain boundaries. (See Plates 24 and 24A.) Some hexagonal quartz grains are more or less rimmed with narrow limonite veinlets. The straight walls of some euhedral quartz crystals show a fairly uniform depth of penetration (or replacement) by limonite, but it is more likely that the limonite has replaced galena that had previously partially replaced and veined the quartz.

TYPE NO. 5 POROUS ORANGE-YELLOW LIMONITE

This is a light orange-yellow to light brown colored limonite with a fine porous structure and a somewhat sandy appearing surface when examined with a hand lens or binoculars. Residual galena is present but most has been oxidized.

The boxwork structure is somewhat masked by numerous tiny grains of limonite and carbonate coating the cell walls, and it is this that gives the sandy appearance. (Plate 25). As in type No. 4, the structure of the boxwork is best demonstrated by cutting or grinding to a flat surface, though it may be detected on a freshly broken surface in small isolated areas. Individual cells are quite small (less than 1mm.) and are cubical, rectangular, and triangular in shape. Cell walls are invariably straight, and show practically no filleting or enlarging at their lines of intersection, thereby forming sharply defined corners. Most of these partitions are quite thin, and appear fragile; but large, stronger, and more continuous partitions take the place of fragile partitions about every third or fourth cell. Flat surfaces show thick (.5mm. to 2mm.) intersecting veinlets, quite widely spaced (5mm. or more), forming a more or less rectangular to triangular major pattern. These veinlets proved to be cerussite.

The fine cellular pattern could readily be formed by the incipient alteration of galena proceeding along its

cleavage planes. The commencement of such an alteration was noted in a polished section of fresh galena from Vein No. 1, in which anglesite veinlets follow the crystal boundaries and cleavage planes of galena. In this Type 5 material, however, the veinlets are cerussite, and no anglesite was found. This material occurred as one large piece and numerous smaller pieces in one locality only, at point X on the west side of Guy Hill. It was not associated with any other type, and there was no Fractured Faith limestone (the "indicator") nearby. A small amount of digging proved that this material had been transported, and had probably been rolled or moved down the slope from its original place of formation, and then subjected to further weathering under different environmental conditions.

Polished sections of this type show very little metallic limonite, and hence no boxwork pattern. The limonite is predominantly the non-metallic powdery material that gives a reddish-brown internal reflection under crossed Nicols.

A small amount of fresh galena is surrounded by an alteration product, which effervesces with nitric acid, and was proven in thin section to be cerussite. A small amount of fresh pyrite remains in centers of small areas of metallic limonite.

In thin sections, the boxwork in this case is seen

to be formed by semi-transparent, non-metallic, orange to brownish-stained carbonate which is probably mainly calcite or dolomite. There is a definite lack of metallic limonite in the cell walls.

Fine grained euhedral to anhedral pyrite is disseminated throughout the sections, and its partial oxidation accounts for the staining of the carbonate. Large areas of galena have been more or less altered to, and are contained in, a transparent mineral determined to be cerussite. The cerussite is mainly white to gray, but some is lavender colored. It has an extremely high birefringence and index of refraction, and under high power the surface has a very crinkled appearance and shows considerable change of relief as the stage is rotated. It is uniaxial negative to biaxial negative with $2V$ less than 10° . The orthorhombic crystal form was detected by crushing some of the material and observing it under the binoculars. These crystals effervesced with nitric acid, but they are so small that a positive blowpipe test for lead could not be relied upon as it was difficult to ensure that a pure sample had been used.

The fact that most of the original carbonate of the limestone has been stained by the oxidation of the pyrite, while the cerussite is clear, may be due to the earlier and easier oxidation of pyrite preceding the alteration of galena to cerussite. This agrees with the well known

comparative rates of oxidation of various metallic minerals. An argument against this explanation becomes obvious when one considers the electro-potential series of sulphides as determined by Gottschalk and Buehler (12). They found that when two sulphides such as pyrite and galena were in mutual contact, a small electric current was set up that flowed from the high potential pyrite to the lower potential galena. This accelerates oxidation of galena and retards oxidation of pyrite. Under perfect conditions, galena could be completely oxidized before pyrite. What usually happens, of course, is that the early oxidation forms a layer of anglesite or cerussite around the galena, thus nullifying the action of the electric cell, and oxidation of each mineral then proceeds more or less individually. In this case it may be that cerussite was less susceptible to replacement or staining by iron oxides than was the original carbonate of the limestone.

Albite was not detected in these thin sections. Only an occasional tiny grain of quartz is present, but whether this is clastic or hypogene is not known.

A colorless mineral, that occurs in very small tabular plates, and radiating rosettes or stellated masses has been determined as barite. Its most distinguishing feature as seen under crossed Nicols in the aggregated crystals is the dark cross caused by their radial uniformity of orientation. IT has perfect cleavage in one

direction, and appears to have two other cleavages intersecting at about 78° . Other optical properties are: $n = 1.63$; $2V = 40^{\circ}$; positive; length-slow; axial plane perpendicular to the length of the crystals (i.e. perpendicular to the best cleavage.) An estimation of the birefringence is rendered inaccurate by the difficulty in determining the correct thickness of these thin sections.

A positive barium flame test could not be obtained from the crushed limonite, possibly because the barite is present in such small amounts and is too small to be recognized in the hand specimen. Barite has not been found in any of the host dolomite, and it is considered that the barite in this limonite was introduced by the hydrothermal solutions along with the metallic sulphides. It is not closely allied with the large areas of galena and cerussite, but occurs in small scattered areas in the iron-stained carbonate.

TYPE NO. 6 MIXED CAVERNOUS LIMONITE

This material has a very dull bluish-black surface with large areas of yellow brown soft limonite (Type No. 3). The latter, combined with relatively large depressions or surface cavities, gives this type a rather coarse appearance. Locally, botryoidal surfaces are developed in the cavities.

The dull bluish-black surface is merely a soft, weathered coating above a hard metallic limonite. In some of the softer material, cubical to rectangular cells form a coarse boxwork pattern. (Plate 26.) Fresh galena is present in some of the specimens in fairly large areas rather than as scattered grains.

This limonite was found about 2 feet to 3 feet below the surface in Trench 1-1, where Vein No. 2 of massive galena was exposed. The surface limonite float here was mainly Type No. 1, blue-black botryoidal limonite, in which only an occasional grain of fresh galena could be found. Type No. 6 appears to be a gradation between Type No. 1, and fairly fresh, but partially oxidized galena.

The cubical to rectangular boxwork (Plate 26) was not seen in the hand specimens to grade into galena, but its form and proximity to galena strongly suggest such an origin. It appears to be quite similar to the "cleavage boxwork" of galena derivation described by Blanchard and Boswell (8, p. 675.) However, the cells are larger, with

the distance between parallel plates up to 2 mm.

In polished sections, the cell walls were found to be formed of metallic limonite. They are straight and parallel over small areas, and are crossed obliquely or at right angles by other partitions. (Plate 27.) Double cell walls are not uncommon. The boxwork pattern occurs in a background of non-metallic powdery limonite, that gives a dull reddish-brown internal reflection under crossed Nicols. In the large areas of massive metallic limonite, no boxwork structure is present.

The residual galena is surrounded with anglesite that grades outward to non-metallic and then to metallic limonite. The typical boxwork (Plate 27) was not seen to grade into the anglesite or galena, although possibly this could be found by further polished section study. The pattern formed in partially weathered galena by the replacing anglesite appears quite similar to the limonitic boxwork seen in Plate 27. The limonitic cell walls are obviously occupying the former position of anglesite noted previously as having formed along the cubic cleavage planes of galena during the latter's incipient alteration. (See p. 40.)

Thin sections show the four distinct colors of limonite; orange, brown, red, and opaque black. The first three are semi-transparent, and the first two are non-

metallic as seen under oblique illumination. Each of the first three colors may occupy large separate areas or may form a network of tiny veinlets through the black opaque metallic limonite. This network also suggests the "cleavage boxwork" pattern of galena. (Plate 28.) However, in the polished section, the boxwork pattern is formed by a metallic limonite network (Plate 27), whereas, in thin section the network is due to semi-transparent, non-metallic, orange colored veinlets in the black metallic opaque limonite. This apparent discrepancy could be explained by proving: (1) that the portions showing the boxwork in thin sections were equivalent to the massive metallic limonite areas in the polished sections where no boxwork pattern is evident, and (2) that the portions showing the metallic limonite boxwork in polished sections were too delicate to preserve in thin sections since their background consists of non-metallic powdery limonite. Accordingly, an attempt was made to prepare thinned polished sections but the technique was not successfully mastered in time for this work.

One area of fresh residual pyrite is partially altered to red metallic limonite in the same manner as shown in Plate 9 and numerous rectangular areas of similar red limonite suggest the former presence of pyrite.

The field relations and the abundance of residual galena left little doubt as to the origin of this type of limonite, but it was studied as a guide to the meaning of microscopic and physical features of other types.

LIMONITE TABLE

This table summarizes the important features of the six types of limonite.

Type No.	Name & Description	Occurrence	Structure (Microscopic)	Associated Minerals	Probable Source
1.	Blue-Black Botryoidal Dull, clinkery.	Surface Widespread	Indefinite Colloform banding.	Pyrite. Carbonate Authigenic albite. Hypogene quartz. Minor galena	Pyrite & Galena
2.	Reddish-Brown Hard Dull, massive; small cavities.	Surface. Hope Hill	Massive. Circular to polygonal cells.	Pyrite. Carbonate.	Pyrite.
3.	Yellow-brown Soft	Widespread in other types.	Polygonal cells. Double walls are common.	Malachite	Pyrite & Chalcopyrite?
4.	Porous Brown Crumbly Cellular Boxwork; light-weight; frothy.	Down to 1 foot on Hope Hill	"Cleavage Boxwork"	Coarse Vein quartz crystals. Carbonate. Authigenic albite.	Galena with quartz.
5.	Porous Orange-Yellow. Boxwork masked by sandy appearance.	West side Guy Hill on surface	Nil, because of lack of metallic limonite.	Galena. Cerussite. Carbonate. Barite. Minor pyrite & Hypogene? quartz.	Galena & Pyrite
6.	Mixed Cavernous. Dull, black & brown; coarse boxwork.	2-3 feet below surface in vein.	"Cleavage boxwork." Double walls.	Galena. Angelsite. Pyrite.	Galena & Pyrite.

CONCLUSIONS

Before starting these investigations, the writer perused the literature, including the references listed in the bibliography, and especially those papers by Boswell and Blanchard (3 to 8) who have emphasized the physical characteristics that distinguish limonite types derived from specific sulphides. After studying each limonite type and forming an opinion as to its source, the author referred back to the works listed in the bibliography to pick out the most important features of corroboration or disagreement.

DERIVATION OF SPECIFIC LIMONITE TYPES

Type No 1, blue-black botryoidal limonite, which the author has attributed to pyrite and galena, appears to be quite similar to the "Botryoidal limonite crusts derived from massive pyrite in limestone gangue" illustrated and described by Boswell and Blanchard (5, p. 373). They state:

"The acid solutions from the oxidizing pyrite were so strong that they overwhelmed the neutralizing power of the limestone."

In Trench 1-1, this limonite was found on the surface and contained only very occasional specks of residual galena. Type No. 6 limonite containing abundant galena was found 2-3 feet below the surface, immediately

above oxidizing massive galena. In this case at least, it appears that as oxidation proceeds the characteristic cleavage boxwork of galena (as seen in Type 6, Plate 26) is lost, and Type No. 1 limonite is formed. Therefore, it is quite likely that this limonite developed its final characteristics from the minor residual pyrite noted, but that galena may also have been present originally.

The similarity between Type No.s 4,5,6, and the "cleavage boxwork" of galena derivation has been mentioned previously. Type No. 5 may be a combination of "cleavage boxwork" largely masked by "partially sintered limonite crusts" of cerussite derivation. (8, p. 678.)

The role of ferric sulphate in the oxidation of metallic sulphides, and the rapid neutralizing action of limestone or dolomite on sulphate solutions, are too well known to be dealt with here. Boswell and Blanchard (4, p. 424, 438-9) found that the significant types of oxidation products of sphalerite and galena were best developed in environments of moderately slow neutralizers, such as feldspathic rock. In environments of rapid neutralizers, the distinguishing characteristics are often partially masked by a fine, fluffy type of pulverulent limonite. They consider that the only reason for any preservation whatsoever of significant types in limestone lies in the fact that galena and sphalerite usually occur in massive form, and that the effects of the CaCO_3 do not

readily penetrate to the centers of large nodules of the sulphides. On the Star Group, the occurrence of massive galena in dolomite, and Type no. 3 soft, powdery limonite partially obscuring the characteristic cleavage boxwork, agrees with the findings stated above.

MATERIAL FORMING THE BOXWORKS

The illustrations by Boswell and Blanchard are hand specimen photographs, or slightly magnified sketches of boxwork patterns as seen with a hand lens or binoculars. Little mention is made of microscopic investigations of polished or thin sections, except when explaining boxwork structure and its rigidity, such as their description of the "Coarse Cellular Boxwork" of sphalerite derivation (4, p. 424.) Here they state that microscopic observations prove that parallel quartz veinlets forming the boxwork in the oxidized products are similar to quartz veinlets in the fresh sulphide, and that this quartz is clearly hypogene. "It was further observed that as oxidation of the sulphide mass proceeds, the veinlets gradually advance their front and "eat" their way into the less coarsely fractured portions of the sulphide mass.... These extensions of the white to glassy veinlets consist, not of pure silica, but of limonitic jasper, and are clearly supergene." In a later paper (6, p. 793-4) it is stated that the SiO_2 content of some of the supergene limonite boxworks is as high as 55%, but that those derived from galena and bornite

are generally low in silica. They found that the silica content of the boxwork varies also with the type of gangue (the most siliceous was derived from oxidation of pyrite in limestone), the district concerned, and physico-chemical laws. They consider that circulating ground waters, containing silica in solution or in colloidal form, may infiltrate along fractures in the fresh sulphide, and thus provide a source of limonitic jasper even when no vein quartz or silicate minerals were originally present.

The cell walls of the limonite boxworks from the Star Group contain no quartz or limonitic jasper, but consist of undetermined metallic iron oxides. The difference between these findings and those of Boswell and Blanchard may be explained by: (a) the general lack of quartz in the veins and the limonite (except in Type No. 4), (b) the improbability of circulating ground waters containing silica reaching the present relatively high elevations at which the veins and limonite are found. It is conceivable that during some earlier geological period the topographic and other conditions may have existed that allowed silica-bearing ground waters to infiltrate the sulphides and produce limonitic jasper boxworks. However, these would have been destroyed by erosion long before now.

If the boxwork in Type 6 limonite contained limonitic jasper in the cell walls, it is not likely that this structure would be destroyed in its alteration to Type 1

limonite. (See p. 49.)

Type No. 4 limonite contains considerable hypogene quartz. Nevertheless, the cell walls of the boxwork structure (which appears quite similar to the "cleavage boxwork" of galena derivation) consist of metallic iron oxide, and not silica. At least some of the structure was found in thin sections to be patterned after the shapes of the euhedral quartz crystals. However, it is considered that most of the boxwork in this type is patterned after the cubic cleavage planes of galena.

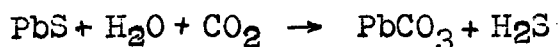
SOURCE OF IRON

During the early part of the exploration of the Star Group, the author was not sure of the origin of the iron in the limonite float. It became apparent that the limonite had formed very close to where it was found (See p.3), and this was corroborated by the discovery of the mineral deposits. However, the possibility still existed that the iron had been introduced in solution in circulating ground waters and had been precipitated as limonite by the neutralizing action of the limestone. The only pyrite found in the field was in the area of disseminated mineralization, and there was little evidence of its alteration to limonite. The minor sphalerite in the same locality suggested another possible source of iron, but it again was quite fresh. Microscopic study of polished and

thin sections has revealed residual pyrite in many of the limonites, and the author now considers that all the iron in the numerous areas of limonite float was derived locally from pyrite or other primary iron-bearing sulphides.

SECONDARY LEAD MINERALS

Most authors seem to agree that galena, when subjected to weathering processes, usually alters to anglesite or cerussite, both of which are quite insoluble in aqueous solutions. Anderson (1, p. 531) states that anglesite always forms first and that any cerussite that may be present is due to replacement of the sulphate and not the sulphide. Boswell and Blanchard, while favoring the formation of limonite by the reaction of ferric sulphate on cerussite, suggest (4, p. 445) that cerussite is formed from anglesite, although they also state (4, p. 448) that "... sphalerite or galena.... may oxidize to the sulphate or carbonate state by ordinary air-water oxidation processes." The author considers that thin sections of Type No. 5 limonite prove that cerussite may form directly from galena (See p.41), and suggests the following as a possible reaction:



It was noted (See p. 40) that this limonite had been weathered in an environment remote from its place of formation. The oxidizing solutions here probably carried more CO_2 and less sulphate than those in the mineral deposits.

SOLUBILITY OF LIMONITE IN HCl

Bateman(2, p. 251) states that limonite derived from iron-bearing sulphides is readily soluble in dilute HCl, while that derived from iron-bearing gangue or rock silicates is not. He makes no attempt to substantiate this statement, but it probably originated with Morse & Locke (10, p. 25?), who state:

"the sulphide iron, having gone to limonite, may be approximated as that easily soluble in dilute HCl",

and further (p. 258):

"that the capping iron soluble in five minutes in 3 or 4% HCl was in fact approximately the same as the sulphide iron content of what we regarded as typical ore vertically below the capping."

Boswell and Blanchard (3, p. 617) state:

"as the chalcopyrite approaches purity, the iron of the indigenous limonite, though variable, approaches one-quarter to one-third that of the sulphide, the rest being removed."

A discrepancy is apparent in the above findings.

Solubility tests were made on some of the limonites from the Star Group, in an attempt to substantiate the former authors. In all cases it was found that the acid required heating to dissolve even the powdered material. The table following shows some of the results.

Type No.	Quality	Condition	Solution	Solubility
1.	50 mg.	Solid	Cold 1:1 HCl	Slight
	50 mg.	Solid	Hot 1:1 HCl	Difficult 15 mins.
	50 mg.	Powdered	Cold 1:1 HCl	Slight
	50 mg.	Powdered	Hot 1:1 HCl	Difficult 10 mins.
	30 mg.	Solid	6cc. Hot 1:5HCl	Difficult. Not all in 5 mins.
2.	20 mg.	Powdered	2 c.c Cold 1:1 HCl	Very little.
	20 mg.	powdered	2 c.c Hot 1:1 HCl	Most in 5 mins.
3.	20 mg.	Powdered	Cold 1:1 HCl	Some solution.
	20 mg.	Powdered	Hot 1:1 HCl	Rapid solution.
	30 mg.	Powdered	6 c.c Hot 1:5 HCl	Most in 5 mins.

All these limonites were probably derived from sulphides, and it is considered that their differences in solubility are related to the type and relative amounts of metallic limonite in each.

In any event, it is inconceivable that a gossan containing up to 55% SiO_2 in the boxworks (See p. 50) would be readily soluble in dilute HCl.

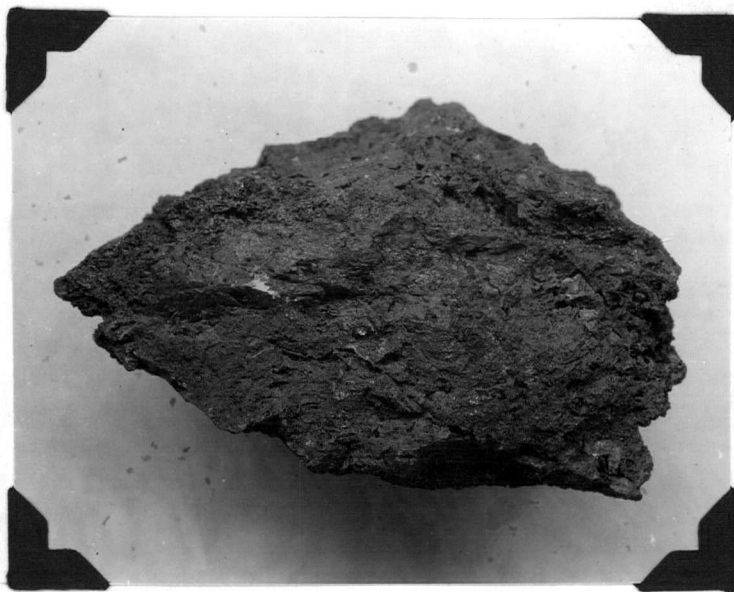


PLATE 1.

A typical specimen of surface limonite float from the Star Group. X 1. Color varies from reddish-brown to black.



PLATE 2.

Partially weathered galena associated with a limonite boxworks structure. X 2 $\frac{1}{2}$. The boxwork grades into galena (g) at the bottom of this photo.

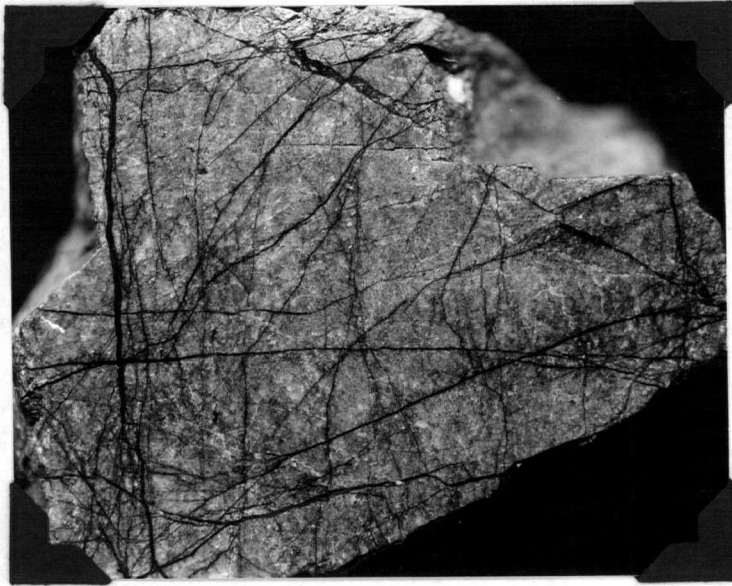


PLATE 3.

Polished surface of "Fractured Faith Limestone" that is often associated with surface limonite float. X 3.

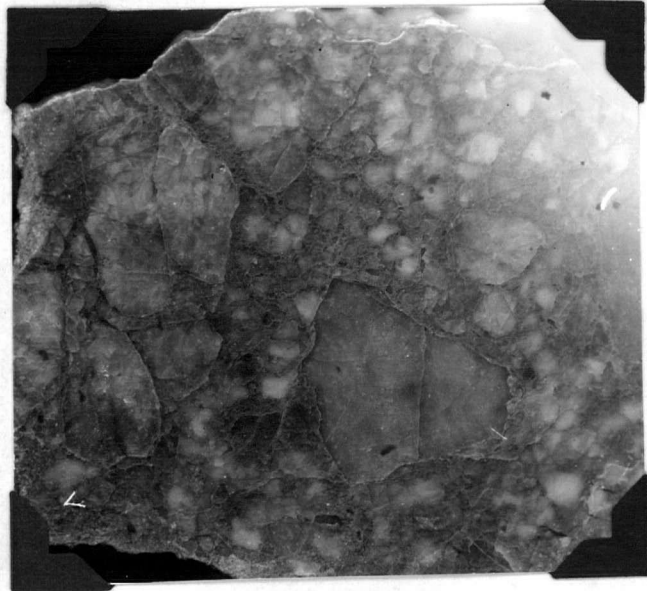


PLATE 4.

Polished surface of "Brecciated Faith Limestone" that occurs near areas of surface limonite float and near pure calcite veins. X 2.

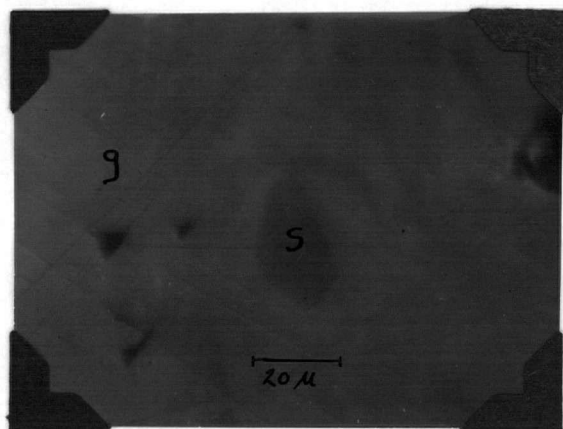


PLATE 5.

Photomicrograph of polished section showing unknown mineral (silver sulpho-salt? S) in galena (g). This is the maximum grain size in which this mineral was found. X 570.

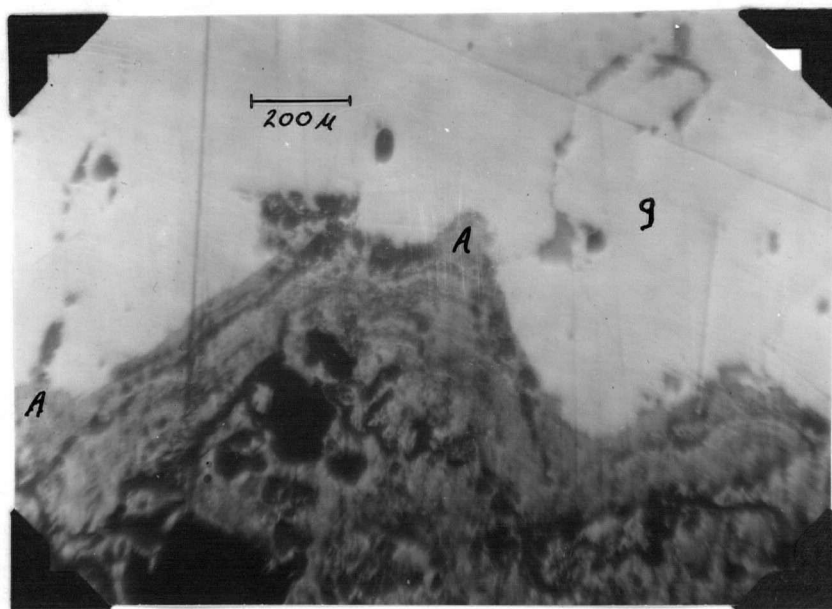


PLATE 6.

Photomicrograph of polished section of fresh galena (g), surrounded by a band of anglesite grading outward to limonite. X 65.

Anglesite (A)

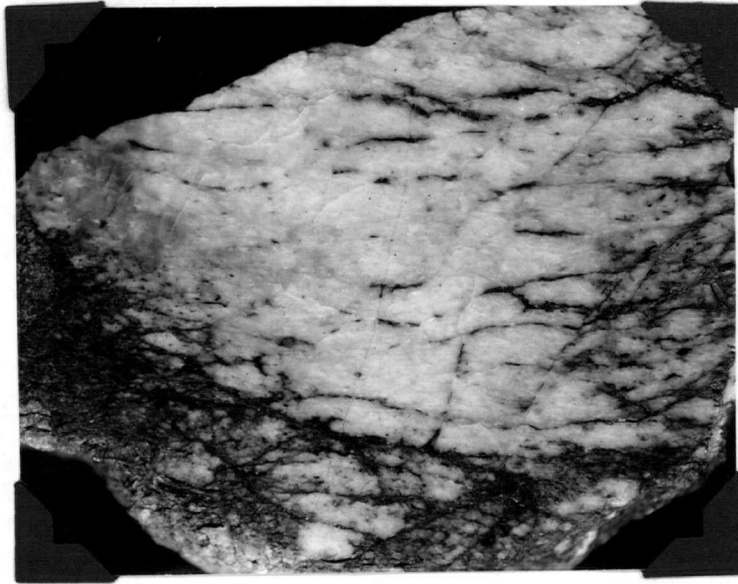


PLATE 7.

Polished surface showing veinlets of fresh galena in
fresh, very slightly silicified Faith Limestone. X 3.

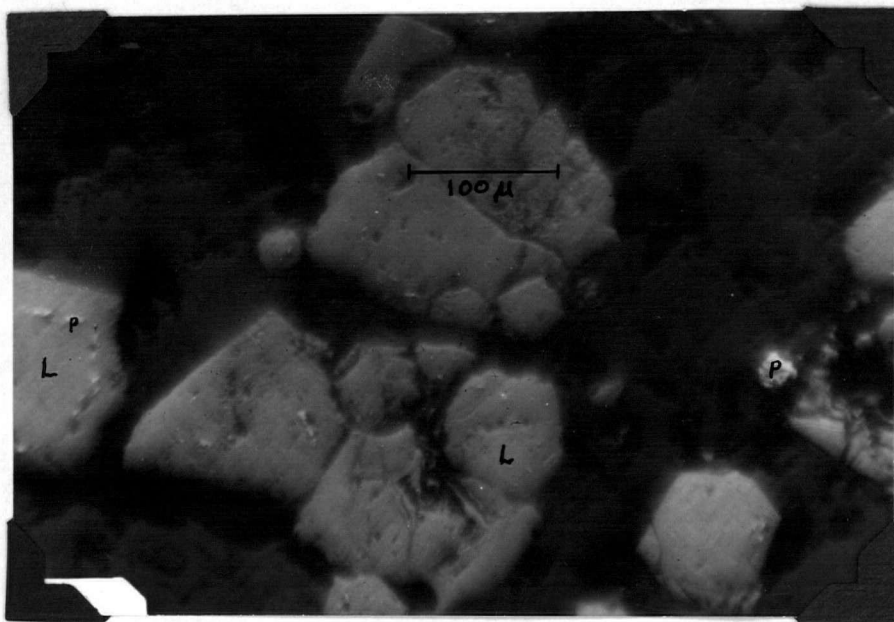


PLATE 8.

Photomicrograph of polished section showing almost complete alteration of disseminated pyrite (P) to gray metallic limonite (L), in fresh rock. X 200.

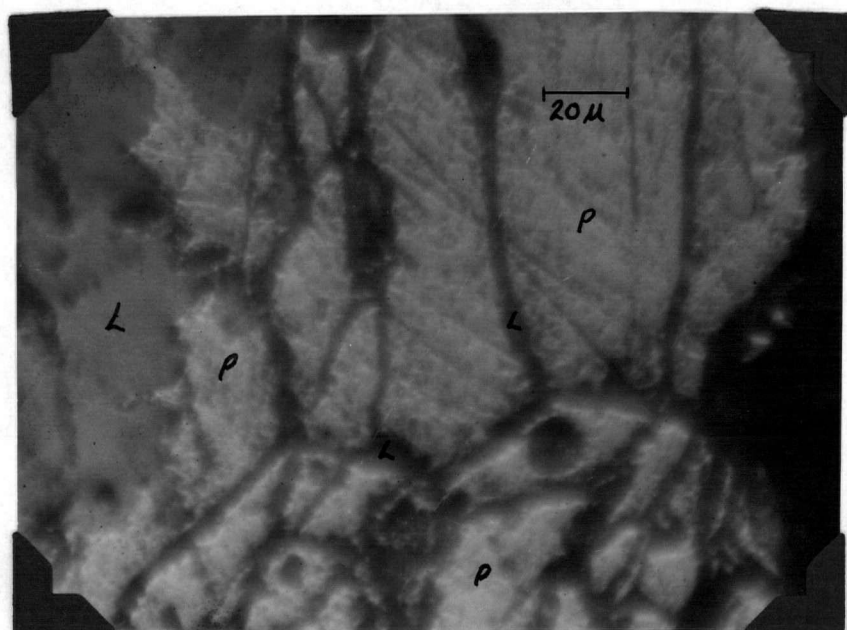


PLATE 9.

Photomicrograph of polished section showing incipient alteration of pyrite (P) to limonite (L). X 570.



PLATE 10.

Polished surface of wad from Vein No. 1, showing irregular masses and veinlets of a fine powdery metallic mixture of iron-manganese minerals.
Note: double-walled tendency. X 3

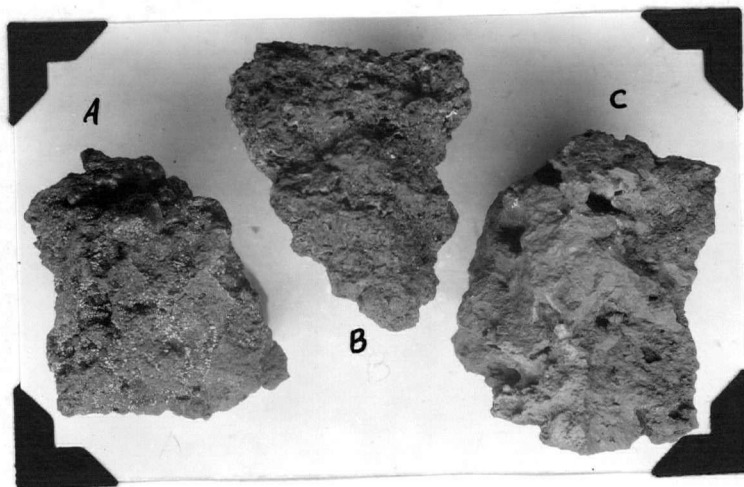


PLATE 11. (Natural Size)

- A - Type 1. Blue-black botryoidal limonite.
- B - Type 4. Porous brown crumbly limonite.
- C - Type 2. Reddish-brown hard limonite.



PLATE 12.

Photomicrograph of polished section showing indefinite pattern formed by metallic limonite veinlets (L) in Type 1 limonite, of pyrite (P) derivation. X 65.

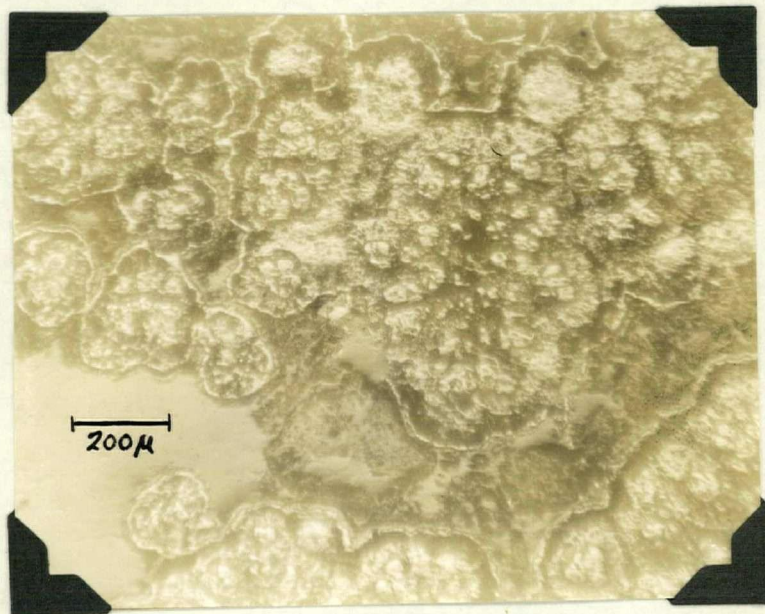


PLATE 13 A.

Photomicrograph of polished section showing typical colloform banding in Type 1 and 1 A limonite. X 65. Gray in lower left is impregnating fluid.

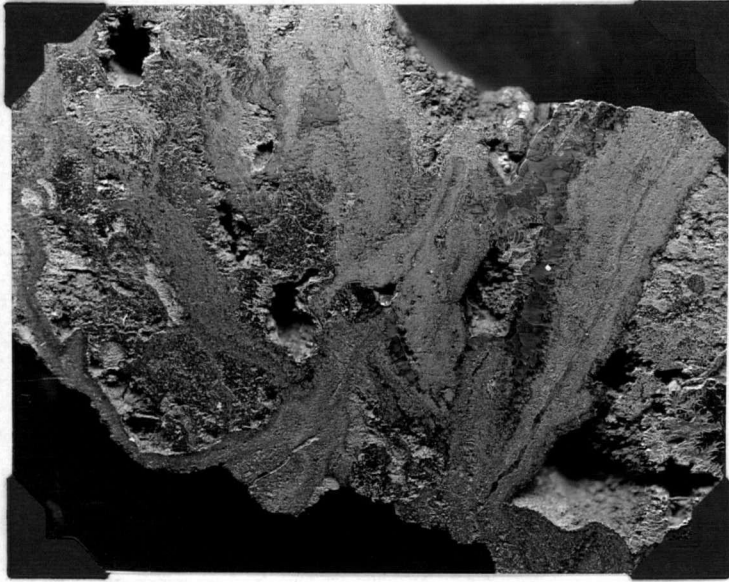


PLATE 13 B

Polished surface of Type 1 A limonite. X 3.

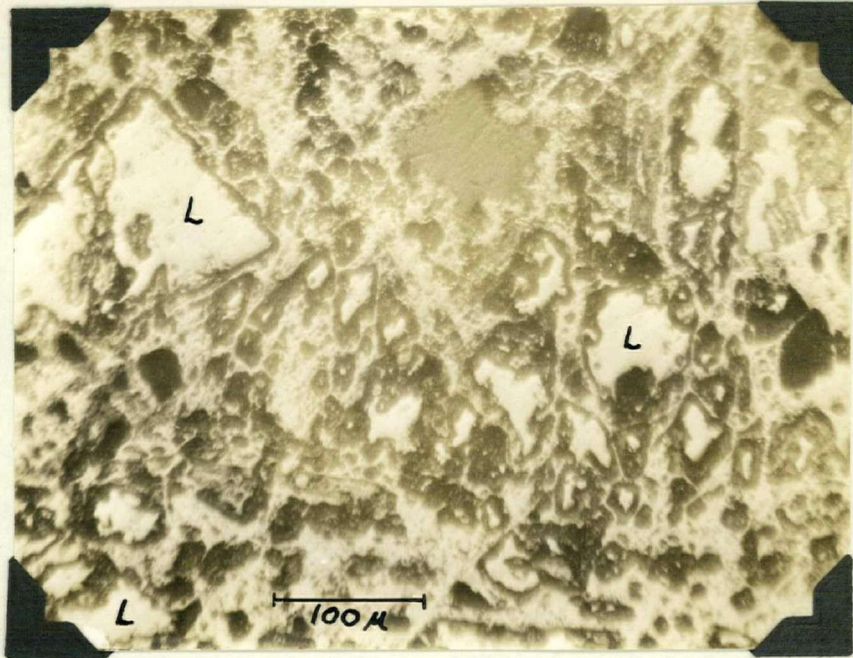


PLATE 14.

Photomicrograph of polished section of Type 2 limonite showing irregular areas and veinlets of metallic limonite (L) in a background of non-metallic powdery limonite. X 200

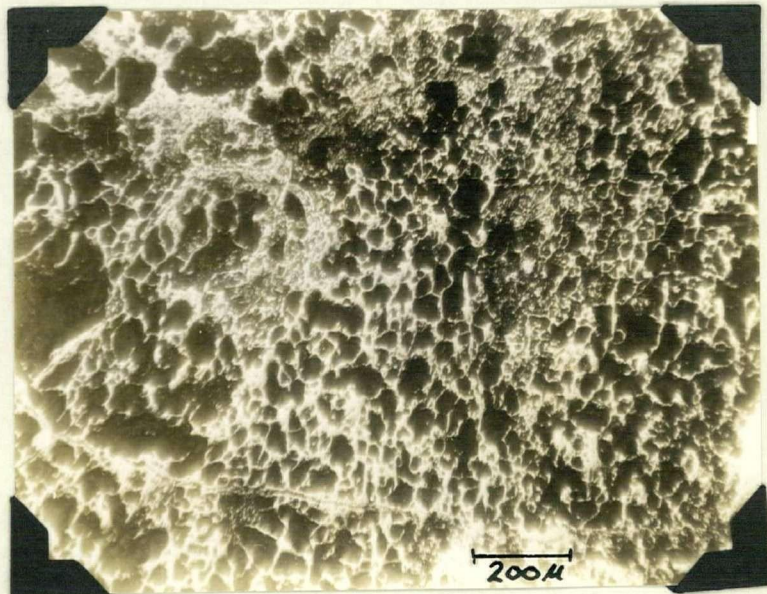


PLATE 14 A

Photomicrograph of polished section showing the typical circular to polygonal cellular structure formed by metallic veinlets in Type 2 limonite. X 65.

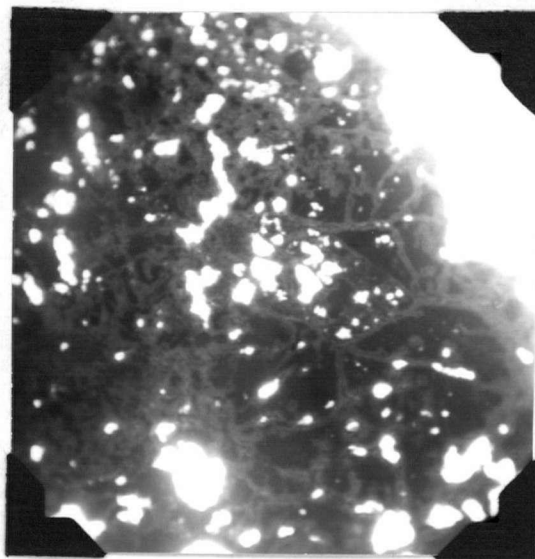


PLATE 15.

Photomicrograph of thin section of Type 2 limonite, with semi-transparent, non-metallic, orange colored veinlets forming a boxwork pattern in opaque metallic limonite. Note the double walls. X 50.

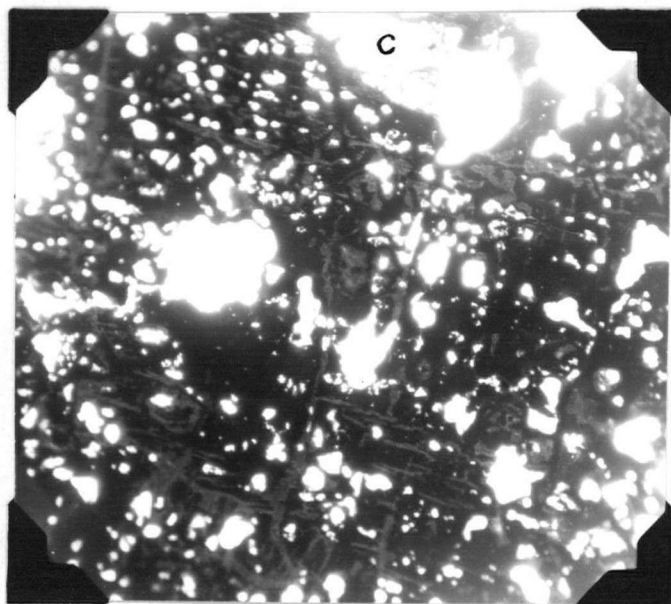


PLATE 16.

Similar to above. X 60. Although type 2 is considered to have been derived mainly from pyrite, local areas in some of the thin sections exhibit a pattern as above that resembles the "cleavage boxwork" noted in Types 4, 5, & 6. (See Plate 28.) White areas are holes, and carbonate. (C).

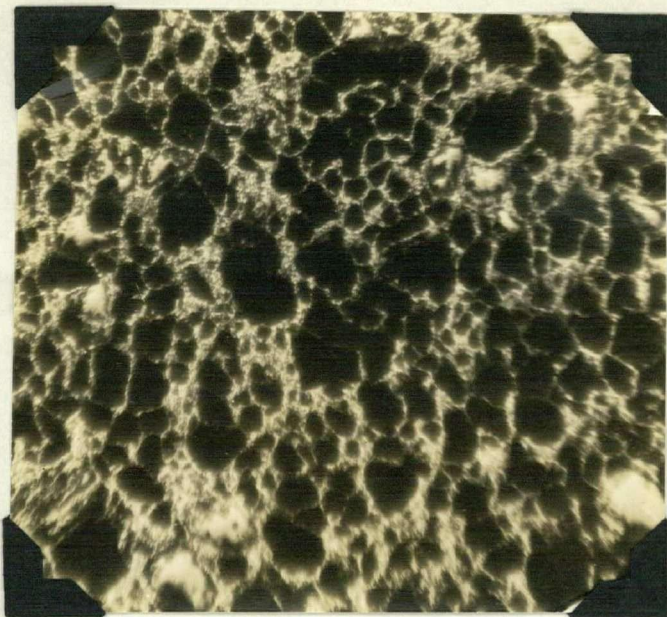


PLATE 17.

Photomicrograph of polished section showing the typical polygonal cellular boxwork of metallic limonite veinlets in Type 3 limonite. X 65.

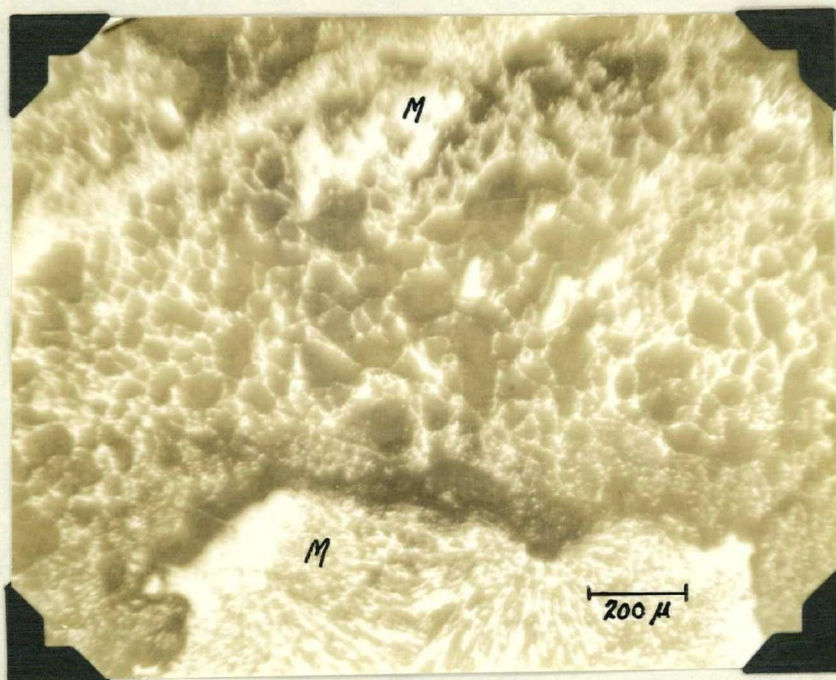


PLATE 18.

Similar to above. Note the malachite, (M); the large area shows its fibrous radiating structure. X 65.

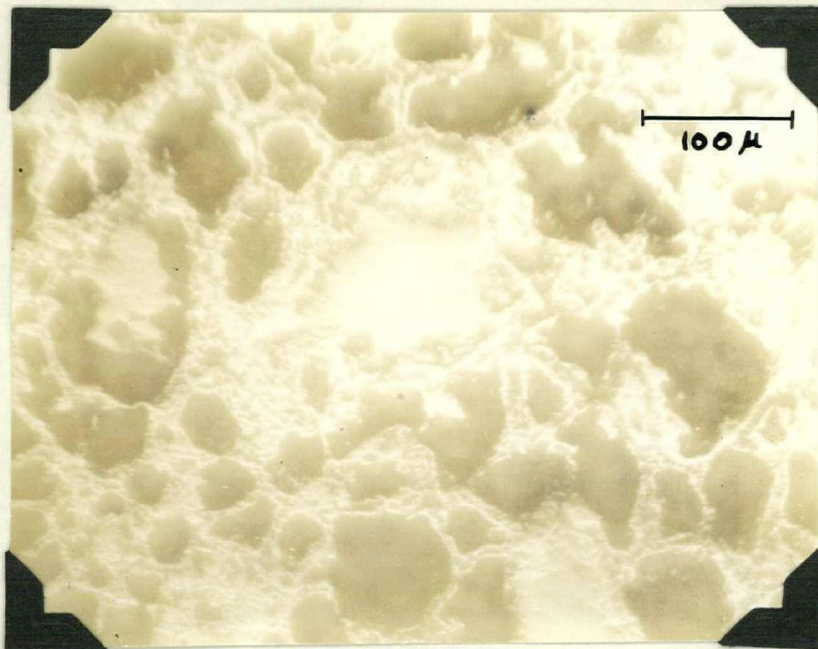


PLATE 19.

Photomicrograph of polished section showing the double walls of some of the typical polygonal boxwork in Type 3 limonite. X 200.

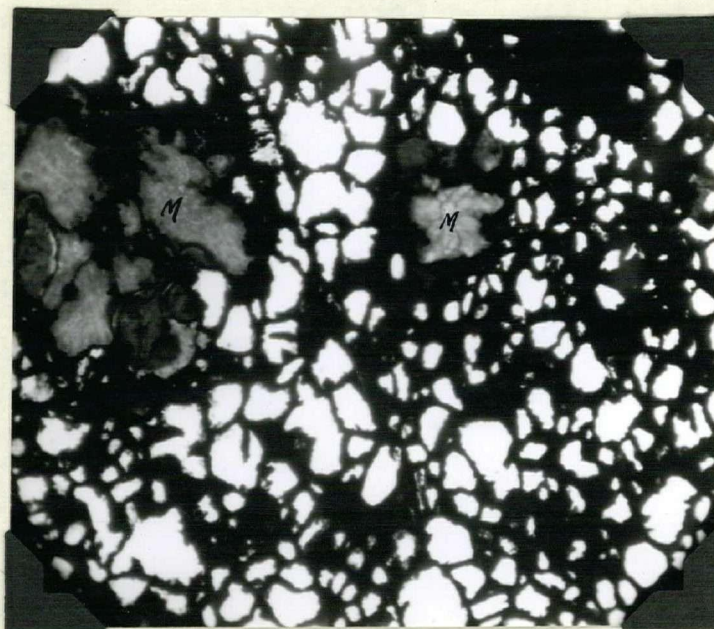


PLATE 20.

Photomicrograph of thin section of Type 3 limonite showing the typical polygonal boxwork, and areas of malachite, (M). X 60.

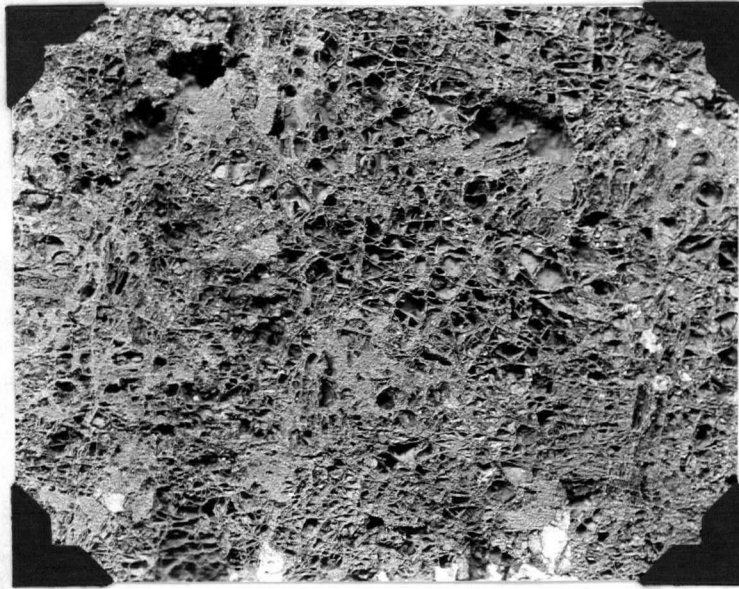


PLATE 21.

Flat surface of Type 4 limonite, showing the well developed "cleavage boxwork", possibly of galena derivation. X 4.



PLATE 22.

Similar to above, but with the boxwork partially masked by powdery limonite. X 4.

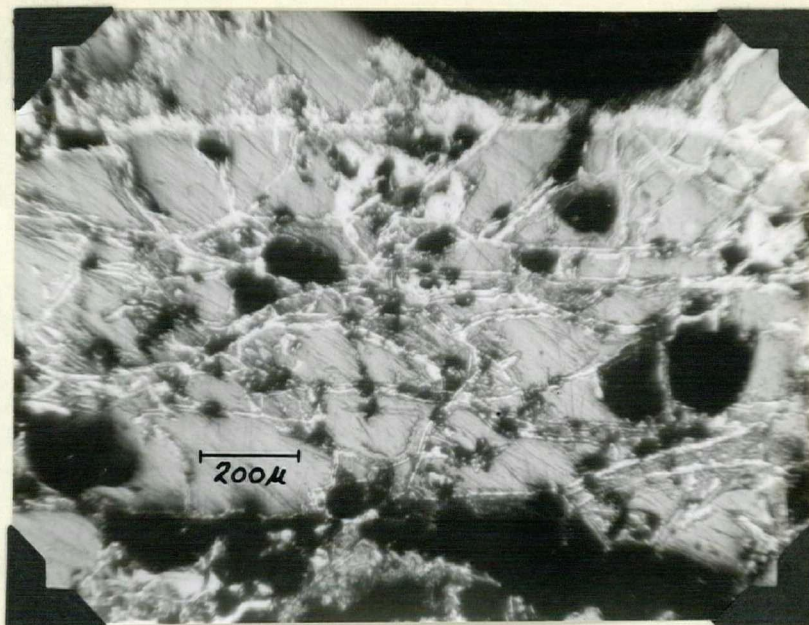


PLATE 23.

Photomicrograph of polished section of Type 4 limonite. Note the regular boxwork pattern formed by double-walled metallic limonite veinlets. Gray is impregnating fluid. X 65.

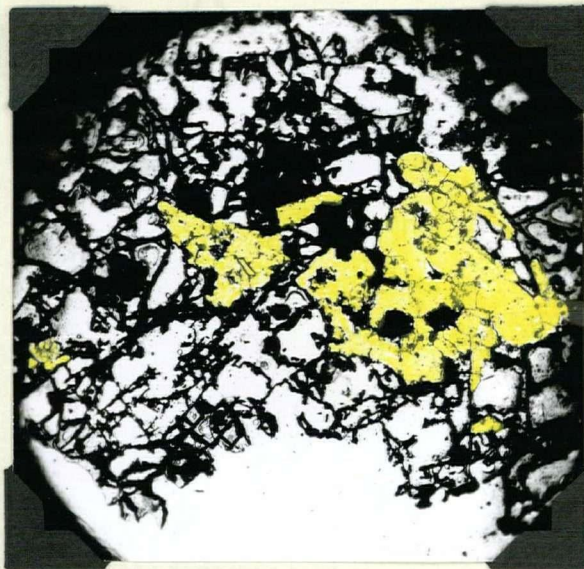


PLATE 24.

Photomicrograph of thin section of Type 4 limonite. Yellow tinted areas are quartz, and white areas are holes. This apparently shows the galena derived "cleavage boxwork" pattern, but also shows that many of the limonite veinlets (black) are formed around euhedral quartz crystals, and along irregular fractures and grain boundaries in the quartz. X 12.

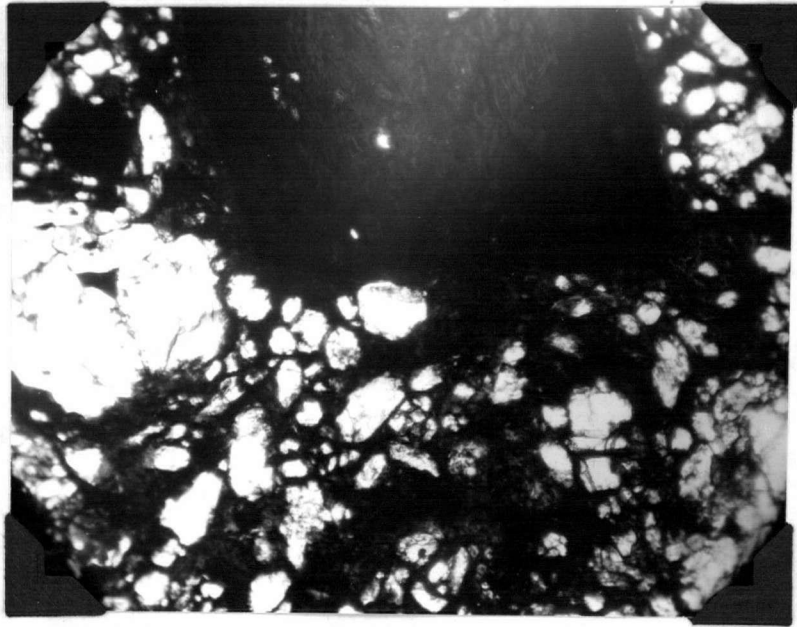


PLATE 24 A.

Photomicrograph of thin section of a relatively fresh rock showing vein quartz (white) surrounded by sub-opaque limonite. X 65.

This specimen came from below trench 6-9, and is unusual in that it consists mainly of quartz, with a small amount of galena. Limonite has apparently formed around the quartz by the oxidation of pyrite, a minor amount of which was noted in the thin section. The dark area in top center is the typical sub-opaque red limonite that has replaced a euhedral pyrite crystal.

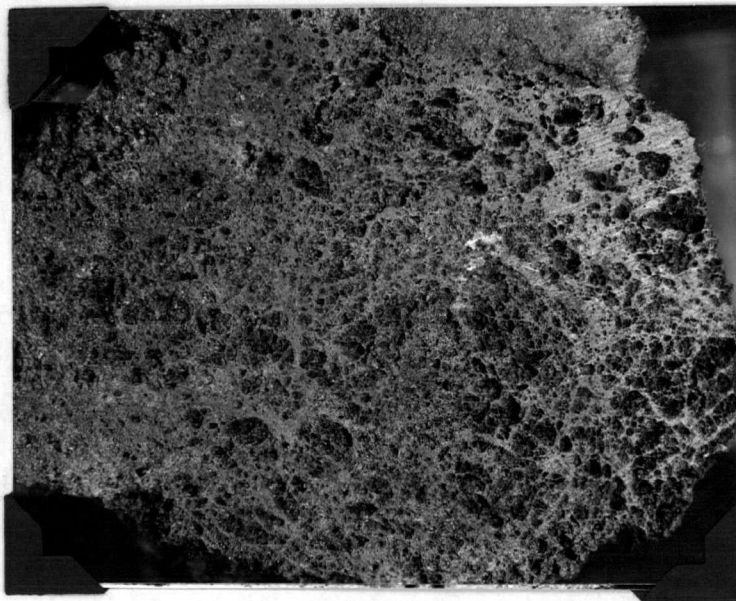


PLATE 25.

Flat surface of Type 5 limonite, showing the "cleavage boxwork" almost completely masked by powdery limonite and cerussite grains, giving it a sandy appearance. X 4.
(Note: two typical photos are included.)

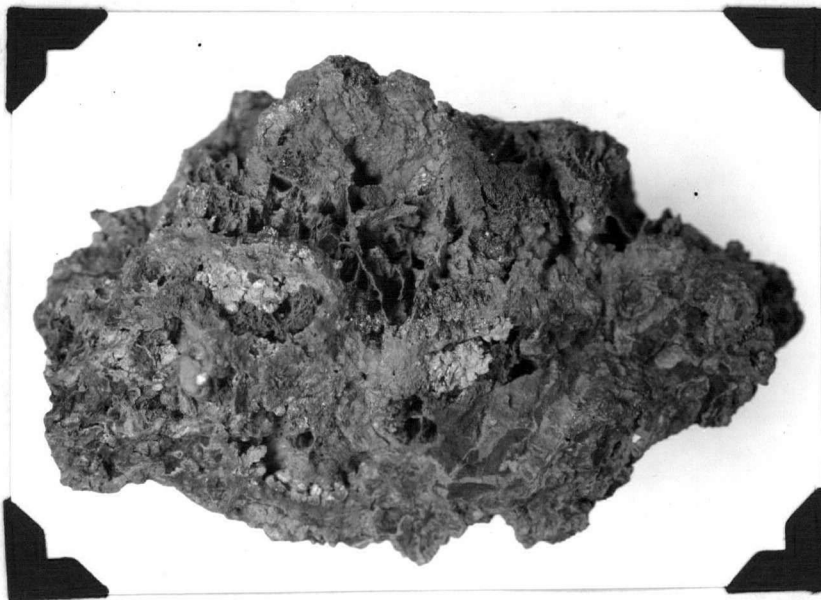


PLATE 26.

Type 6 limonite, showing the "cleavage boxwork" of galena derivation. The other side of this specimen contains weached galena. X $1\frac{1}{2}$.



PLATE 27.

Photomicrograph of polished section of Type 6 limonite, showing the "cleavage boxwork" of galena derivation. The cell walls are metallic limonite. Note the tendency toward double walls. X 65.



PLATE 28.

Photomicrograph of thin section of Type 6 limonite, with semi-transparent, non-metallic, orange colored veinlets forming a "cleavage boxwork" pattern in opaque metallic limonite.

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APPENDIX

PREPARATION OF THIN AND POLISHED SECTIONS

Due to the porous and fragile nature of some of the specimens, difficulty was encountered in attempting to make satisfactory polished sections, and it was found almost impossible to make thin sections in the normal manner. attempts were made to impregnate the specimens with Canada balsam before grinding and polishing, but these were not very successful.

J.A. Donan suggested and tried a method that proved satisfactory, and this method was used for most of the thin and polished sections described herein. The specimen should be heated to about 100° C for a few hours to drive off most of the oil taken up during the sawing operation. It is then completely immersed in an "impregnating fluid" bath and the whole subjected to a fairly strong vacuum for 24 hours. Upon removal, the specimen should be found to be well coated and impregnated with the now sticky and viscous impregnating fluid. It is then heated in an oven at a controlled temperature of 70° C for 24 hours, followed by a further 24 hours at 100° C. (Note- Donan has since found that one 24 hour period of heating at 100° C is satisfactory.) At the end of this time the impregnating fluid has become "baked" to a fairly hard and brittle mass. The polished or thin section may then be finished in the normal manner.

The impregnating fluid used was "Bakelite Plastics", manufactured by C.I.L., and commonly referred to as Bakelite Varnish. It was thinned by adding methyl alcohol, or a 50-50 mixture of methyl alcohol and ether. This reduces the viscosity and allows the impregnating fluid to more easily penetrate the cavities, pores and capillary openings. Under the vacuum the volatile substances are "boiled off", leaving the remaining very viscous "Plastic" filling the spaces.

In these first few attempts, while success was achieved, it was found that some large cavities were not wholly filled, and some smaller ones hardly at all. Nevertheless the porous structure was still preserved even in thin sections, though of course holes were left. It seems that the baked plastic that forms an enclosing shell around the whole border as the section is being ground, holds it so rigidly that the structure is saved in spite of the imperfect impregnation. It may be found that improved impregnation would result by using a low vacuum during the early part of the immersion period.

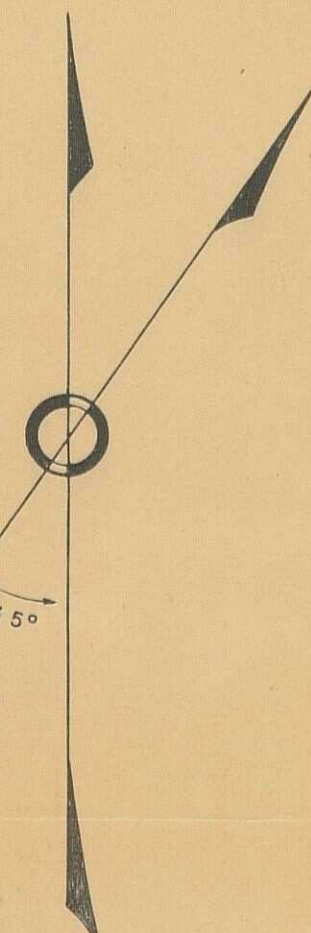
— STAR GROUP —

SCALE 1" = 500'

OCT. 1946.

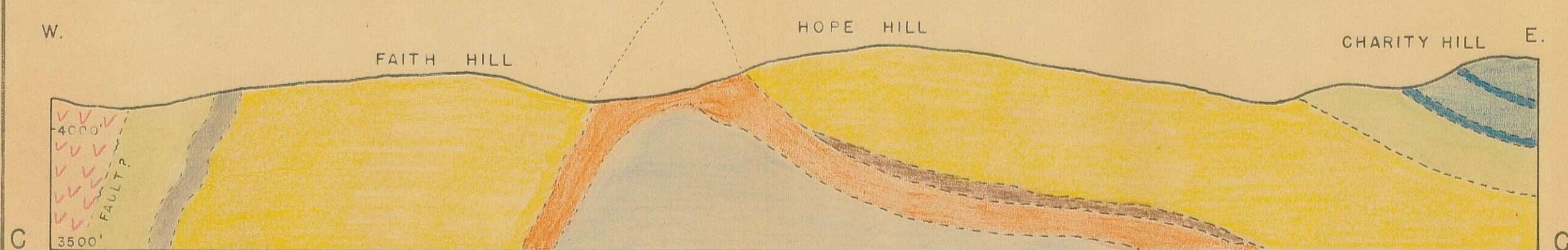
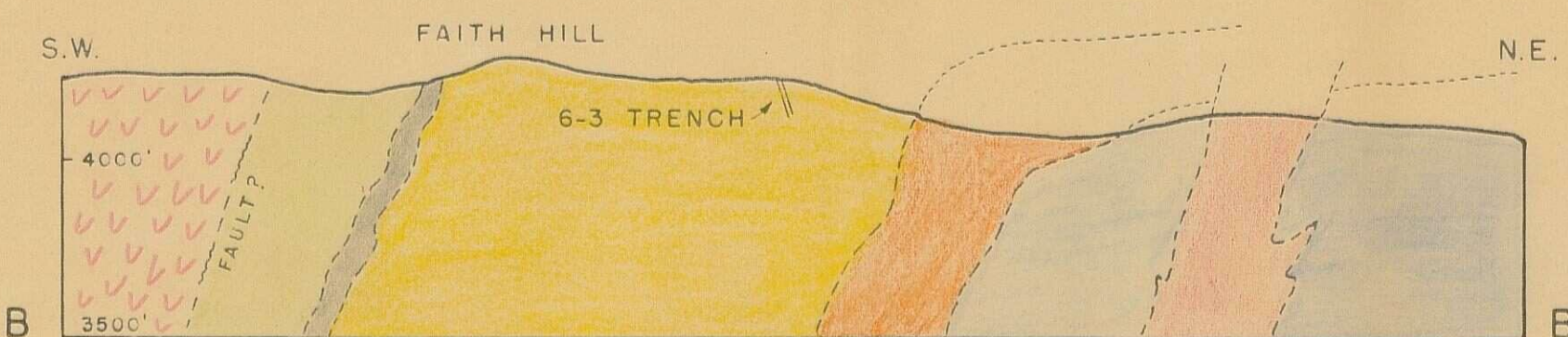
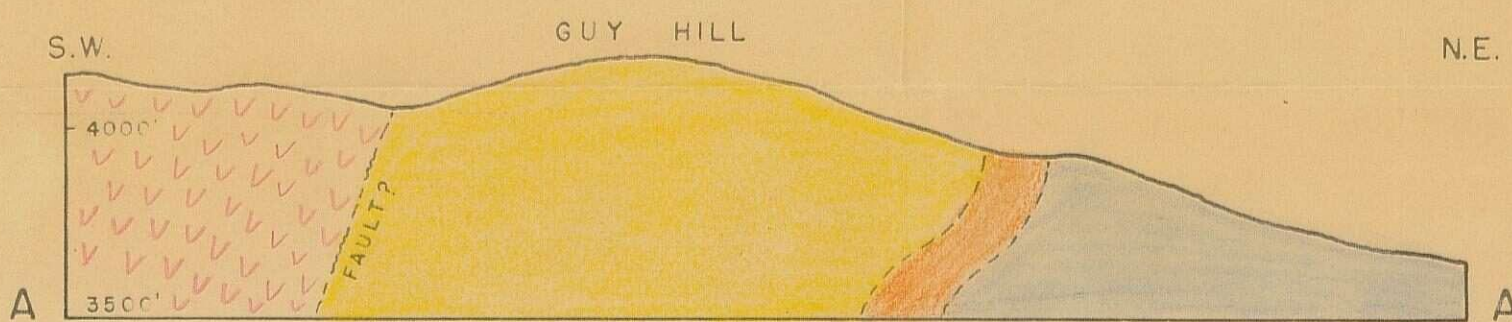
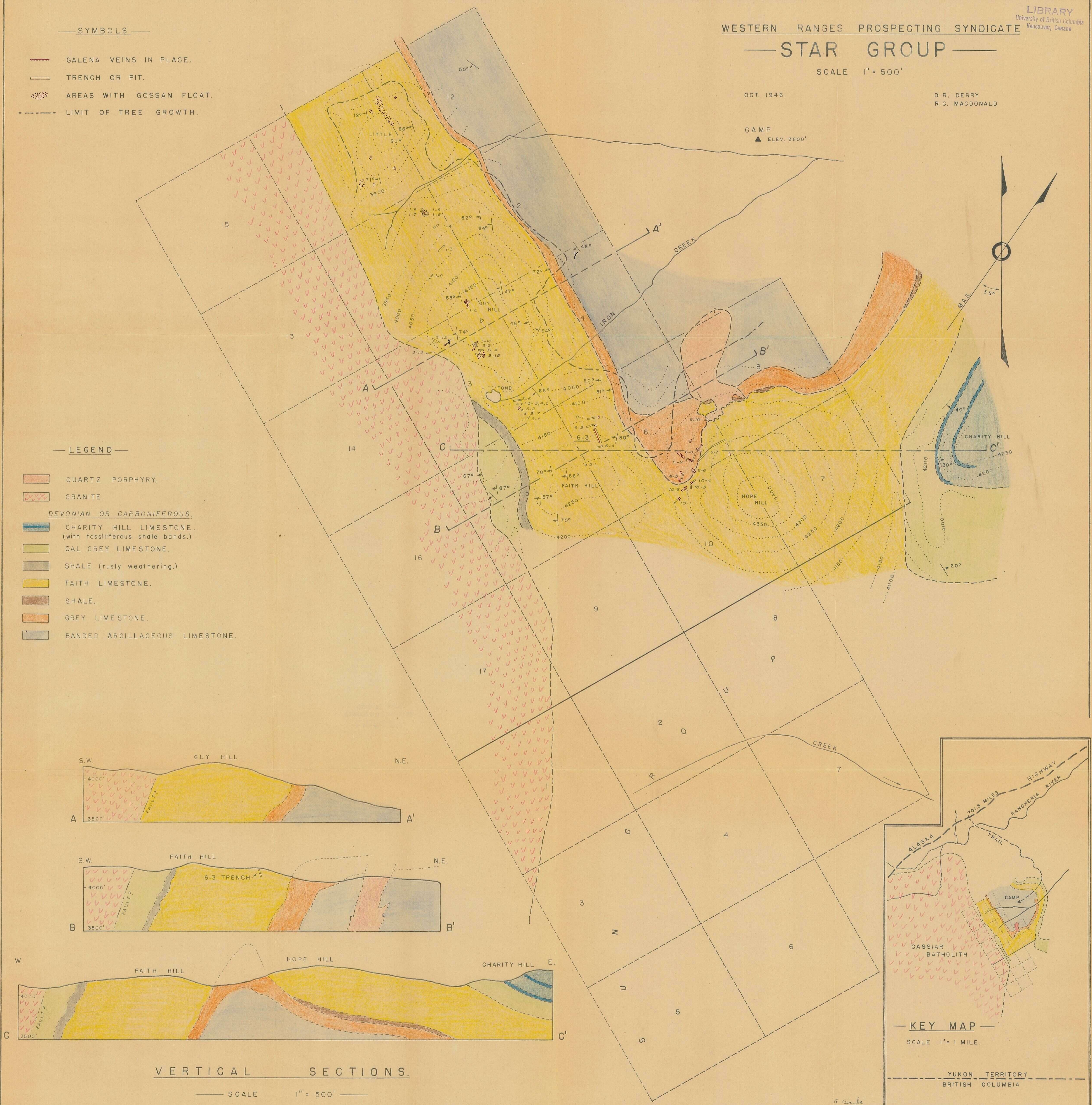
D.R. DERRY
R.C. MACDONALD

CAMP
▲ ELEV. 3600'



- SYMBOLS —
- GALENA VEINS IN PLACE.
 - TRENCH OR PIT.
 - AREAS WITH GOSSAN FLOAT.
 - LIMIT OF TREE GROWTH.

- LEGEND —
- QUARTZ PORPHYRY.
 - GRANITE.
 - DEVONIAN OR CARBONIFEROUS.
 - CHARITY HILL LIMESTONE.
(with fossiliferous shale bands.)
 - CAL GREY LIMESTONE.
 - SHALE (rusty weathering.)
 - FAITH LIMESTONE.
 - SHALE.
 - GREY LIMESTONE.
 - BANDED ARGILLACEOUS LIMESTONE.



VERTICAL SECTIONS.

SCALE 1" = 500'

