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REPORT OF INVESTIGATIONS

No. 52

PRE-CAMBRIAN GEOLOGY OF THE GALENA-ROUBAIX DISTRICT, BLACK HILLS, SOUTH DAKOTA

by

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Vermillion, South Dakota
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Page 4, line 14	Rochford for Rockford
Page 4, line 21	lithologic for lithiologic
Page 9, line 5	phyllites for phylites
Page 19, line 5	some for ome
Page 21, line 32	microperthitic for micropertheti c
Page 30, line 17	Becke for Becks
Page iii, line 2*	Tanganyika for Tanganyaika

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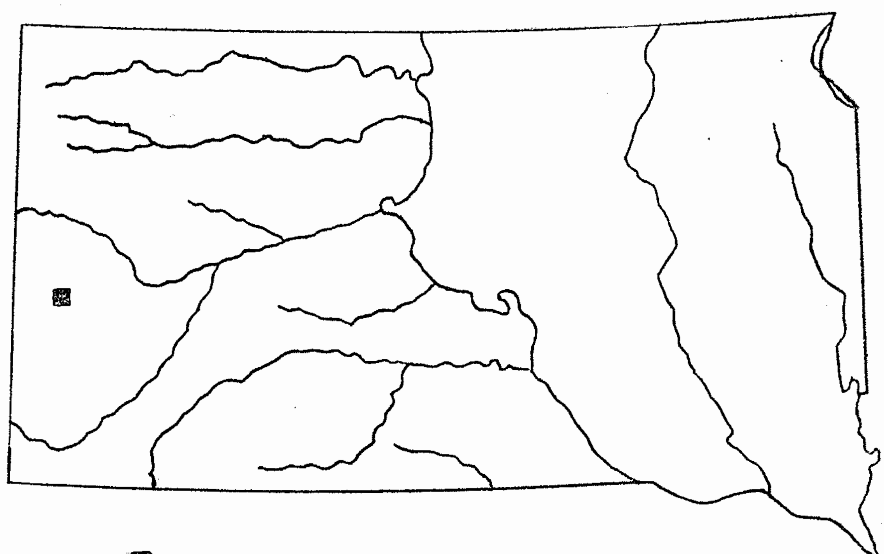
INDEX MAP



■ Area Covered By This Report

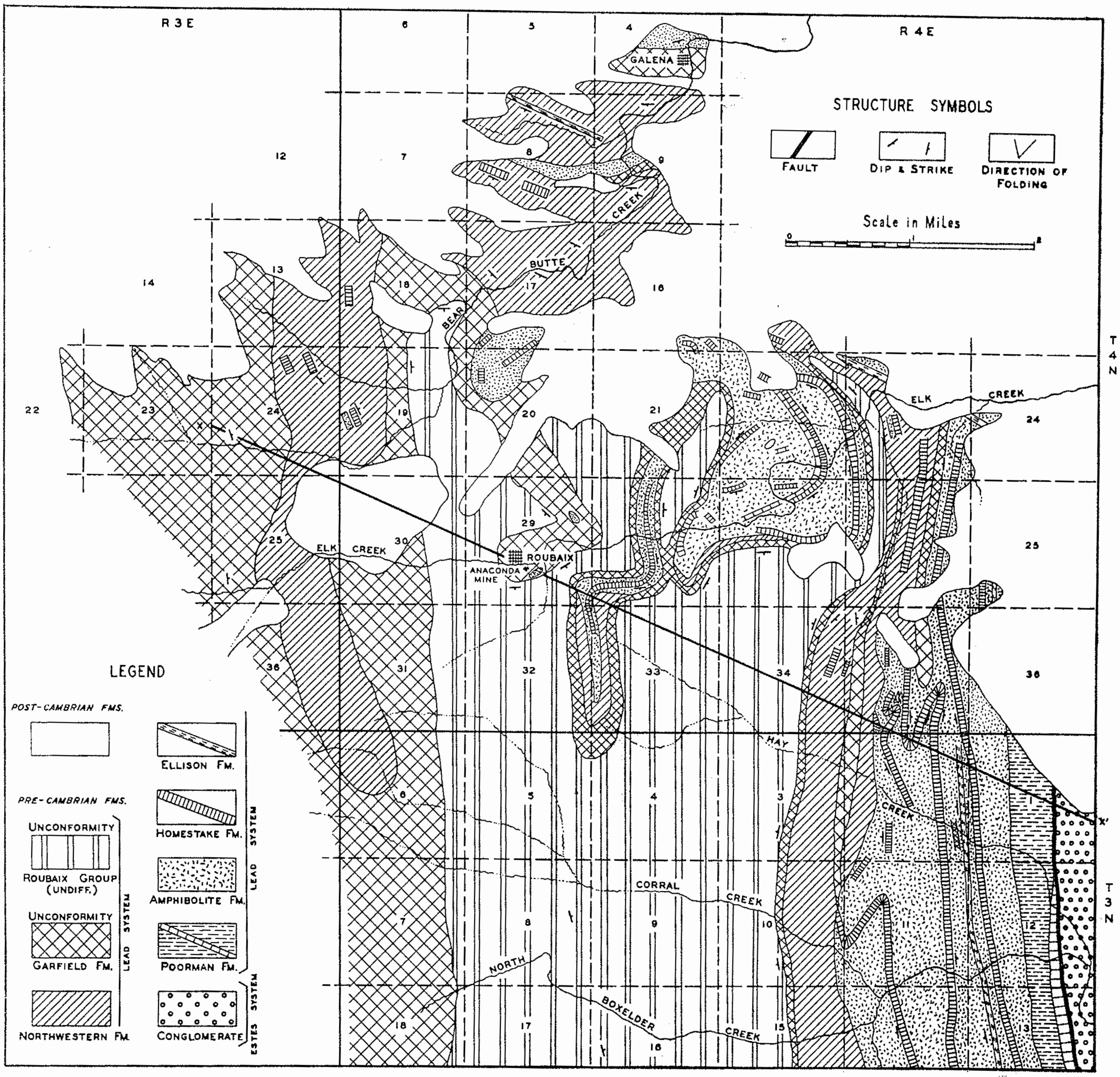
GEOLOGIC MAP

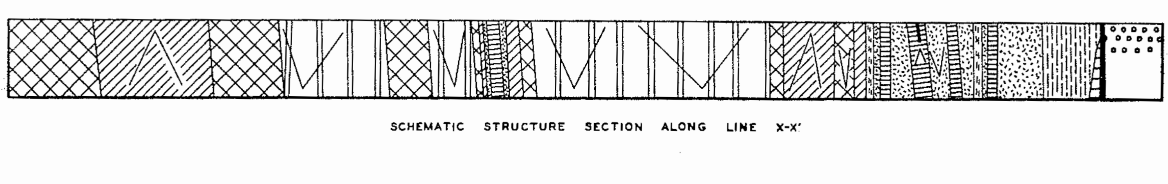
OF THE

GALENA - ROUBAIX DISTRICT

IN

SOUTH DAKOTA





SCHEMATIC STRUCTURE SECTION ALONG LINE X-X'

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PRE-CAMBRIAN GEOLOGY OF THE GALENA-ROUBAIX DISTRICT,

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INTRODUCTION

The following account of the pre-Cambrian geology of the Galena-Roubaix District was undertaken in an attempt to decipher the stratigraphy and structure of the pre-Cambrian rocks of the region, and to secure further data on the problem of the amphibolites, and the effects of thermal and dynamic metamorphism on various kinds of rocks.

The field work for this study was inaugurated during the summer of 1940, by a six weeks stay during July and August in the area. In the ensuing academic year, 1940-41, a petrographic examination and study of the rock specimens was made. During the summer of 1941, eight weeks were spent in the area, during which time the formations were mapped in some detail. In the following academic year, 1941-42, a more comprehensive study by petrographic examination was made of a more varied series of rock types, with particular emphasis on the varied facies of the amphibolites.

The aid rendered by Douglas Klemme of Coe College (Cedar Rapids, Iowa) as field partner during the summer of 1940 is appreciatively acknowledged. During the summer of 1941, the assistance in plane-table mapping by George De Buchananne of the State University of Iowa is acknowledged. During the whole period of study of this area, grateful acknowledgment is accorded the constructive criticisms and valuable suggestions of Dr. J.J. Runner of the State University of Iowa, under whose suggestion and supervision this study was undertaken.

Geography

The Galena-Roubaix District is located in the northeastern part of the Black Hills of western South Dakota, about ten miles southeast of the Lead Region which is famous for the presence here of the Homestake Gold Mine, the largest gold producer in the western hemisphere. The Galena-Roubaix District more specifically centers around T. 4 N., R. 4 E., of the principal Black Hills meridian.

The Black Hills comprise a dome-shaped elliptical uplift, about sixty miles wide east and west, and over one hundred miles long north and south. The higher elevations are several thousand feet above the surrounding plains; the average elevation of the Galena-Roubaix District is between 5500 and 6000 feet above mean sea level. The higher elevations provide greater relief formed by the canyons cut into pre-Cambrian and Paleozoic rocks. Younger sedimentary formations form gently-dipping hogbacks away from the center of the Hills. Completely surrounding the Hills is the "Red Valley," formed in the Triassic red beds; surrounding the red valley are prominent hogback-forming Cretaceous sandstones, the back slopes of which dip gently out to the plains.

In the numerous stream valleys as well as on the parks formed by gravel deposits on the old erosion surfaces, small farms are occupied mostly with the raising of grains and grasses for the feeding and grazing of cattle. The wide "Red Valley" contains numerous large farms.

The only other stimulus to settlement of the region is the presence of various types of ore deposits, particularly gold. The town of Roubaix was formerly the scene of the operation of the Uncle Sam or Clover Leaf gold mine. In the early 1900's some lead, silver, and zinc were mined at the town of Galena. The largest towns in the northern Hills are Lead (population, 5000), and Deadwood (population, 2500). Lead is the seat of location of the Homestake gold mine. Deadwood, which grew up in the early part of the century largely as the result of rich placer deposits in adjacent stream valleys now thrives mainly on tourist trade. Sturgis, Spearfish, and Rapid City serve mostly as supply depots for ranchers.

The region is served by the Chicago and Northwestern and Chicago, Burlington, and Quincy Railroads, many hard surfaced highways, and Inland Airlines.

Previous Literature

The pre-Cambrian rocks of the Galena-Roubaix District have never been mapped in detail, nor have formation names been applied to the various types of rocks found in this area. Newton and Jenney (1880), Crosby (1888), and Van Hise (1890), early contributed to the general geology of the Black Hills regions. The work of Irving (1904), and Paige (1913) deal more specifically with the economic resources of the Black Hills. Runner (1921) was the first investigator to do any other detailed stratigraphic work outside of the Lead Region, when he discussed the evidences of unconformity within the Black Hills pre-Cambrian rocks of the Nemo District. The Nemo District lies adjacent to the Galena-Roubaix District at its southeast extremity. The papers of Hosted and Wright (1923); Paige, Hosted, and Wright (1923); and Paige, Hosted, and Wright (1924); deal specifically with the geology of the Lead Region and its relation to the Homestake ore body.

In 1925, the government folio on the general geology of the Central Black Hills was published. Since then, McLaughlin (1931), Gustafson (1933), and Wright (1936), have published papers relating specifically to the geology of the Lead Region and its relation to the origin of the Homestake ore body.

In 1934, Runner published an elaboration of his earlier paper (1921), on the geology of the Nemo District. The relation of certain igneous and sedimentary amphibolites, (1933), and the subject of intrusive sedimentary amphibolites (1936), have also been discussed by Runner. Hamilton (1935) also suggested the possible original sedimentary character of amphibolites in the Keystone District of the Southern Black Hills. In addition to the works cited above, numerous writers have published on the geology of the Southern Black Hills, especially in relation to the granites. This subject, however, is not concerned with the subject matter of the present dissertation.

General Geology of the Black Hills Pre-Cambrian Rocks

The pre-Cambrian of the Black Hills consists mostly of metamorphosed sedimentary rocks, the metamorphic equivalents of calcareous and arenaceous shales, sandstones, and limestones. Two or three series of granitic intrusives occur, the largest of which is the Harney Peak pegmatitic granite. Amphibolites, which have been described as basic igneous intrusive rocks, are to be found intercalated with the sedimentary rocks.

There are three systems of pre-Cambrian sedimentary rocks described in the Black Hills; this is evidenced in the vicinity of Nemo. According to Runner (1934): (1) the oldest system includes quartz schist and iron formation; this is designated the Nemo System. (2) Unconformably overlying the Nemo System is the basal conglomerate of the Estes System; this basal conglomerate contains contorted and drag folded boulders of Nemo quartz schist and iron formation, indicating that the older system had been subjected to severe folding before being eroded to produce the basal conglomerate. Overlying this basal conglomerate are four other formations of the Estes System. (3) Overlying the system unconformably, or separated from the Estes System by a fault is the Lead System; the rocks of the Lead System are well represented at Lead and in the Homestake Mine.

Sediments similar to those of the Lead System are found also in the Galena-Roubaix District, in the Rockford District (J.J. Runner, personal communication), and in the Keystone District (Hamilton, 1935). A division of rocks younger than those of the Lead System may well constitute another division. The name Roubaix Group is used for this division of rocks in this paper. The Roubaix type of rocks are designated a "group" inasmuch as they constitute "a local or provincial subdivision of a system based on lithiologic features.....is less than a standard series, and contains two or more formations" (Bartram, 1939).

The above Nemo and Estes Systems were first described and named by Runner (1934). The formations of the Lead System were first described by Hosted and Wright (1923), and these formations were designated the Lead System by Runner (1934).

Field research up to the present time seems to indicate that in the Galena-Roubaix District the younger pre-Cambrian rocks occupy the center of the area of pre-Cambrian rocks, while the older systems are found on the periphery of the pre-Cambrian outcrop. This would indicate that the structure is, in general, that of a synclinorium, of great magnitude (Darton and Paige, 1925). Superposed on the larger structural feature of the synclinorium are minor anticlinal and synclinal structures, numerous drag folds, and some faults. The beds are severely metamorphosed, and folded into a series of tightly closed, isoclinal folds. The dips of the beds are relatively steep, from sixty to ninety degrees; some beds are found to be overturned.

Younger than the above described systems of sedimentary rocks are the intrusive granites; these are almost wholly confined to the Southern Black Hills, but may have effected some thermal metamorphism in the Northern Black Hills.

According to Taylor: An earlier gray granite is fine-grained, and contains biotite and oligoclase as prominent constituents; this granite is designated the Game Lodge granite. The Harney Peak granite is pink, very coarse-grained, and consists dominantly of microcline, quartz, muscovite, and tourmaline; it is believed to be younger than the Game Lodge granite. The late pegmatitic phase of the Harney Peak granite is noted for its development of large crystals. The Little Elk Creek genissoid granite is exposed on Little Elk Creek, only a few miles southeast of the Galena-Roubaix District; it is questionably correlated with the Game Lodge granite (Taylor, 1935).

The only other known occurrences of granite in the Northern Black Hills are the inclusions in Tertiary rhyolite of several blocks of pegmatitic granite near Whitewood Peak, two miles east of Deadwood. The small veins of granitic composition occasionally found in the sediments in the Galena-Roubaix District may have some genetic relation to one of the principal granites.

STRATIGRAPHY OF THE GALENA-ROUBAIX DISTRICT

General

Most of the rocks found in the Galena-Roubaix District are believed to be correlatives of rocks of the Lead System. The Galena-Roubaix District overlaps the Nemo District at the former's southeast extremity. Certain formations of the Nemo District which Runner has mapped as belonging to the Lead System (Runner, 1934), continue northwestward into the Galena-Roubaix District. In the north and northwest portions of the Galena-Roubaix District, rocks which are described and mapped as the Garfield and Northwestern formations, strike northwestward toward outcrops of the Garfield and Northwestern formations in the Lead District. However, these formations cannot be traced directly to the Lead District because of the Cambrian and Tertiary igneous cover which separates the Lead District from the Galena-Roubaix District.

The interpretation that the rocks designated as such represent the Lead System may be incorrect. There is evidence that the strata at Roubaix represent another division of rocks that do not correlate with the Lead System. The two most potent arguments that this is not the Lead System are the absence of the Pluma formation, and the very poor development of the Ellison formation. Of the Ellison formation Paige says: (Paige, Hosted, and Wright, 1924)

> "The beds, as might be expected from their origin, change from place to place in thickness and relative position with reference to the included slate bands, and have been thickened, thinned, and broken by folding."

Paige (Darton and Paige, 1925) has also described localities in the Lead District where quartzites have been duplicated as well as omitted. That the Pluma formation may have been removed by erosion is suggested by its absence in the Galena-Roubaix District, and by the coarse grit in the base of the formation, overlying the sequence of rocks designated the Lead System.

The older Nemo and Estes System are only exposed in the Nemo District to the southeast (Runner, 1934). The bulk of the rocks in the area under consideration are believed to belong to the Lead System. The youngest rocks in the area are younger than and overlie the rocks of the Lead System; in this report this youngest division of rocks has been designated the Roubaix Group. In their description and definition of the formations at Lead, Hosted and Wright (1923) described no rocks of this lithology or stratigraphic position.

What has been designated the Roubaix Group in this report may well be further divided into formations and members. However, no attempt has been made, within the scope of this present report to map these formations separately. The distinctive change in lithology from the schists and meta-limestones of the Lead System to the arkosic, quartzitic, and coarsely grit stone character of the Roubaix type of rock, is the essential reason for this subdivision, and the designation of the Roubaix type of rock as the Roubaix Group. The coarsely gritstone character at the base of the Roubaix Group gives credence to a supposed erosional unconformity at this juncture.

The rocks of the Roubaix Group are very similar to and may correlate with the Samelias formation of the Keystone District, in the Southern Black Hills. The Samelias formation, which Hamilton (1935) has mapped on the west side of the Keystone District possibly extends northward to Rapid Creek, and westward to include the rocks of the Hill City area (J.J. Runner, personal communication). The Samelias formation and the Roubaix Group are of apparently the same stratigraphic horizon. In the Keystone District, the Samelias formation overlies a system of rocks which Hamilton has tentatively correlated with the rocks of the Lead System. (Hamilton, 1935). Inasmuch as the Roubaix Group is of a lithology somewhat similar to the Samelias formation, and inasmuch as the Roubaix Group also overlies a division of rocks which are interpreted as correlatives of the Lead System, it is possible that these two divisions of rocks, the Roubaix Group and the Samelias formation, may be stratigraphic equivalents. There is some indication that the rocks of the Roubaix Group can be traced directly southeastward to the Keystone District. This type of rock has been traced from the northwest portion of the Galena-Roubaix District, southeastward to south of Rapid Creek, southwest of Pactola (T. 1 N., R. 5 E.).

The amphibolites of the Lead, Galena-Roubaix, Nemo, Rochford, Keystone, and Bear Mountain areas have been described by Paige (Darton and Paige, 1925) as metamorphosed basic igneous rocks, originally of dioritic or gabbroic composition. According to Paige these occurrences are almost invariably parallel to the bedding of the sedimentary strata, and are usually found at the same stratigraphic horizon. The amphibo-

EXPLANATION OF PLATE 1

a. Silicified Homestake fm. ridges; E. of NW. of Sec. 27 (4,4).

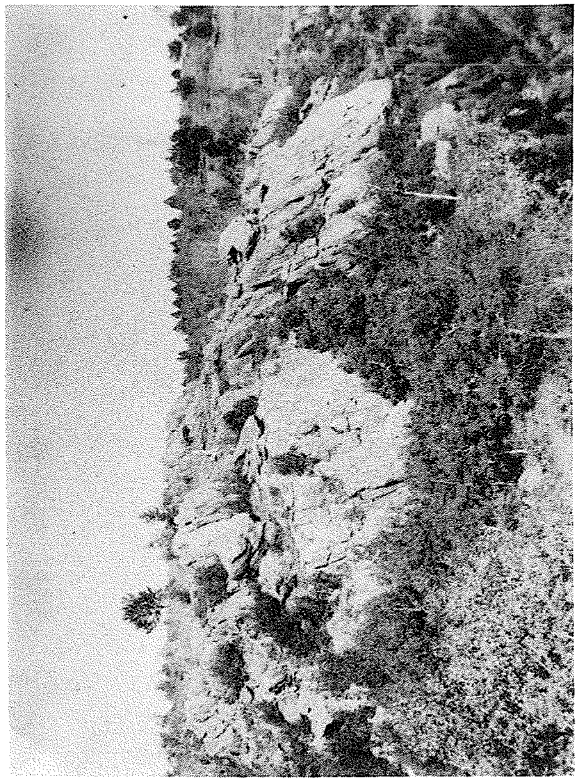
b. Contorted Roubaix schist and quartzite; NE. of SW. $\frac{1}{4}$, Sec. 23 (4,4).

c. Silicified outcrops of Homestake fm. in amphibolite; SW. $\frac{1}{4}$, NE. $\frac{1}{4}$, Sec. 22 (4,4).

d. Contorted Homestake fm. showing alternate layers of saccharoidal quartzite and silicified ferruginous-carbonate layers.

PLATE I

A



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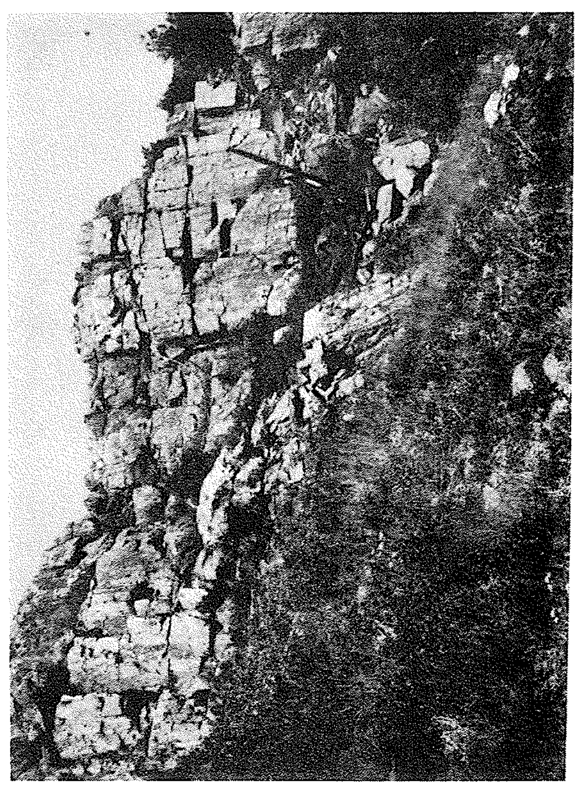

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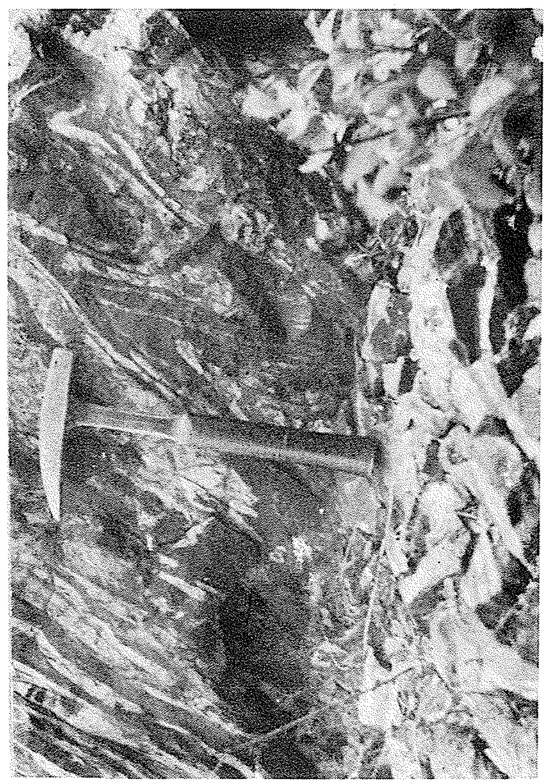

D

lites in the Lead District are also prominent in another stratigraphic horizon.

Descriptions of formations of Galena-Roubaix District

Poorman formation: The Poorman formation consists of black slates and phylites, often somewhat calcareous, green chloritic schists, some interbedded limestones, and amphibolite.

The lithology of the black slates and phyllites varies considerably. Many are ferruginous, hard, and have a high specific gravity; this variety is not at all schistose but does appear to be laminated. The iron content of these rocks weathers into segregations of pure hematite, and gives the rock a scoriaceous or slag-like appearance. Some graphitic material is present in the high iron varieties. Where there is less iron present in the rock it is essentially a graphitic slate that is soft and has a low specific gravity; where more schistose this rock has numerous small garnets developed along planes of bedding. Both of these types of rocks grade into a schistose rock that is largely a chloritic schist.

The Poorman formation is almost invariably very calcareous, and in the Nemo District the formation includes thick limestones (Runner, 1934). In the Galena-Roubaix District, what may be the silicified equivalent of metamorphosed limestone is the rock occurring contiguous to the Homestake formation, in the SE $\frac{1}{4}$ of sec. 22, the N $\frac{1}{2}$ of sec. 27, and in the SW $\frac{1}{4}$ of sec. 35 (T. 4 N., R. 4 E.). It is a very silicified and ferruginous rock often containing radiating amphibole. Macroscopically, the rock appears very altered due to weathering. It is bright red to reddish-brown in color, due to oxidation of the iron. Silicified, honey-colored relicts of radiating amphibole are discernible, and veins or layers of saccharoidal quartzite are commonly present. In this section the quartz is found to be clear and crystalline, presenting a sutured texture. The quartz shows no strain shadows or separated isogyres in the interference figure. The quartz gives no evidence of having been sheared or under stress. This indicates that the quartz is secondary. Either it has recrystallized from the quartz originally present, or it has replaced calcareous material. The radiating amphibole is grunerite.* Although the euhedral prismatic outline of the

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*$N_p = 1.670$; $N_m = 1.690$; $N_g = 1.705$; $N_g - N_p = .035$; $Z \wedge c = 13°$; Z = pale yellow; X and Y = colorless; $-2V = 80°$.

amphibole crystals is still present, the borders of the individual prisms are weathered to hematite, leaving a relatively small area of birefringent amphibole in the center of the weathered crystal. This and the optical properties both indicate a chemical composition high in iron. The optical properties indicate a chemical composition approximating $(OH)_2(Fe, Mg, Ca, Mn)_7Si_8O_{22}$; the ratio Fe:Mg:Ca:Mn = 81:11:4:4. (Larsen and Berman, 1934, p. 186).

Amphibolite: Amphibolitic rocks may constitute a separate formation or they may be an integral part of the Poorman or Homestake formations. However, it is believed that the amphibolites that usually characterize the contact of these two formations, are possibly the metamorphosed facies of calcareous, ferruginous sediments. Their description and the problem they present will be discussed more fully later.

Homestake formation: The Homestake formation usually has a distinctive appearance, although its lithology may vary considerably along the strike, laterally, and especially with depth. The formation is distinctly calcareous, and may be characterized as a ferruginous and calcareous amphibolite schist, containing saccharoidal quartzite lenses in the form of triaxial ellipsoids. Individual specimens may vary from calcareous chloritic schists to calcareous amphibolites. Common constituents are amphibole (hornblende and grunerite), various micas, chlorite, quartz, intermediate plagioclase feldspar, and ferruginous and calcareous carbonates. Less common constituents and those occurring in lesser amounts include garnet, apatite, tourmaline, and numerous ores (pyrrhotite, pyrite, and arsenopyrite).

Due to alteration by weathering and silicification of the surface exposures, the variation of lithology with depth is significant from the standpoint of identifying and mapping the formations from surface exposures. Specimens taken from surface outcrops or from near-surface prospects would not very likely show more than a few of the above enumerated minerals.

A comparison of specimens from various depths in the Lead District is interesting. The description of the lithology of the Homestake formation at various depths in the Homestake Mine is compiled largely from Paige and Wright. (Paige, Hosted, and Wright, 1924; Wright, 1936).

1. Specimens from varying depths of the Homestake Mine are characterized as a carbonate

series of rocks including many varieties of schist. "A highly metamorphic bed......contains many small flattened lenses and bands of sugar-grained quartz set in a compact matrix of cummingtonite, and a lime-iron-aluminum garnet......A common variety of this calcareous schist is characterized by chlorite and biotite. This rock exhibits various shades of green and has in many places a decidedly micaceous appearance.....On casual inspection it shows little resemblance to limestone, though it may carry as much as 50% of carbonate......scattered patches of oxidized ferriferous dolomitic carbonate.

"....the more highly metamorphic example.... is an abundant development of cummingtonite and green mica emeshed in a groundmass of quartz and a subsidiary feldspar. Residual carbonate is seen with the microscope.....and illustrates clearly the fan-shaped development of cummingtonite. The cummingtonite has replaced not only the carbonate but also much quartz.

"....the carbonate series includes many varieties of schist in which, besides varying amounts of iron, magnesium, and calcium carbonate, there occur biotite, sericite, phlogopite, chlorite, amphibole, garnet, and quartz." (Paige, Hosted, and Wright, 1924)

2. In the near surface prospects, in road and railroad cuts, and occasionally in other surface exposures, the quartzite lenses are similar in appearance to those described from rocks in the mine. However, the intercalated layers of schist are here a ferruginous and silicified, rusty-brown aggregate of essentially hematite and quartz. In a few instances sideroplesite rhombs and cummingtonite are discernible.

3. In other surface exposures the rock is essentially a quartzite. The formation in many of these occurrences is so silicified that the saccharoidal character of the quartzite lenses has been destroyed by recrystallization during silicification. The lithology is then considerably changed from the above occurrences. The rock appears to be a quartzite with a few intercalations or rusty brown stringers of hematite. In some instances silicified vestiges of radiating amphibole are discernible.

EXPLANATION OF PLATE 2

a. Garfield fm. in abandoned railroad cut, center Sec. 23 (4,3).

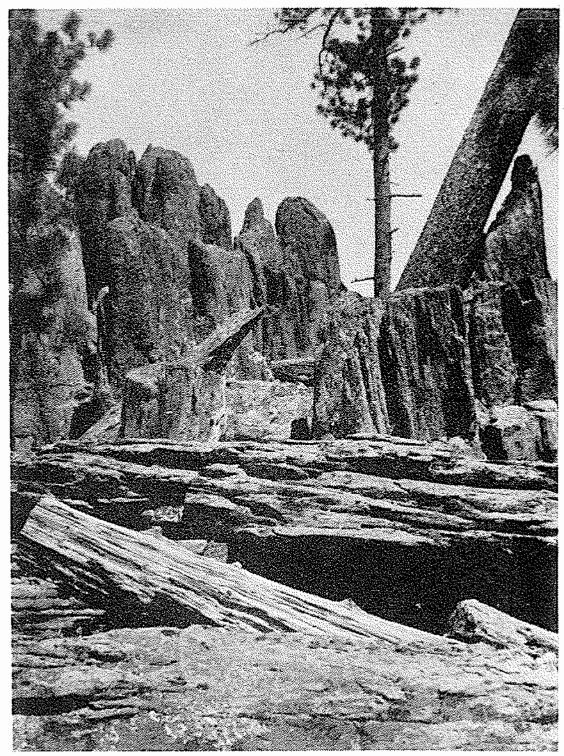
b. "Needles" of Roubaix quartzite; center Sec. 34 (4,4).

c. Massive Roubaix quartzite ridges; extreme SE. $\frac{1}{4}$, Sec. 33 (4,4).

d. Roubaix quartzite "needles;" center Sec. 34 (4,4).

PLATE 2

A



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In the Galena-Roubaix District most of the outcrops of Homestake formation are weathered to a ferruginous quartzite. Other occurrences are chloritic schists with a high percentage of carbonate. It is only upon recognition of the variations of this formation that one is able to map the formation correctly.

Ellison formation: The Ellison formation is only sporadically represented in the Galena-Roubaix District. Quartzite of typical Ellison lithology occurs in the N $\frac{1}{2}$ of sec. 8, T. 4 N., R. 4 E., and rarely next to the Homestake formation within the larger areas of amphibolite. However, it is well represented in the Nemo and Lead Districts. In the Nemo District, a limb of typical Ellison quartzite lithology is found on the west side of the anticline in the Lead System, extending from sec. 23, T. 2 N., R. 5 E. northwestward to sec. 13, T. 3 N., R. 4 E. (Runner, 1934). The northwestward continuation of this limb in the contiguous Galena-Roubaix District, is only poorly represented in the E $\frac{1}{2}$ of sec. 2, T. 3 N., R. 4 E., and sec. 35, T. 4 N., R 4 E.

The Ellison formation is a black and white banded granular quartzite, for the most part. The white bands are almost pure silica, while the black layers contain considerable ferruginous and graphitic material. Interbedded with the quartzites are occasional layers of mica schist, and dark gray to black quartzose phyllite. The quartzites in many instances contain a large amount of milky-white, cross-cutting vein quartz. Paige (Paige, Hosted and Wright, 1924) has suggested that the large amount of vein quartz in this formation in comparison with other formations, may be due to local derivation during metamorphism.

Northwestern formation: The Northwestern formation is composed of thick beds of garnetiferous mica schists. Intercalated are some lenses of amphibole schists, biotite schists, and quartzites. The formation does not form very prominent outcrops, and is not extensively exposed except in road or railroad cuts. The original lithology of the Northwestern formation must have been such as to make it particularly susceptible to the effects of thermal metamorphism. Garnets are characteristic of the formation, although they are not usually very large, -from 1 to 4 mm. in size. However, where the effects of thermal metamorphism are evident, for example, in Ruby Gulch (sec. 4, T. 4 N., R. 4 E.), very large garnets, up to 6 cm. in diameter are developed. Here also, in an occurrence of granitic material in the schist, large tourmaline crystals are found; some are as large as 10 cm. long and 1 cm. in diameter. South and west of Galena, in secs. 4, 8, and 17, the mica schists contain garnets up to $\frac{1}{2}$ cm. in diameter.

West of here in T. 4 N., R. 3 E., the formation is more ferruginous and contains small garnets profuse in layers along bedding planes. Here also, the formation contains thin quartzite lenses, 5-10 mm. wide. These quartzite lenses are also well developed in the garnet schists east of Roubaix, in sec. 26, T. 4 N., R. 4 E. This quartzitic phase may correspond to the quartzite member in the Northwestern formation in the Lead District.

Garfield formation: The Garfield formation, in this area, resembles the Poorman formation in some respects. It is easily recognized by its characteristic graphitic slates; intercalated in many occurrences are micaceous schists, but these also are somewhat carbonaceous or graphitic. The graphitic slates in places contain minute garnets, some of which have weathered to only a pin head sized spot of limonite. In places the graphitic slates are highly ferruginous; in other occurrences there is much sulfur in the formation. This was found to be ferrous sulfate, and occurs as copious yellowish-white to yellow incrustations on the under surfaces of weathered Garfield rocks, (e.g., in the railroad cuts, in west center, sec. 23, T. 4 N., R. 3 E.). Due to the large segregations of pyrite and marcasite abundant in the graphitic slates and schists, there are in many places abandoned prospects in the Garfield formation, (e.g., sec. 9, T. 4 N., R. 4 E.).

Pluma formation: Overlying the Garfield formation in the Lead District is a thick series of garnetiferous, amphibolitic, and carbonaceous schists, which are apparently not present in the Galena-Roubaix District. In this area the Roubaix rocks directly overlie the Garfield formation. If the interpretation that these rocks represent the Lead System is correct, the absence of the Pluma formation gives further credence to the supposed erosional unconformity at this horizon.

Roubaix Group

The Roubaix Group of rocks are varied in lithology, including more than two lithologically mappable units, so that the group may well be separated into formations. As aforementioned the Roubaix Group of rocks are very similar in appearance to the Samelias formation of the Keystone District

(Hamilton, 1935). They are also very much similar to the same type of rock in the vicinity of Hill City in the Central Black Hills. This type of rock has been traced from the northwestern portion of the Galena-Roubaix District, southeastward to south of Rapid Creek, southwest of Pactola (T. 1 N., R. 5 E.).

The basal portion of the Roubaix Group is in places a blue-grey quartzite; in other places it may be described as a grey to brown quartzose schist. Both of these varieties locally contain relatively coarse grit (grains from 2 to 6 mm. in diameter).

In one section the gritty quartzose schists and quartzites are found to contain approximately 50% quartz, 10% intermediate plagioclase feldspar, 30% mica (including biotite and sercite), and varying percentages of dolomitic carbonate.

In addition to these more prominent constituents, hornblende, garnet, muscovite, sulfides and oxides of iron, titanite, ilmenite, and apatite are occasionally seen.

The texture is typically porphyroblastic showing larger grains of quartz and feldspar in a fine-grained lepidoblastic groundmass of smaller quartz grains and various micas.

The quartz is in whole grains approximately 1-.5 mm. in diameter, or in aggregates of smaller grains. The shape of the quartz grains is curvilinear to sub-angular with numerous salients and re-entrants. In some instances the quartz grains show cross fractures, and under crossed nicols usually show strain shadows, wavy extinction, and separated isogyres in the interference figure.

The feldspar ranges from oligoclase to andesine and shows good albite twinning. Some orthoclase is present. The feldspar grains are about the same size as the quartz grains. Both quartz and feldspar usually have their long axis parallel to the directive texture of the rock.

Biotite is dark brown (rarely green) in color. It occurs in irregular but oriented and strung-out aggregates, which gives the rock a marked directive texture. In addition, biotite occurs concentrated and completely surrounding the larger grains of quartz and feldspar.

Sericite and some muscovite (Al:Fe = 15:1; K:Na = 6:1) are distributed in minute grains (usually .06 mm.) throughout the section. The carbonate (impure Mg calcite) occurs in strung-out masses parallelling the directive texture. The carbonate occurs in grains as large as the quartz and feldspar (1-.5 mm.); however, it is not nearly so prevalent as the quartz and feldspar. The calcite shows well developed twin and glide planes. These carbonate masses may have some relation to the solution pits and weathered-out cavities so common to and characteristic of the Roubaix type of rock (see p. 33).

Interbedded with the upper portion of the quartzose schists and quartzite are black quartzose schists of similar lithology, differing only in color. The grit they contain is smaller in grain-size and lesser in amount. Where more severely contorted, metamorphosed, and intruded by abundant quartz veins, this black variety of the quartzose schist is essentially a biotite schist. The biotite schist lithology is most characteristic northeast and southwest of Hay Creek, east of Roubaix (sec. 33 and 34, T. 4 N., R. 4 E.; and secs. 3, 4, and 5, T. 3 N., R. 4 E.)

West and northwest of Roubaix the Roubaix rocks are less quartzose. Although they form relatively prominent outcrops, they do not compare in topographic expression with the outcrops on the bare, treeless slopes northeast of Hay Creek. Northwest of Roubaix (secs. 18 and 19, T. 4 N., R. 4 E.), the rocks are thinly laminated, grey to almost white in colors, and their composition is a slightly quartzose schist. Minute garnets (1 - 2 mm. in diameter) are often developed along bedding planes where the rock is of this lithology. This type of rock is typical of the Roubaix aluminous sediments.

In thin section they are composed of 70 to 80 per cent mica, 10 to 20 per cent quartz, and some plagioclase feldspar. About 50 per cent of the mica is a green biotite, oriented directively in aggregates; these aggregates of biotite average from .5 to .25 mm. in length, and from .12 to .06 mm. in width. The grains and aggregates of sericite are usually smaller. The marked orientation exhibited by the micas gives the rock a distinctive lepidoblastic texture.

Garnet occurs as small crystalloblasts (1-.25 mm.) showing poikiloblastic texture. It has well defined six-sided, isometric outlines. The border and a narrow peripheral zone (probably 30 per cent of the crystal) is clearly crystalline, isotropic, and contains no relicts of quartz. The centers of individual crystals are usually birefringent due to myriads of extremely minute relicts of quartz (.016-.008 mm.). This center also contains some grains of magnetite about the same size as the quartz relicts. The tiny grains of quartz are oriented at an angle to the schistosity determined by the biotite and sericite. This orientation is the same as the elongation of random chlorite plates; apparently the garnet has developed from or has replaced chlorite. The chlorite is present as prismatic crystals slightly larger than the biotite fragments. Some of the chlorite is strongly pleochroic and may have developed from hornblende. Garnet may have been formed directly from the hornblende and the chlorite may be a later alteration product of the hornblende still remaining.

A minor amount of minute grains of quartz, intermediate plagioclase feldspar, and magnetite are distributed throughout the rock.

Where less resistant and more schistose the aluminous sediments show biotite porphyroblasts, or segregations of biotite; this gives the rock a spotted appearance. This type of rock occurs as a thin member and is present only sporadically. However, it seems to be characteristic of this horizon of rocks and may represent a stratigraphically mappable unit. (This type of lithology is well developed in the N $\frac{1}{2}$ of the SW $\frac{1}{4}$ of sec. 28; in the S. center of sec. 32, T. 4 N., R. 4 E., et al loc.

The rock containing the biotite porphyroblasts is of much the same lithology as the above described aluminous sediments. However, no garnet is found to be present. The "spots" or segregations of biotite are found in thin section to be aggregates of biotite flakes, rather than porphyroblasts or single crystals. These aggregates of biotite are often concentrated around a nucleus of granulated quartz grains. In this respect they show some similarity to the concentrations of biotite around the large grains of quartz and plagioclase feldspar in the grits. (Refer to page 16.)

Ellipsoids: The Roubaix type of rocks contain some triaxial ellipsoidal-shaped structures. These may correspond to the "meta-calcareous concretions" of Runner and Hamilton (1934), inasmuch as they are similar in lithology and occur at approximately the same stratigraphic horizon. Rather than being concretions, the structures found in the Galena-Roubaix District may represent lenses of calcareous matter rolled into cylindrical-shaped pods during shearing. The ellipsoids found in the Galena-Roubaix District are roughly cigar-shaped, -from 5 to 10 cm. across the short and intermediate axes, and from 0.3 to over one meter in length.

Their center is a calcareous, ferruginous, titaniferous nucleus, now porous and almost destroyed by modern weathering; the porosity suggests solution of calcareous material, and the remaining weathered products consist of oxides and hydrated oxides of iron and titanium. Surrounding this nucleus are heterogeneously oriented crystals of hornblende, and some garnet (both crystalloblasts), set in a white matrix of plagioclase feldspar (labradorite) and quartz. Surrounding this zone of material is the thinly laminated aluminous sediment in which the ellipsoid was developed. Ellipsoids of this lithology were only found in two localities, along old railroad cuts in the SW $\frac{1}{4}$ of sec. 27, and in the NW $\frac{1}{4}$ of the SW $\frac{1}{4}$ of sec. 23, T. 4 N., R. 4 E.

The ellipsoids in both these localities seem to have been developed where the formation was constricted by cross-folding, and where calcareous material was present for the formation of hornblende, garnet, and calcic feldspar.

Smaller ellipsoids, much similar in outward appearance to those containing hornblende, are found profusely in rocks of the Roubaix Group. On the surfaces of outcrops they weather out in the solution pits and cavities described later.

Thin sections of the hornblende ellipsoids reveal an interesting structure and mineralogy. Their chocolate-brown-colored nucleus now consists almost wholly of leucoxene and limonite, together with some ilmenite, hematite, and magnetite, and often much recrystallized secondary quartz.

Surrounding the central zone is a zone rich in calcium carbonate (contains some $FeCO_3$ and $MgCO_3$). Carbonate minerals comprise 20 to 60 per cent of the section. Individual grains of carbonate are from .25 to .12 mm. in diameter, but aggregates are strung out in masses from 2 to 1 mm. long. Interspersed between the carbonate masses are smaller grains of quartz (10 to 30 per cent) and labradorite feldspar (5 to 10 per cent).

Hornblende comprises from 10 to 50 per cent of the outer zone. It occurs in prismatic porphyroblasts as large as 2 cm. in length. The hornblende shows excellent poikiloblastic texture. In replacing calcic plagioclase feldspar and carbonate, quartz has been left as relicts; in ome instances, carbonate has been abundant enough to have been left over in the reaction to produce the hornblende, and it then occurs as relicts in the poikiloblastic hornblende. Hornblende is later than or contemporaneous with garnet development. Hornblende is occasionally replaced by penninite.

Garnet occurs in very imperfect crystalloblasts that do not show poikiloblastic texture. The garnet shows no well defined outlines as in the above described aluminous sediments. The component parts of the garnet are oriented parallel to the directive texture of the quartz-plagioclase aggregates, the separated garnet fragments forming only a rough outline of a crystal.

The quartz and plagioclase feldspar form a granoblastic texture of small grains. The plagioclase is untwinned, its composition from An_{50} to An_{55}. The grains of quartz and feldspar both show wavy extinction, and other effects indicating strain.

Apatite is sparingly present in late well crystallized grains from .25-.12 mm. in cross-section. The presence of apatite may indicate some genetic relation of the ellipsoids to the period of thermal metamorphism.

Solution pits and cavities: Solution pits and weathered-out cavities are abundant in the rocks of the Roubaix group. That these features may have some relation to the segregations of carbonate material in the Roubaix rocks, is entirely possible. Carbonate is also abundant in the coarse grits, and here also cavities and solution pits are developed. That these cavities have some relation to the hornblendic ellipsoids is also evident. Apparently the ellipsoids have developed where the proper constituents were present for the formation of hornblende, garnet, and other minerals that characterize the ellipsoids.

Megascopically, the material from which the pits form appears very similar to the ellipsoids' composition. The material is light gray to white in color in contrast to the gray to brown color of the quartzose schists or the blue-gray

EXPLANATION OF PLATE 3

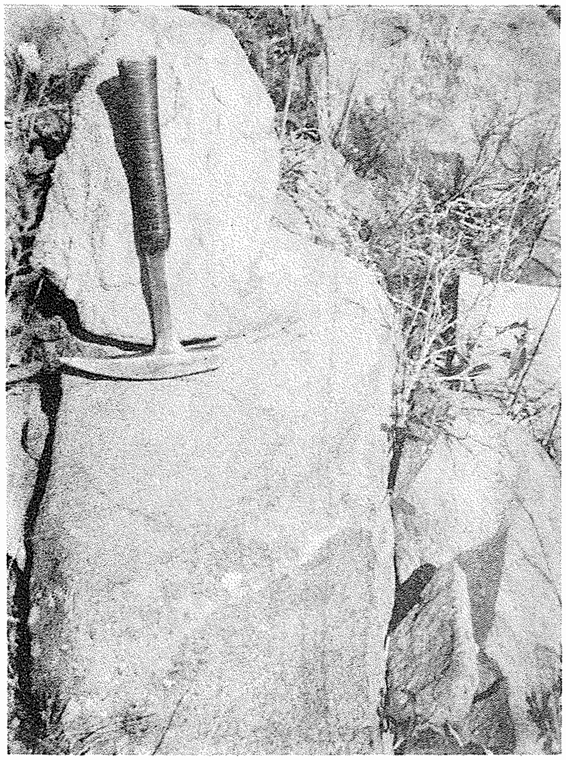
a. Roubaix quartzite with interbedded coarse grit; bedding N.-S.; schistosity, N. 50° E.

b. Roubaix quartzite; note coarse grit to right; bedding, N.-S.; schistosity, E.-W.

c. Weathered pits in Roubaix quartzite aligned parallel to bedding (N. 75° E.); schistosity, N. 30° W.

d. Roubaix quartzite and quartzose schist, Sec. 34 (4,4).

PLATE 3



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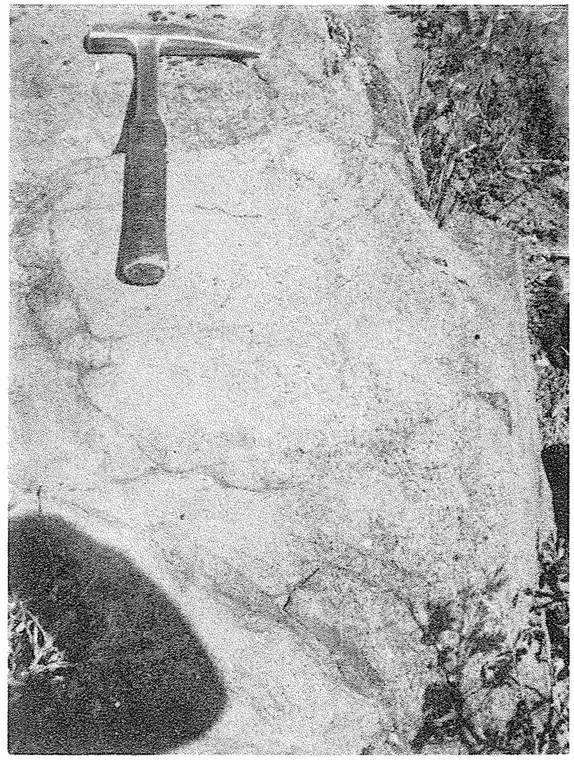

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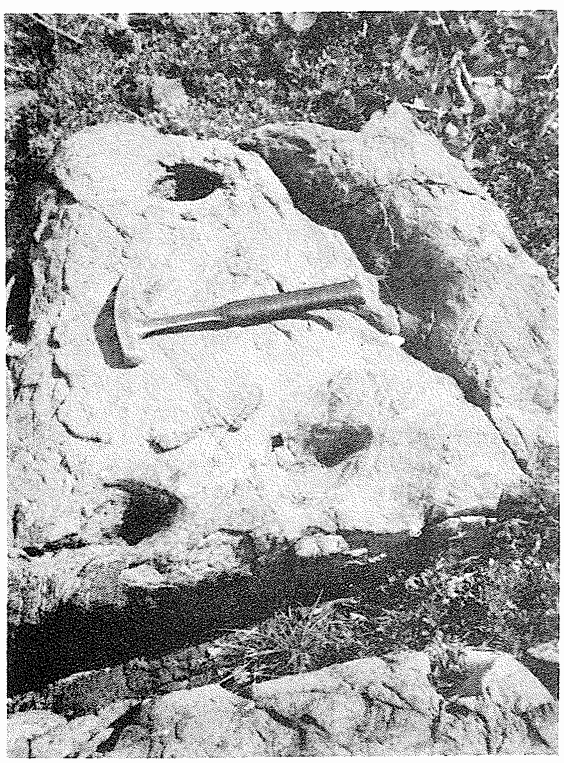

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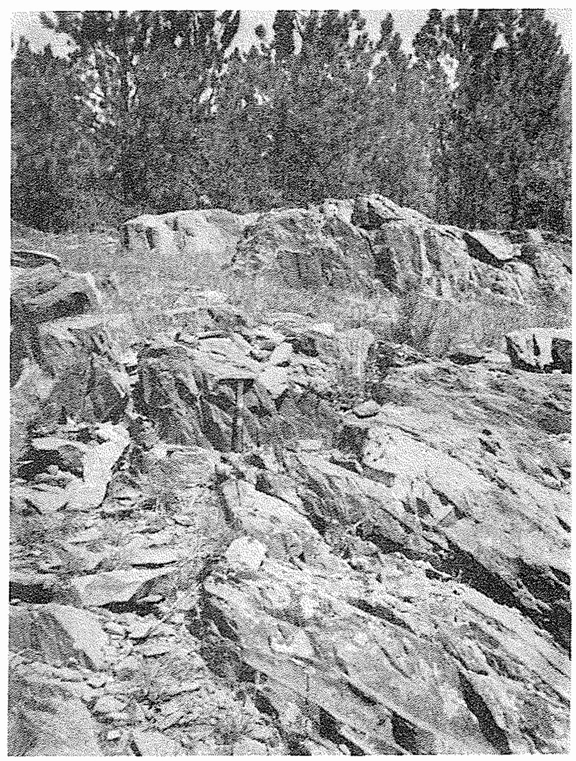

D

color of the quartzites. The cavities are cross-sections of ellipsoids which pitch in the same direction as the pitch of the structures. The lenses are from one-half to several meters in length. Their short dimension is from 1 cm. to 10 cm., and their intermediate dimension is from 5 to 15 cm. Their intermediate axis parallels the schistosity, but a group of the ellipsoids are oriented in lines parallel to the planes of bedding.

Veins in the Roubaix rocks: Veins of transparent quartz, milky white quartz, and granitic material seem to be more abundant in the Roubaix group of rocks than in other rocks of the region. They are particularly abundant in the quartzites and quartzose schists. These veins may be parallel to the bedding or the schistosity, but most often they are found to be cross-cutting in relation to both the schistosity and bedding. The veins are commonly only 1-3 mm. in width, and of great vertical and longitudinal extent. Where spaced at intervals greater than their width the veins appear as ribbed flutings on the rocks. The abundance of quartz veins in quartzitic rocks has been explained by some (Paige, Wright and Hosted, 1923) as being due to local derivation during metamorphism. However, these veins often expand from their most common dimensions into larger lenticular granitic masses from .2 to 5 cm. in width. Here, they contain a greater variety of minerals which seem to relate the veins to emanations from a granitic source.

In thin section the larger masses of granitic material are found to consist of biotite, intermediate plagioclase feldspar, penninite, chlorite, muscovite, ilmenite, and titanite. The feldspar ranges from oligoclase to labradorite; some of the crystals are large (8-4 mm.), show excellent polysynthetic albite twinning, and microperthetic intergrowths. Other instances show small granules of untwinned plagioclase (.12 mm.). The penninite is secondary after the hornblende and biotite. Quartz is rarely present; some of the larger masses contain tourmaline; some contain carbonates.

It is believed that these veins represent introduced material contemporaneous with the intrusion of the larger massifs of granite of the Southern Black Hills. That the veins are not local or related to earlier periods of dynamic metamorphism is suggested by their granitic composition, and by the fact that they usually show no relation to the direction of bedding or schistosity.

MINERALOGY OF THE AMPHIBOLITES

Megascopic description

The amphibolites show a great deal of variation in color, coarseness of grain, degree of schistosity, and mineral composition. Their color is usually some shade of green, commonly from a dark grass green color to greenish-black. Some are brown to honey-colored due to hydration of iron compounds; others are almost coal black due to the abundant carbonaceous matter contained.

A common variety is a very coarse massive rock composed of bunched aggregates of radiating amphibole crystals. Individual aggregates of radiates are as large as one cm. in diameter. Individual hand specimens show little evidence of schistosity, but larger areas of amphibolite in the field show a directional structure parallelling the strike of the body. This variety is usually grass-green in color.

Another variety is termed a "podded amphibolite," since it is composed of numerous closely spaced, ellipsoidal shaped pods of amphibole crystals; these pods impart a rough linear cleavage to the rock. Individual pods (aggregates of hornblende crystals) are 1-2 cm. in length and 2-5 mm. in diameter. The long axis of the individual pods is oriented parallel to the regional pitch of the structures. This type of amphibolite is also dark green in color.

Other varieties include a very black, schistose amphibolite showing a marked plane cleavage; a fine-grained, quartzose, massive, hard variety; others which contain a high percentage of calcium carbonate and chlorite, and are soft and schistose; and still others of fine-grained green amphibolite containing ellipsoidal-shaped pods of feldspar.

Many of the green amphibolites are cut by veins of zoisite or clinozoisite. These are almost invariably associated with an abundance of calcite. Calcite also occurs in rounded and flattened lenses, ellipsoidal or cigar-shaped. The calcite is well crystallized in small rhombs; the individual rhombs are from one to three mm. in diameter. The lenses are from 10 to 15 cm. in cross-section, and usually from two or three to many meters in length. Quartz veins are also found cutting the amphibolite, but they are neither so abundant nor as large as the calcite and zoisite veins.

General discussion of mineralogy

The most prominent and abundant constituents of the amphibolites are the various amphiboles, constituting from 50 per cent to 90 per cent of the rock. Some rocks which appear megascopically to be amphibolite contain as little as 5 per cent amphibole; this is because the amphibole is largely replaced by chlorite.

Calcium carbonate, intermediate plagioclase feldspar (An_{40}-An_{60}), and quartz are relatively persistent minerals of the amphibolites. These constituents are present in roughly equal amounts, -from 10 to 15 per cent of each. Their combined percentage usually totals the same in different amphibolites. In general, the percentage of $CaCO_3$ equals that of feldspar and quartz.

Various ores and their weathered products are present in the amphibolites. These include pyrrhotite, pyrite, magnetite, ilmenite, and the hydrous oxides, limonite and leucoxene. Chlorite and zoisite, developed after hornblende and plagioclase feldspar respectively, are less commonly present; when present, however, they constitute a large percentage of the rock. Constituents less commonly found and those found in lesser amounts are carbonaceous material, apatite, titanite, albite, and garnet (rarely).

Although some writers believe that the amphiboles have been derived from pyroxenes by metamorphism (Darton and Paige, 1925), the writer has found no evidence of original pyroxene, or evidence of amphibole secondary after pyroxene.

Microscropic Textures

The texture of the amphibolites composed largely of amphiboles is usually nematoblastic. Individual hornblende or other amphibole prisms often exhibit a poikiloblastic texture with relicts of quartz of $CaCO_3$, dependent upon the chemical composition of the rock. Less commonly a decussate texture is observed, showing prisms of amphibole randomly oriented.

TABLE I

Average and Median Percentage Composition of Amphibolites

Mineral Constituent	Average per cent	Median per cent
Amphiboles	50.0	60.0
Plagioclase feldspars	15.0	15.0
Calcium carbonate (including some varieties containing Mg and Fe)	12.5	12.0
Quartz	9.0	10.0
Ores	1.5	1.0
Chlorite	6.0	2.0
Zoisite and clinozoisite	5.0	30.0
Carbonaceous material	0.2	1.0
Garnet, titanite, apatite, et al. accessories	0.02	1.0

Where larger amphibole crystals are present in a groundmass of various other minerals, the amphibole usually occurs as porphyroblasts exhibiting poikiloblastic texture. Other constituents of the rock, including quartz, feldspar, and calcite often show a granoblastic texture. In rocks containing a lower percentage of amphibole, a diablastic texture is occasionally observed.

Detailed descriptions of the amphibolite minerals

Amphiboles: The most common amphibole found in the amphibolites is hornblende. The hornblende is usually highly pleochroic from dark green (Z) to lighter shades of green (X). Some varieties exhibit a bluish-green and green pleochroism; others are green to yellowish-green.

There are so many different molecules in hornblende that cause variations in optical properties that it is difficult to derive their chemical composition by correlation of optical properties found in published graphs. The usual properties found indicate a hornblende of the composition $H_2(Mg)(Na)Ca_2Fe_3Al_2Si_6O_{24}$.* (Winchell, 1934, p. 251) These properties indicate a composition higher in Ca and Fe, and lower in Mg and Na than the hornblende of the Southern Black Hills. (Hamilton, 1935) The amphiboles have apparently developed from the recrystallization and reaction of basic plagioclase feldspar and an iron rich calcium carbonate. Some hornblende may have developed from chlorite or other minerals. The hornblende usually shows a poikiloblastic texture, carbonates or quartz occurring as relicts in the sieve-like texture.

Two other amphiboles found less commonly in the amphibolites are of the cummingtonite-grunerite series, and of the actinolite-tremolite series. The mineral of the former series is a grunerite rich in iron. Optical properties indicate the composition $(OH)_2(Fe, Mg, Mn, Ca)_7Si_8O_{22}$; the ratio Fe:Mg:Ca:Mn = 81:11:4:4.** (Larsen and Berman, 1934, p. 186). The grunerite occurs in the hand specimen not as aggregates but as rosette-like radiates from a common center; their color is

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*N_m = ca. 1.690; $N_g - N_p$ = .020; $-2V$ = 70-80°; Z = dark green, X = light green; $Z \wedge c$ = 14°.

**N_p = 1.670; N_m = 1.690; N_g = 1.705; $N_g - N_p$ = .035; $Z \wedge c$ = 13°; Z = pale yellow; X and Y, colorless; $-2V$ = ca. 80°.

grey to brown with a silky luster. In thin section they show a well developed 110 cleavage and are only weakly pleochroic. The crystals and cleavage fragments characteristically show borders and surfaces covered with limonite and hematite stains. The comparable amphibole of the Southern Black Hills is cummingtonite, a variety much richer in Mg and poorer in Fe.

Members of the actinolite-tremolite series are rare in the amphibolites of the Galena-Roubaix District. It approximates the composition of actinolite containing 60 mol per cent $H_2Ca_2Fe_5Si_8O_{24}$ molecule. This is a high Fe, low Mg variety. It occurs as long, bladed, acicular crystals. Its pleochroic colors are usually weak bluish-green, $Z > X$.

The usually higher Ca-Fe percentage (low Mg-Na) in the amphiboles of the Galena-Roubaix area in comparison with the lower Ca-Fe (high Mg-Na) percentage in the amphiboles of the Southern Black Hills is interesting but logical. The higher Ca-Fe percentage is shown in all the amphiboles just described when compared with Hamilton's (1935) descriptions of the amphiboles higher in Mg and Na from the Southern Black Hills. The higher Mg-Na percentage in the amphiboles of the Southern Black Hills is apparently related to the intrusion of the granite there. The intrusion of the acidic granite mass has resulted there in the addition of soda and the formation of sodic minerals; the addition of much silica with the intrusion of the granite has resulted in a reaction with magnesian minerals already present in the rock and the precipitation of magnesian minerals. In this way the total composition of the amphiboles of the Southern Black Hills is seen to be higher in Mg and Na, and lower in Ca and Fe.

Feldspar ranges in composition from andesine to labradorite. Most often the more calcic feldspar is untwinned, and occurs in minute grains, similar in appearance to quartz, except that the feldspar has higher relief. The more sodic feldspars (An_{30}-An_{45}) are more often in larger crystals and often exhibit albite twinning. The feldspars form with the quartz a granoblastic texture, and often exhibit a mortar structure. The feldspars as well as the quartz, appear to have been granulated.

Quartz constitutes a variable percentage of the amphibolites. It exhibits with the feldspars a granoblastic texture or mortar structure. In many instances the grains appear mashed and mylonitized. The individual quartz grains are invariably minute, usually less than .06 mm. (Amphibole crystals in the same rock are usually many times this size, --from 1 mm. to .25 mm.). The quartz often shows separated isogyres in the interference figure, wavy extinction, irregular cross fractures, and other appearances of having been strained. However, in some instances quartz is completely normal and has apparently been recrystallized.

Calcium carbonate is a most common constituent of the amphibolites, sometimes comprising 40 per cent of the rock. The $CaCO_3$ usually contains some Fe but very little Mg. It occurs uniformly distributed in irregular-shaped masses throughout the sections, as relicts in hornblende, or in larger masses showing good twinning (grains from .5 to .25 mm. diameter). These larger masses appear to be concentrated in bleb-like forms. In one amphibolite in which the amphibole had been replaced by chlorite, the calcite is found stretched out in marked planes of lamination; the section then appears as alternate layers of ellipsoidal-shaped calcite masses and layers of quartz-chlorite aggregates. This variety shows much iron stain (limonite) associated with the calcite. It is possible that in some cases the limonite-stained $CaCO_3$ represents the disintegration of sideroplesite rhombs. Some examples preserve a roughly euhedral rhomb of calcite the periphery of which is formed of limonite.

Almost every thin section of amphibolite will show some percentage of the various ores, even though it be small. Pyrrhotite is most common; pyrite, magnetite, and ilmenite also occur accompanied by the hydration products, -limonite and leucoxene.

A deep olive-green penninite is often found replacing hornblende. It shows the characteristic anomalous interference colors. In places the penninite is abundant enough to form a chlorite schist.

Clinozoisite commonly replaces plagioclase feldspar, standing out in bold relief against the other minerals of the section, and characterized by its blue anomalous interference colors.

Garnet occurs very rarely in the amphibolites of the Galena-Roubaix District. Garnet was found in a single instance in an amphibolite from west of the town of Galena. This garnet does not show a poikiloblastic texture, is perfectly euhedral, and is crossed by irregular fractures.

EXPLANATION OF PLATE 4

a. Roubaix quartzite; bedding N.-S.; schistosity, N. 60° W.

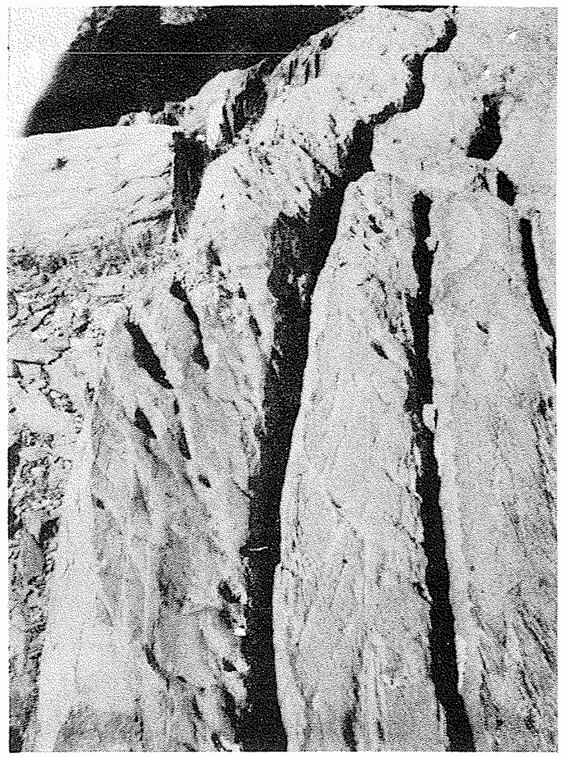
b. Massive and coarse-grained Roubaix quartzite; bedding N. 20° W.; schistosity, N.-S.

c. Typical solution cavity in Roubaix quartzite.

d. Weathered-out cavities in Roubaix schistose quartzite.

PLATE 4

A



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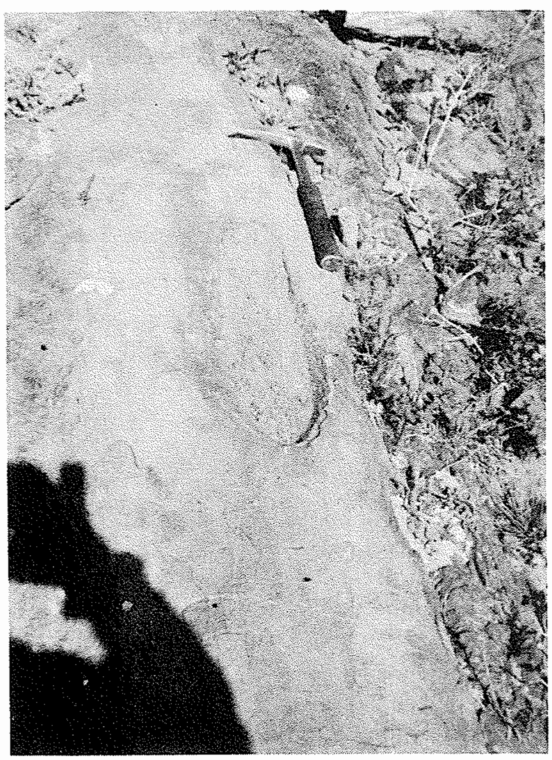

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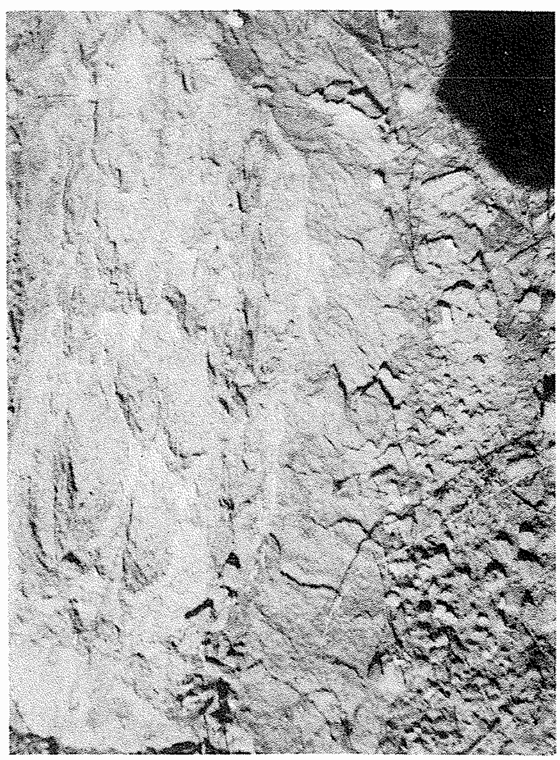

D

Carbonaceous and graphitic material occurs as a black opaque material. It is persistent in many of the amphibolites. (Ref. microphotograph, Plate 9, fig. 3) Megascopically the material is black in color, and has a black streak; it is soft and friable. In thin section it is opaque; it is black and non-metallic in reflected light. As seen in the microphotograph it occurs in parallel bands that are somewhat wavy. Less often it occurs sporadically disseminated throughout the thin section. It is believed that this material may represent carbonaceous material of an originally sedimentary rock.

DISCUSSION OF THE ORIGIN OF THE AMPHIBOLITES

Amphibolites and other rocks of similar chemical and mineralogical composition (including greenstones, epidiorites, meta-gabbros, etc.) are believed to have been developed in one or more of the following ways:

1. Granitization of limestones (Adams and Barlow, 1909).

2. Metamorphism of basic tuffs or lavas (numerous Lake Superior and European writers).

3. Metamorphism of basic igneous intrusive rocks, (Tilley, 1923; Paige, 1924, 1925).

4. Metamorphism of sedimentary beds (Wiseman, 1934; Runner, 1936).

Furthermore, the occurrence of these kinds of rocks has been noted along fault planes; because of this several writers have suggested a relationship between the regional tectonics and the development of this type of rock (Becks, Bertrand, Harker, Prior, Benson). Runner (personal communication) has suggested that these rocks may have developed _in situ_ along fault planes. An alternative explanation has been offered to account for the characteristic occurrence of amphibolites and similar rocks in sills and in association with calcareous rocks. It has been suggested that calcareous beds may have localized basic intrusives and caused their precipitation (Runner, 1933).

Paige states that most of the amphibolite rocks of the Black Hills are "metamorphosed igneous rocks of diorite-gabbro composition." However, of one lenticular mass of amphibolite west of Hill City, he states that "although no residuals or carbonate occur, the bed probably represents an impure sideritic dolomite." (Darton and Paige, 1925) However, according to Runner (personal communication), residuals of carbonate are very abundant in this rock. On the geologic map in the same publication (Darton and Paige, 1925), this rock, designated as an amphibole-garnet schist, strikes into and continues at its northern end as a mass of what Paige considers to be igneous amphibolite.

In the Galena-Roubaix District, the field relationships of the amphibolites always show two characteristics that are more typical of sedimentary rocks than of igneous rocks:

1. The amphibolites almost everywhere occur in concordant lenticular masses, parallel to the bedding of the sedimentary rocks.

2. The amphibolites are found at one stratigraphic horizon.

In addition to the points cited above, two other characteristics may be points of significance as to their origin, although they are not necessarily distinctive of sediments:

3. The amphibolites occur in zones adjacent to rocks characterized by abundant carbonate minerals, or carbonaceous material.

4. The amphibolites occur along planes of faults or shear planes.

These characteristics are also to a large extent true of the other areas of amphibolite rocks in the Black Hills. (Darton and Paige, 1925; Runner, 1934) These areas include the Keystone, Rochford, Nemo, and Bear Mountain Districts. In the Lead District the amphibolites are also well developed in another stratigraphic horizon. Cross-cutting relationships are rarely seen in areas of amphibolite; the most notable exception to this is in the Nemo District, just northwest of the town of Nemo. In this same area, a fault has been mapped along the contact and strike of the outcrop of the amphibolite. (Darton and Paige, 1925; Runner, 1934)

The mode of occurrence and rocks associated with the amphibolites in the Galena-Roubaix District are characteristics of the amphibolites that are similar to those found in other areas investigated. In an investigation of the literature on widely separated areas the world over, similar relationships to those cited above are found to exist. However, most authors have interpreted the amphibolites and similar rocks of these widely separated areas as meta-igneous in origin. The following table shows the relationships prevailing in approximately one hundred areas, at various localities on most of the continents.

Table II

Structural relationships			Contact rocks			Author's interpretation	
// to sediments	Cross-cutting	Both	C & CO_3	Other rocks	No data	Meta-sedimentary	Meta-igneous
85%	8%	7%	72%	21%	7%	27%	73%

The writer does not mean to imply in the ensuing discussion that the rocks of all areas represented in the above table are meta-sedimentary in origin. No doubt rocks of known meta-sedimentary and known meta-igneous origin have been included. The table merely represents the data on areas containing a particular kind of rock, including amphibolites, greenstones, epidiorites, meta-gabbros, etc.

However, the table makes it clear that geologists working in various regions of the world have found amphibolites, greenstones, and similar rocks, in great numbers, occurring in sill-like masses parallel to and in contact with sedimentary beds, of which the dominant type is carbonate or carbonaceous rock. In 73 per cent of the cases, the geologists have interpreted the amphibolites or greenstones as either intrusive or extrusive igneous rock. In only 27 per cent of the occurrences have these rocks been interpreted as meta-sedimentary in origin.

The problem then may be stated thus: If a considerable percentage of the amphibolites and similar rocks are of intrusive igneous origin, why do so many occur as sills? Furthermore, why should lava flows or basic intrusives be so commonly found in zones of calcareous rocks? If on the other hand, the amphibolites are of sedimentary origin, why have they so characteristically been metamorphosed to rocks closely resembling basic igneous rocks, whereas the metamorphosed shales and sandstones are still identifiable as such?

Inasmuch as the Galena-Roubaix District furnishes good examples of amphibolites in the typical occurrences, a consideration of the origin of these rocks seems pertinent.

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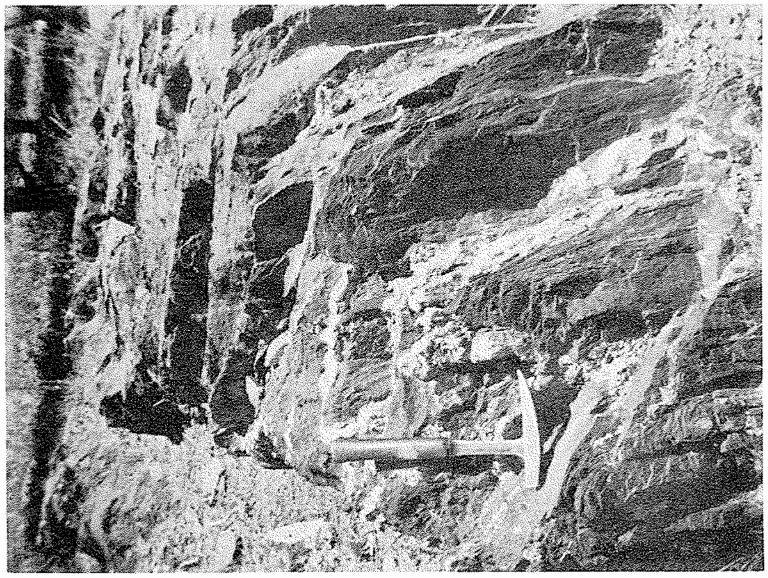
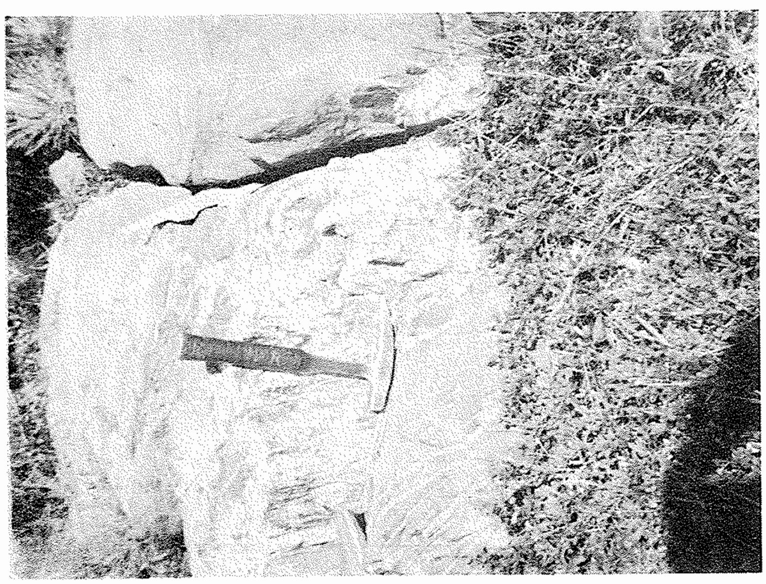
PLATE 5





TYPICAL VEINS IN
ROUBAIX QUARTZOSE SCHISTS

That a definite problem does exist in relation to the origin of this type of rock has long been recognized. Wiseman (1934) aptly summarizes some of the early works and opinions, especially in relation to the metamorphism of basic igneous rocks.

> "Ever since the publication of Teall's description of the Scouric dike (1885), and its passage from a dolerite into a foliated amphibolite by the ordinary processes of metamorphism, petrologists have from time to time directed their researches......to the study of the metamorphism of basic igneous rocks.
>
> "......among the earlier writers may be mentioned Maculloch (1821), De la Beche (1834), and Sterry Hunt (1875). Although frequently the work of these authors was a model of careful and accurate description, their inference that hornblendic rocks were chemical precipitates from a thermal ocean can today be regarded as of historical interest only. It was left for Jukes (1862) to suggest that hornblendic rocks were altered tuffs or lavas. Dealing with the amphibolites chiefly from southwest England, Allport (1876), Philips (1876), and Bonney (1883), expressed the view that they were metamorphosed igneous rocks. Shortly afterwards, the Scottish Geological Survey (Geikie, 1884), in the course of their investigations on the amphibolites of Aberdeenshire and Banffshire came to a similar conclusion."

Earlier than Wiseman's summary, Benson (1926) prepared a comprehensive memoir on the "Tectonic Conditions Accompanying the Intrusion of Basic and Ultrabasic Rocks." Benson investigated numerous areas all over the world in the light of Suess' generalization that "the green rocks form sills in dislocated mountains that sometimes follow the bedding planes and sometimes the planes of movement." Benson concluded that a relationship existed between tectonic conditions and the intrusion of basic igneous rocks:

> "Thus we may believe that the evidence here collected tends to the conclusion that each of the several morphological types of basic and ultrabasic rocks is very generally associated with as definite a set of

EXPLANATION OF PLATE 6

1. Albite (An_{10}) feldspar; calcium carbonate (shaded areas in upper left corner and right center portion); short biotite plates to right and left of feldspar; and hornblende; in granitized amphibolite. x14

2. Ellipsoid near contact of aluminous sediment; directive textured white area contains biotite, quartz, chlorite and intermediate plagioclase feldspar; poikiloblastic hornblende to left. x14

3. Center of metamorphosed ellipsoid; lower half is poikiloblastic hornblende; upper half is calcium carbonate (dolomitic); white areas are quartz. x32

4. Fine needles of very iron-stained and altered grunerite-amphibolite in almost wholly silicified rock. These rocks have been mapped as quartzite by the U.S. Geol. Surv. (Darton and Paige, 1925). x14

PLATE 6

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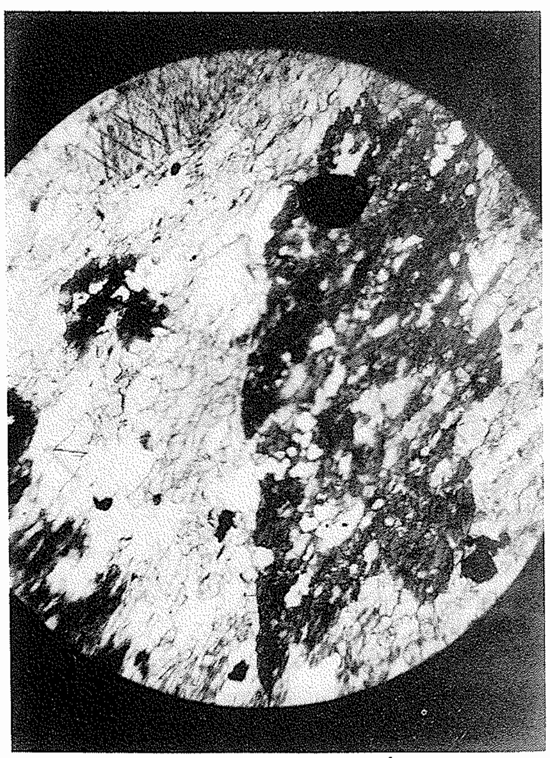

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tectonic conditions, and often with as definite a group of less basic igneous rocks."

Benson visited many of the areas on which he based his conclusions, but much of his data is based on reference to literature only. He assumed that all the areas he investigated were areas of basic and ultrabasic igneous rock. No doubt many of the areas investigated by Benson are areas of basic igneous rocks. However, many of these regions show certain relationships which raise a question as to a possible alternative mode of origin of the rocks. These relationships are similar to those cited in Table II. A large number of the "areas of basic and ultrabasic igneous rocks" show parallel and concordant relations to the adjacent sediments, and adjacent contact rocks are often calcareous rocks. We again question why rocks of this general composition should so often show concordant relations to the adjacent sediments, and why the contact rocks should so often be calcareous.

In order to account for the concordant nature of amphibolite rocks and to explain their characteristic occurrence in zones of calcareous rocks, Runner (1933) developed an hypothesis which might be in keeping with the data secured in the field. The abstract of this paper is quoted in full:

> "Several workers in the Black Hills pre-Cambrian have noted a remarkable coincidence in occurrence of amphibolites derived from basic intrusives with others derived from pure carbonate rocks. Recent studies in this region have revealed further examples of this phenomenon, together with a close association of these rocks with ferruginous quartz veins. There are many thousands of feet of pre-Cambrian in which igneous amphibolite and quartz veins are lacking, but much of the greatest development of the basic intrusives is in the horizons of calcareous rocks. Various explanations for this association are suggested with the emphasis laid upon the possible effect of calcareous beds in localizing the intrusives by causing their precipitation. The silica of the accompanying quartz veins is believed to be derived from the igneous rocks at the time of their consolidation."

Later (1935), Runner suggested an alternative explanation on the origin of certain of the amphibolites of the Black Hills.

"In the pre-Cambrian of the Black Hills amphibolites quite clearly derived from sediments have the chemical composition of rather basic igneous rocks and locally show intrusive relationships. The sedimentary amphibolites were formed from calcareous, magnesian, and ferruginous shales by recrystallization under great pressure. The intrusive amphibolites represent portions of the sedimentary amphibolites that have migrated as plastic masses along zones of weakness in the enclosing rocks. There seems to be little or no evidence that fusion was involved; hence, process is not properly regarded as anatexis or syntexis."

In an effort to bring out the similarities and differences between hornblende of meta-sedimentary origin and hornblende of meta-igneous origin, Tilley (1938) compared the hornblende "in low-grade metamorphic zones of the Green Schists." This investigation and comparison was made on two groups of British rocks, "the Green Beds of the Highlands (Philips, 1930), and the Green Schists of the Start Area of South Devon (Tilley, 1923), the former sedimentary and the latter genuine derivatives of basic igneous rocks."

More recently, Temperley (1938) discusses the presidential address of Read to the British Society (1939). Temperley was particularly perturbed by two points in Read's address. The similarity of these points to characteristics of amphibolites cited earlier in this discussion is notable:

"1. How was the bulk of the dolorite sill converted to amphibolite?

2. Why is the plane of foliation of the amphibolites parallel to the surfaces of the sills at whatever angle they lie?"

These quotations on the problems of certain metamorphic rocks and summaries of their interpretation by various researchers makes clear certain points:

1. Metamorphic rocks clearly derived by the metamorphism of certain sediments, and those derived by the metamorphism of basic igneous rocks, are distinguished only with difficulty.

2. Amphibolites, greenstones, and similar rocks either show certain characteristics that are unique to the intrusion of basic igneous rocks, or, there is something inherent in the physical and chemical constitution of certain sedimentary rocks to easily metamorphose them to rocks of seemingly dioritic or gabbroic composition and texture.

Origin of the Galena-Roubaix Amphibolites

It is the belief of the writer that the amphibolites of the Galena-Roubaix District are metamorphosed calcareous, dolomitic, and ferruginous shales, rather than metamorphosed igneous rocks of gabbroic or dioritic composition. Some of the reasons for this belief have already been suggested; these and other evidence will be here presented.

1. a. In no instances are cross-cutting or discordant relations found. The amphibolites occur with their strike (elongation) parallel to the strike of adjacent known sedimentary beds.

b. The amphibolites everywhere occur at the same stratigraphic horizon.

c. The amphibolites everywhere occur in zones of calcareous rocks or rocks containing carbonaceous material.

2. The writer believes that propounders of the theory of derivation of amphibolites from gabbroic and dioritic rocks have failed to take into account another factor. Such derivation is a higher grade metamorphic change than that which produced the chloritic-pelitic assemblage of minerals with which the amphibolites are associated.

If the amphibolites were derived by the metamorphism of igneous rocks of dioritic or gabbroic composition, one would expect to find some evidence of the alteration of augite to hornblende or perhaps the remains of zoned plagioclase feldspars. Both of these constituents (augite and zoned plagioclase feldspar)

EXPLANATION OF PLATE 7

1. Zoisite (at top) replacing labradorite; hornblende and quartz. x14

2. Shredded hornblende in groundmass of andesine feldspar (An_{38}); opaque mineral is pyrrhotite. x14

3. Poikiloblastic hornblende with relicts of quartz; quartz and andesine in white areas; darker mineral (in white areas) with higher relief is chlorite. All constituents except hornblende show a marked directive texture. x14

4. Zoisite has here almost completely replaced plagioclase feldspar; some hornblende in upper portion. This section is from the center of an orbicular concretion-like mass in the amphibolite. x14

PLATE 7

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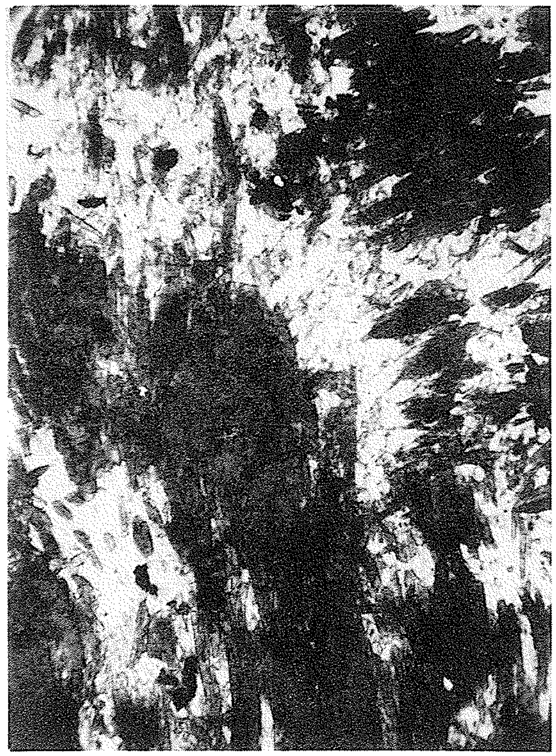

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are characteristic of rocks of this composition (diorite-gabbro). However, according to Paige, (Darton and Paige, 1925), "Augite was not recognized with certainty, metamorphism having proceeded too far to leave any of this common constituent of diorites and diabases." This statement is made on the basis of petrographic examination of amphibolites of numerous areas of the Black Hills. Neither were any evidences of augite found in any of the petrographic examinations made of the amphibolites of the Galena-Roubaix District.

3. Within the amphibolite areas are layers resembling quartzite or chert. These layers were described in the section on stratigraphy, and include the ferruginous-quartz-amphibole rocks (Homestake fm.) and the siliceous limestones (Poorman fm.). These rocks were mapped as quartzites by Paige (Darton and Paige, 1925), and were apparently regarded as of sedimentary origin. These layers occur wholly enclosed by the amphibolite in places where the formations are terminated normal to their strike by shearing. These layers now contain granular quartzite, altered amphiboles, and carbonaceous material, in addition to other minor constituents, including plagioclase feldspar, calcite and ores. These siliceous layers everywhere maintain a parallel and concordant relation with respect to the strike of the amphibolites.

4. Certain petrographic evidence it seems is also significant in this problem:

a. Thin sections of some amphibolites show quartz, plagioclase feldspar, ore, and chlorite, in a marked directive texture. Cross cutting the directive texture are abundant poikiloblasts of hornblende. In some instances the hornblende now constitutes over fifty per cent of the rock. It appears that the minerals showing the directive texture represent the metamorphosed constituents of an originally ferruginous and dolomitic shale. A subsequent period of metamorphism has resulted in the development of the hornblende from plagioclase feldspar, quartz, and the impure carbonates. (Plate 7, fig. 3)

EXPLANATION OF PLATE 8

1. Labradorite partly replaced by zoisite; hornblende in upper left corner; chlorite after hornblende in upper half of section. x32

2. Zoisite has partly replaced plagioclase feldspar (An_{50}); and needle-like hornblende prisms. x32

3. Hornblende showing decussate texture in groundmass of plagioclase feldspar; solid, twinned calcite in upper half and left upper corner. x32

4. Poikiloblastic hornblende in abundant chlorite-calcite groundmass. x32

PLATE 8

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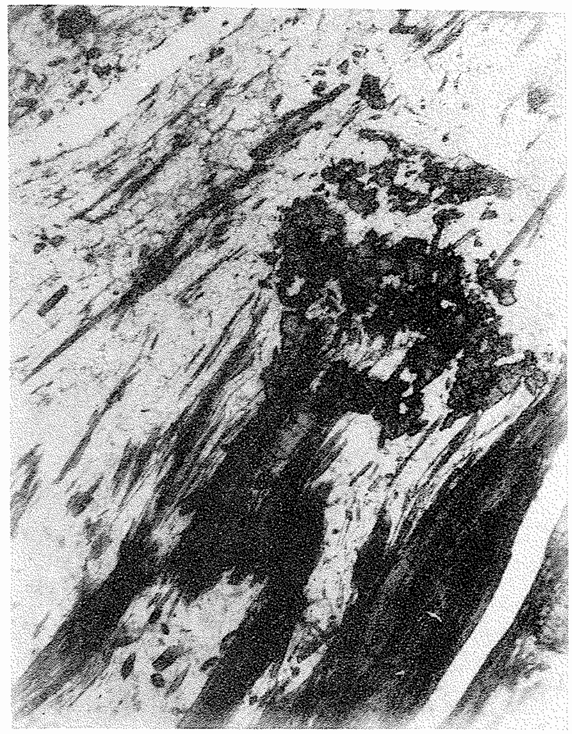

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b. Other thin sections of both amphibolite and the layers believed to represent the Homestake formation contain abundant carbonaceous and graphitic material. The presence of the carbonaceous matter is certainly an excellent criterion for the sedimentary origin of the rocks in which it is present. It is true that graphite might occur as a contact metamorphic mineral in igneous rocks, but it is doubtful that carbonaceous matter would be generally distributed throughout the rock as shown in Plate 1, fig. d. The parallel aspect of the carbonaceous bands may possibly represent the bedding of an originally sedimentary rock.

c. Other thin sections taken from the areas of amphibolite contain as much as forty per cent calcium carbonate and other carbonates (Fe > Mg). The abundance of carbonate minerals in the rocks should not alone be taken as a criterion of sedimentary origin. But the consistently high percentages of carbonate minerals is at least suggestive of a sedimentary origin. Other thin sections from rocks which appear megascopically to be very schistose amphibolites, are found to contain largely chlorite and calcite as the dominant constituents. Lenses of pure calcite are also found; in the field these are often many meters in length.

d. That hornblende can and does develop in calcareous shales is aptly illustrated in the metamorphosed ellipsoids in the Roubaix rocks. From the field relations and petrographic descriptions (refer p. 17) the reader should have no doubt that the ellipsoids have developed in a sedimentary rock. In calcareous portions of this rock lenses of calcareous material have been "rolled" into the shapes of ellipsoids. During this shearing and metamorphism abundant hornblende has developed (refer Plate 6, figs. 3 and 4).

METAMORPHISM

The metamorphic changes which the pre-Cambrian rocks have undergone are closely allied to the structural configuration of the region. In fact, the structure gives a helpful key to deciphering the dynamo-metamorphic history which concerns the strata. The cross-folding suggests that there may have been more than one period of dynamic metamorphism. That there has been another period of metamorphism of the thermal type is not as well illustrated in this district as it is contiguous to large granite masses in the Southern Black Hills. But thin sections of the rocks of Galena-Roubaix District show minerals which could have only been introduced by the emanations of a granitic mass.

The original composition of the sedimentary beds was probably not greatly different from the lithology of many of the Paleozoic and Mesozoic sedimentary beds of the Black Hills. The original beds probably included grits, sandstones, limestones, carbonaceous shales, arenaceous shales, and calcareous shales.

The earliest period of metamorphism of which there is any record was a metamorphism characterized by great stress, and accompanying relatively high temperatures. This metamorphism was probably the result of and contemporaneous with the folding which formed the major structural features now present, i.e., the tightly closed isoclinal folds.

Limestones and sandstones were probably recrystallized into marbles and quartzites respectively. In impure shales, biotite, quartz, plagioclase feldspar, and sulfides were the newly crystallized minerals. In addition to severely contorting the sedimentary strata into a series of tightly closed isoclinal folds, this period of great stress was responsible for the development of characteristic minerals. The relatively high temperatures may have developed from friction due to stress or heat created by the friction, or it may be related to some body, emplaced contemporaneously with this period of folding. It is not known whether a second period of folding was contemporaneous with the final period of thermal metamorphism. However, stress minerals are found that are later than the earliest period of metamorphism described in the last paragraph. This is the period of dynamic metamorphism occurring with the folding that produced the cross folds. Inasmuch as both unoriented minerals have developed at this time, a relatively high temperature was probably existent.

Hornblende and other amphiboles are found to be later than the earlier group of minerals developed (biotite, quartz, feldspar, et al.). It is possible that these amphiboles may have been formed during this period of stress metamorphism.

It is the belief of the writer that the period of thermal metamorphism may be related to the intrusion of granite in the Southern Black Hills. Although the granite massif is more than thirty miles distant from the Galena-Roubaix District, it is possible that small injections emanating from the granite may have penetrated to within a short distance from the Galena-Roubaix District. These injections have either been intruded as veins in the schists, or hydrothermal volatile constituents from the granite have had contact metamorphic effects on the schists.

Such seems to have been the case in a number of smaller areas within the Galena-Roubaix District. The introduction of soda, silica, and various volatile constituents (F, B, H_2O, S) has produced characteristic mineral assemblages of granite. Microphotographs (Plate 8, figs. 1 and 2) show albite developed due to the introduction of quartz and soda. The albite occurs in large, well twinned crystals. Biotite is more abundant and better developed than in any of the other chloritic-pelitic sediments. In the same rock from which this thin section was made titanite, apatite, and late sulfides were also apparently introduced materials.

The veins in the vicinity of Galena show particularly well the effects of the intrusion of granitic material. Certain veins in Ruby Gulch at Galena contain vein quartz containing large black tourmaline crystals. These are commonly 4 to 5 cm. long and 4 to 5 mm. in diameter; some are as large as 10 cm. long. In adjacent schists of the Northwestern formation large garnets are found, commonly 3 to 4 cm. in diameter; one portion of a garnet crystal showing three dodecahedron faces was 7 cm. in diameter. It was also in this general vicinity that the only amphibolite containing garnet was found.

East and south of Roubaix, in the schists and amphibolites, veins are found containing quartz, zoisite, tourmaline, and some hornblende. The tourmaline is black and well striated in the hand specimen; in thin section it is highly pleochroic $O > E$. O is dark bluish-green; E is reddish-violet; this is a tourmaline high in iron.

EXPLANATION OF PLATE 9

1. Poikiloblastic hornblende porphyroblasts with relicts of quartz and calcite; high relief mineral in white quartz areas is calcite. x32

2. Nematoblastic hornblende prisms in groundmass of quartz and plagioclase feldspar (An_{50}). x14

3. Bedding preserved by graphitic or carbonaceous material in amphibolite. x32

4. Penninite has here completely replaced amphibole. Relicts from amphibole are still evident; plagioclase feldspar (labradorite) in light colored areas. This rock has almost been converted to a mica schist. x32

PLATE 9

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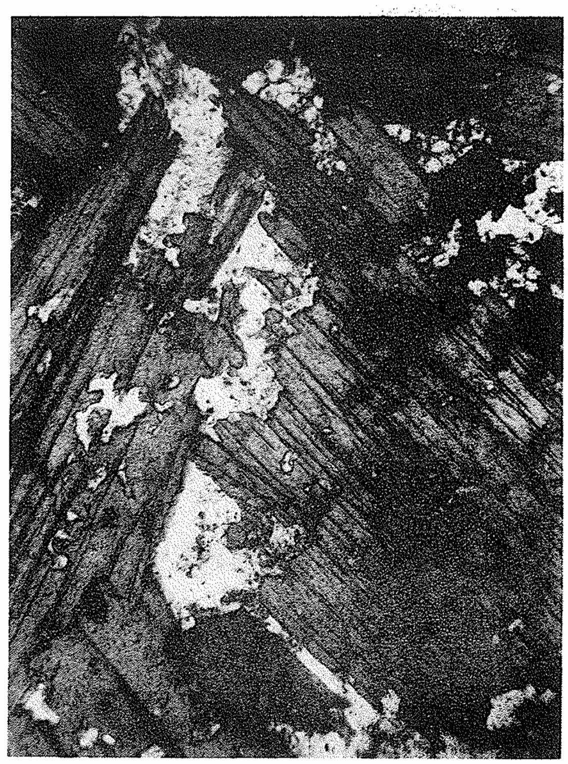

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Other veins are quartz-oligoclase veins. They contain crystalline, glassy-appearing quartz, and white to pale yellow feldspar.

Some veins in the amphibolites contain abundant muscovite. Individual aggregates of micaceous plates are as large as one cm. in diameter. Many of these were found in sec. 29 east of Roubaix, and on the eastern border of the largest amphibolite area, in sec. 26, T. 4 N., R. 4 E.

Besides those minerals developed from the introduction of material, thin sections show the evidence of alteration of minerals and development of new minerals from those already present in the rock. Some of these have been described under the mineralogy of the amphibolites. Zoisite has commonly replaced plagioclase feldspar; hornblende has altered to penninite and other varieties of chlorite.

STRUCTURAL GEOLOGY

General

Most folds of the pre-Cambrian rocks of the Northern Black Hills are of the isoclinal type. Axialplanes, schistosity, and beds have, as a rule, relatively steep dips, -from sixty to ninety degrees; some of these are overturned folds.

Plane flow cleavage is well developed, especially in the abundant schists and amphibolites. These rocks commonly show a weak linear cleavage. During the folding of the rocks in pre-Cambrian times, rock flowage must have taken place under the conditions of rather high temperature, and great pressure and stress, resulting in the development of many minerals not present in the original rock. During folding, plane and linear cleavage are developed by the formation of new minerals (stable under the existing conditions of temperature, pressure and stress), from chemical constituents already present in the rock, and, in some cases from introduced material. The micas and chlorite best exhibit plane cleavage, while the amphiboles quite commonly show linear cleavage.

Inasmuch as plane cleavage is commonly parallel to the axial plane of folds, the cleavage is nearly parallel to the strike of the beds on the limbs of the long isoclinal folds, and is normal to the strike of the beds on the axis of the folds. Thus, there is a gradational change between the limbs and the apices, from cleavage that is parallel to cleavage that is normal to the strike of the strata.

Plane cleavage is best exemplified in the micaceous and chloritic schists which contain an abundance of platy minerals. Muscovite rarely produces plane cleavage since it is an added constituent and cross-cuts the directive texture determined by the other platy minerals. Linear cleavage is sometimes evident in the schists, but it is most characteristic of the amphibolites due to the elongated character of the amphiboles. Linear cleavage evidences the development of minerals in one direction only, or in a line at the intersection of two planes. Linear cleavage has much the same relation to the elements of a fold and the strata as does plane cleavage.

In the Southern Black Hills, Runner and Hamilton (1934) found that the major axis of ellipsoidal concretions, flattened boulders, and the major axis of elongated crystals to be in the direction of and nearly if not quite parallel to the pitch of the folds. In the Galena-Roubaix District minerals showing linear parallelism, stretched structures, and structures having the shapes of triaxial ellipsoids, are found also to be of aid in determining the pitch of folds. This principle was of much help in confirming the direction of pitch as determined by other means.

In the Galena-Roubaix District numerous principles were used to determine the age of beds, and in deciphering the structure. No one of these principles alone would be sure proof of the age of beds, or whether they were folded into anticlines or synclines; but the confirmation of each of the criteria by each other into a logical whole suggests the correct order of superposition and the nature of the folds.

1. Assuming that the pitch is not overturned, we know that an anticline apexes in the direction of pitch, and a syncline apexes opposite to the direction of pitch.

2. The direction of pitch is in the direction of the linear cleavage.

3. Certain sequences of repetitions of beds indicate anticlines and synclines if the age of the beds is previously determined.

4. The relation of cleavage to bedding and the relation of minor drag folds to bedding is such that the relative direction of movement of adjacent beds may be determined.

5. From the direction of shear on the limbs of folds in adjacent beds the position of axes of anticlines and synclines may be determined.

6. Opposing dips over large areas indicate structure in general. E.g., in general the dips taken on the west side of the area, in the northwest portion of T. 3 N., R. 4 E., are to the east; dips on the eastern border of the Roubaix rocks are to the west. This, in general indicates a syncline here.

7. Coarser materials more often occur at the base of a certain division, group, or member. E.g., the coarse grit stones of the Roubaix Group of rocks occur near the base of the formation, thus indicating relative superposition.

The Galena-Roubaix District is located at the northern apex of a synclinorium. The axis of this structure runs in a general north-south direction slightly west of the center of R. 4 E., T. 3 N., and T. 4 N. Reference to the Geologic map will show that the axis runs through the center of the mapped outcrop of Roubaix type of rocks. Superposed on this larger structure are anticlines and synclines, often in the form of drag folds. Progressively superposed on the larger folds are smaller drag folds down to structures centimeters in dimensions. In addition, anticlines and synclines are affected by cross folds with axial planes crossing the first formed ones. This is best illustrated in secs. 28 and 33, T. 4 N., R. 4 E. The axial plane of the anticline indicated there is itself folded into an S-shaped curve.

Jaggar mentions the peculiar change of strike in the vicinity of the Anaconda Mine, in an early report on the economic geology of the Black Hills (Irving, Emmons and Jaggar, 1904). "Summing up the Algonkian section along the ridge northeast of the Clover Leaf (Anaconda) Mine, we see that the west-southwest strike is unusual, suggesting that there is some sudden change in structure east and west of the ridge in question. This change on the west takes place in the immediate vicinity of the Clover Leaf (Anaconda) ore body."

Faults are questionably represented in the Galena-Roubaix District. No major faults at any great angle to the bedding or schistosity were observed. However, in the southeastern portion of the area the absence of the Ellison quartzite and the truncation of certain beds within the amphibolite suggests faulting out of some beds.

The whole pattern of structure of the region under consideration shows a shearing of the west side of structures in a northwardly direction, to those on the east in a southwardly direction. That faults may be present along bedding planes is possible; it is difficult to discover the magnitude or even the presence of strike-slip faults. However, the cross-folding does give some evidence of relative movement of the beds along a north-south plane.

Specific structure:

As mentioned in the general discussion of structure, the largest single structure in the region is the large synclinorium, the axial plane of which trends in a north-south direction slightly east of the center of the area. This is apparently the same structure which Paige mentions (Darton and Paige, 1925); Paige traces the axial plane of this structure southward to the granite. The great thickness of beds of the Roubaix Group in the N $\frac{1}{2}$ of T. 3 N., R. 4 E., is due to repetitions by folding.

West of the area of Roubaix rocks is a minor anticline involving the Northwestern and Garfield formations.

The westernmost minor syncline of the Roubaix synclinorium apexes in the SE $\frac{1}{4}$ of sec. 18, T. 4 N., R. 4 E. There are here some good examples of the bedding being normal to the cleavage. The east limb of this syncline may be traced toward Roubaix. The apex of a minor anticline is indicated at the Anaconda Mine. Irving, Emmons, and Jaggar (1904) in an early economic report on the Anaconda Mine, mention the peculiar change of strike at this point.

The apex of another syncline is presumably under the Cambrian cover in sec. 21, T. 4 N., R. 4 E.

The next anticline to the east involves most of the beds represented in the area. It is a tightly closed isoclinal fold. Its axial plane dips steeply to the east, and trends generally north-south in the center of sec. 28. The axial plane then assumes an east-west trend in the SW $\frac{1}{4}$ of sec. 28, and later resumes the north-south trend along the border of secs. 32 and 33, T. 4 N., R. 4 E.

The axial plane of a minor syncline passes between the amphibolite areas in the S. $\frac{1}{2}$ of sec. 28, trending in a north-south direction. The structures east of this point involving the Roubaix Group of rocks, are less easily defined. In general, the beds are probably repeated one or more times in the anticline, south of the large amphibole mass. Presumably the great thickness of beds within the large amphibolite area is due to repetitions by folding.

A minor syncline apexes to the east of the large amphibolite mass in the NE $\frac{1}{2}$ of sec. 22, T. 4 N., R. 4 E.

The beds to the east of the Roubaix Group of rocks represent the older rocks on the east limb of the large synclinorium that occupies the center of the area. East of the Galena-Roubaix District, Runner (1934) has described a doubly-pitching anticline, the west limb of which is composed of rocks of the Lead System. The east limb of the Roubaix synclinorium is then identical with the west limb of Runner's doubly-pitching anticline.

However, the situation is not quite so simple. In order to explain the repetition and omission of certain beds in this general area (secs. 14, 11, 2, T. 3 N., R. 4 E.), one must conclude that shearing and faulting within the amphibolite areas has resulted in the repetition of certain beds and the omission of others.

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