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Lateral variations of carbonate rock adjacent to ore deposits in the Upper Mississippi Valley zinc-lead district, Wisconsin, Illinois, Iowa

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LATERAL VARIATIONS OF CARBONATE ROCK ADJACENT TO ORE DEPOSITS IN THE UPPER MISSISSIPPI VALLEY ZINC-LEAD DISTRICT, WISCONSIN, ILLINOIS, IOWA

BY

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THESIS

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ABSTRACT

The lateral variation and nature of carbonate host rock in the Upper Mississippi Valley zinc-lead district were petrographically studied within the McGregor and Quimbys Mill Members of the Platteville Formation of the Middle Ordovician System. These members are dolomitic limestone in the Upper Mississippi Valley district of southwestern Wisconsin, northwestern Illinois and northeastern Iowa.

One hundred and twenty-seven specimens were collected or were available from pull drifts in the Shullsburg mine. The specimens were collected at regular intervals of 50 or 100 feet in seven pull drifts between eight ore bodies.

Thin sections prepared from the carbonate specimens were studied, described and classified according to the Folk and Pettijohn classifications. The McGregor and Quimbys Mill carbonates consist of the following lithologic varieties: biosparite, dolomitic limestone, calcitic dolomite and dolomite.

The host rock carbonate distal from ore bodies consists of an intimate mixture of very fine-grained calcite and dolomite in roughly equal proportions. Allochems may be moderately abundant locally; clay minerals constitute a minor constituent. Toward ore bodies, the composition of the carbonate rock gradually becomes more dolomitic. Closer yet to the ore zones the rock consists entirely of the coarser dolomite rhombs. The gradual change in carbonate composition toward the margin of ore bodies begins at an average distance of about 200 feet from the ore zones. The

writer believes this change in composition to be due to the solutions which deposited the ores.

ACKNOWLEDGEMENTS

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Frontis piece at the Shullsburg Mine, Wisconsin.

Chapter I

INTRODUCTION

A. Location

The Upper Mississippi Valley zinc-lead district, comprising an area of about 4,000 square miles, includes the southwestern part of Wisconsin, the northwestern corner of Illinois, and a narrow fringe of Iowa along the west bank of the Mississippi River (See Fig. 1). Zinc-lead deposits occur throughout the entire area, and small isolated deposits of lead, copper and zinc occur beyond the main district.

B. Climate

The climate of the district is cool. Heavy snows and considerable periods of subzero temperatures are characteristic of most winters. The average winter temperature is between 20°-30° F. and the average summer temperature is between 65°-75°F. The annual precipitation of about 25 to 30 inches is rather evenly distributed throughout the year (Heyl, 1959, p. 3).

C. Geography

The topography is relatively rugged as compared with most of the region surrounding the Driftless Area. The dominant topographic feature is an upland of about 900 feet in altitude in the southern part of the district, but which rises gently toward the north to an elevation of 1,250 feet near Highland, Wisconsin. The local relief normally ranges between 100 and 300 feet, but the maximum relief is

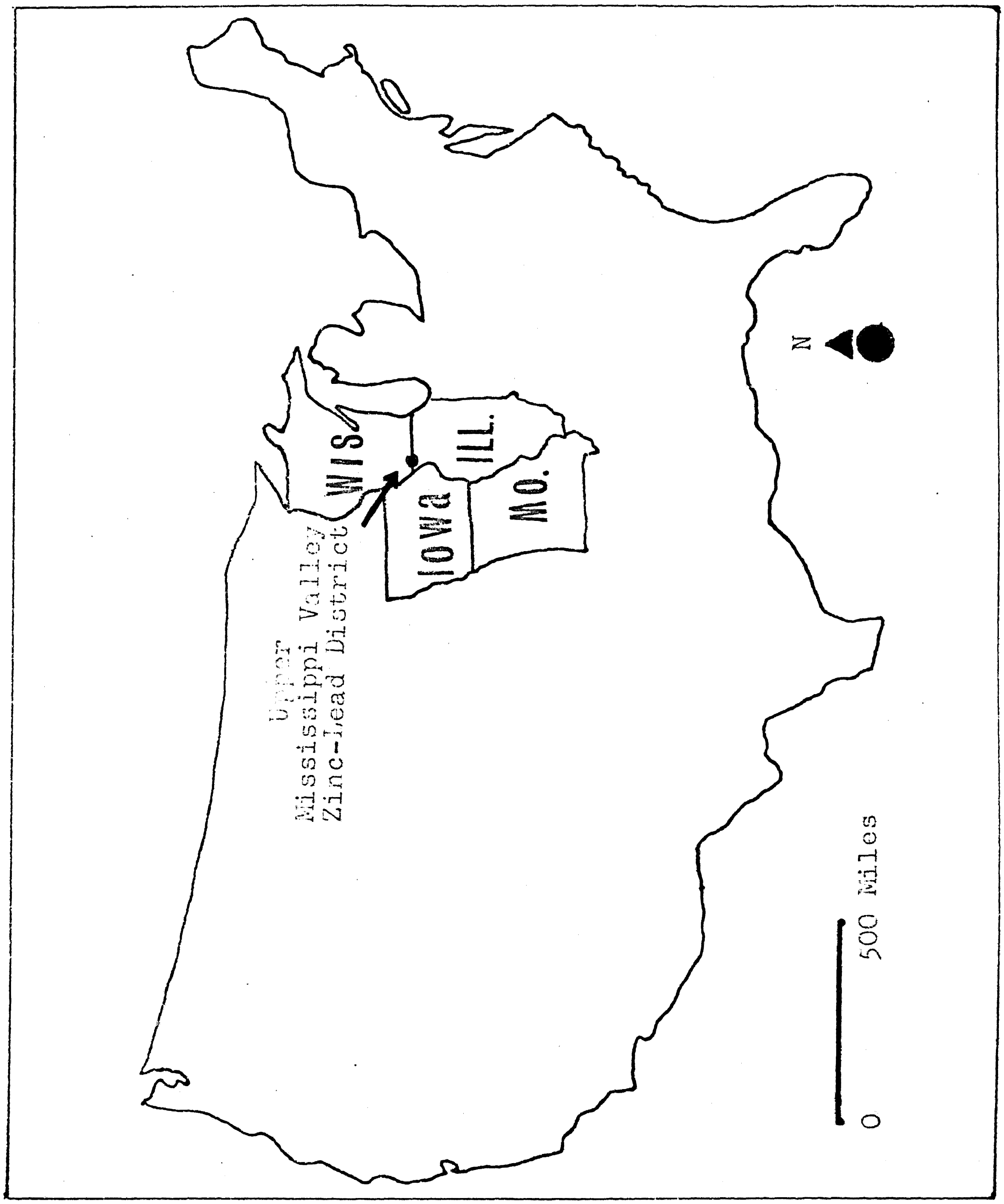


Figure 1. Index Map showing the location of the Upper Mississippi Valley Zinc-Lead District.

1,100 feet. A number of low escarpments and isolated hills rise above the general level of the gently rolling upland.

A generally dendritic network of streams, all tributary to the Mississippi River, drain the area and occupy shallow valleys which are more deeply incised near the master streams. The major tributaries of the Mississippi River from the east are the Wisconsin River, which essentially bounds the district on the north, the Grant, Platte, Sinsinawa, Galena (Fever), and Apple Rivers.

D. Cultural Development

The principal city in the district, Dubuque, Iowa, has a population of about 50,000. Other towns of importance, Monroe and Platteville, Wisconsin, and Galena, Illinois, each have a population of 5,000 (Heyl and others, 1959, p. 3).

The district is served by the railways. These are: Illinois Central, Chicago Burlington and Quincy, the Chicago Great Western, Chicago Milwaukee, St. Paul Pacific, and the Chicago and Northwestern Railroads.

Highways connect the principal towns; bus and truck lines serve all larger towns. Some secondary roads in Wisconsin are maintained in excellent condition by the use of mining tailings as a road base.

Economical transportation is available on the Mississippi River. Dubuque, Iowa, is the chief port, with Prairie du Chien, Wisconsin, as the second most important.

Most companies have their own mills usually located near the mines.

E. Field and Laboratory Investigations

The field work for this thesis, which was accomplished during the month of June, 1967, consisted of underground collection of host rock carbonate specimens from the walls of pull drifts driven for haulage purposes, between mined areas in the Shullsburg Mine in Wisconsin. Specimen collection was guided by Mr. Thomas H. Pullen, District Geologist of the Eagle-Picher Company. The specimens were collected at 100 foot intervals from a series of seven pull drifts beginning in the southern part of the Shullsburg Mine and progressing northward. A total of 86 specimens were obtained along the pull drifts from the Quimbys Mill and McGregor Members of the Ordovician Platteville Formation. The specific locations from which each specimen was obtained are plotted on the underground mine maps with a scale of 200 ft. per inch. A previous study by R. D. Hagni of thin sections of 41 specimens from three pull drifts in the Shullsburg Mine, were available for the present investigation.

The laboratory investigation, during the latter portion of the Summer and Fall of 1967, consisted of binocular and petrographic microscopic examination and description of thin sections of other specimens from the same pull drift. The percentages of the major constituents observed in the thin sections were plotted on charts to examine the lateral variation in carbonate constituents.

F. Scope of Investigation

The discovery of carbonate alteration halos in the Tri-State district (Hagni and Saadallah, 1965) and the presence of a distinct variation in carbonate lithology in one suite of samples collected from three pull drifts in the Shullsburg Mine for a brief microscopic study by R. D. Hagni, suggested that a detailed study of carbonate host rocks from additional pull drifts might yield useful information regarding the lateral distribution of carbonate lithologies with regard to the positions of ore bodies in the Upper Mississippi Valley zinc-lead district.

The basic scope of this petrographic study was to determine the types of carbonate present and their lateral distribution with respect to the location of contiguous ore bodies. Lateral variations in the character of the host rock carbonate were investigated within two beds, the Quimbys Mill and the McGregor. The basic variations investigated were types and abundance of allochems (fossils), orthochems (calcite and dolomite), grain size, terrigeneous (quartz and clay) and opaque minerals.

Chapter II

GENERAL GEOLOGIC SETTING OF UPPER MISSISSIPPI VALLEY

A. Stratigraphic Description

Detailed recent stratigraphic descriptions of the Upper Mississippi Valley zinc-lead district are given by Heyl and Agnew (1956) and Deininger (1964), but a brief review is given here.

The district contains sedimentary rocks that range in age from Late Cambrian to Early Silurian. The total thickness of these Paleozoic strata is about 1800 feet, of which 800 feet is Cambrian, 780 feet Ordovician, and 200 feet is Silurian. The dominant rock among the Cambrian strata is sandstone. The Ordovician rocks, which comprise most of the exposed bedrock in the zinc-lead district, include dolomite, shale, sandstone and limestone. The beds of Silurian age consist of shaly and cherty dolomite.

The following description is a brief summary of the main characteristics of the formations starting with the oldest one (See Fig. 2).

1. Precambrian Sequence

Precambrian rocks have been encountered in drill holes at Platteville, Wisconsin, where the drill penetrated "granite" at a depth of 1700 feet. Precambrian strata are separated from the overlying Cambrian sedimentary rocks by an unconformity of considerable relief.

2. Cambrian System

The oldest rocks of Paleozoic age found in the Upper Mississippi Valley are sandstone, siltstone, and dolomite of Late Cambrian age (See Fig. 2). These beds are exposed only along the northern and northeastern edge of the zinc-lead district and are encountered farther south in deep drilled wells. The oldest beds of Cambrian age in the mining district are termed the Mount Simon Sandstone. This formation has an average thickness of 440 to 780 feet.

The Mount Simon is overlain by the Eau Claire Sandstone, which normally is very silty and reddish. Its thickness is between 70 and 330 feet. This formation is overlain by the Dresbach Sandstone which ranges from 60 to 140 feet in thickness.

The Dresbach Sandstone is followed by the Franconia Sandstone which is between 110 and 140 feet in thickness.

The Franconia Sandstone is overlain by Trempealeau Formation, which is principally sandstone and siltstone, although the lower strata are dolomite. The uppermost beds of the Trempealeau Formation, called the Jordan Sandstone Member, are comprised of well-sorted and subangular quartz grains. The average thickness of the Trempealeau Formation is 100 to 150 feet. The Madison Sandstone overlies the Jordan Sandstone Member of the Trempealeau Formation, but it is not consistently recognizable in the mining district.

Lead minerals are found in Cambrian rocks "in the lower part of the Dresbach Sandstone". Sphalerite was recognized in dolomitic sandstone.

System	Series	Group or formation	Description	Average thickness, in feet	
SILURIAN	Middle and Lower		Dolomite, buff, cherty; *Pentamerus* at top,	90	200
			Dolomite, buff, cherty; argillaceous near base	110	
ORDOVICIAN	Upper	Maquoketa shale	Shale, blue, dolomitic; phosphatic depauperate fauna at base	108-240	
	Middle	Galena dolomite	Dolomite, yellowish-buff, thin-bedded, shaly	40	225
			Dolomite, yellowish-buff, thick-bedded; *Receptaculites* in middle	80	
			Dolomite, drab to buff; cherty; *Receptaculites* near base	105	
		Decorah formation	Dolomite, limestone, and shale, green and brown; phosphatic nodules and bentonite near base	35-40	
		Platteville formation	Limestone and dolomite, brown and grayish; green, sandy shale and phosphatic nodules at base	55-75	
		St. Peter sandstone	Sandstone, quartz, coarse, rounded	40+	280-320
		DISCONFORMITY	DISCONFORMITY		
	Lower	Prairie du Chien group (undifferentiated)	Dolomite, light-buff, cherty; sandy near base and in upper part; shaly in upper part	0-240	
CAMBRIAN	Upper	Trempealeau formation	Sandstone, siltstone, and dolomite	120-150	
		Franconia sandstone	Sandstone and siltstone, glauconitic	110-140	
		Dresbach sandstone	Sandstone	60-140	700-1050
		Eau Claire sandstone	Siltstone and sandstone	70-330	
		Mount Simon sandstone	Sandstone	440-780	

Fig. 2. Generalized stratigraphic column for the Upper Mississippi Valley zinc-lead district (from Heyl and others, 1959).

NOTE: The Mount Simon and Eau Claire sandstone formations are usually Dresbach sandstone (Keroher et al., 1960, pp. 1454, 1157, 1209 and 2641).

3. Ordovician System

a. Lower Ordovician Series

The Lower Ordovician Series comprises one group, the Prairie du Chien. The group is divisible into three units: a) the Oneota Dolomite which directly overlies the Cambrian beds, b) the New Richmond Sandstone, and c) the Shakopee Dolomite. Additional lithologies in the Prairie du Chien locally are sandstone, red shale, green shale, silicified limestone and limestone.

The dolomite in this group is light buff to light gray, finely to medium crystalline, in part vuggy, and thin to thick bedded. The thickness of this group is about 40 feet. Cryptozoan are common in some strata.

Small quantities of lead and zinc minerals have been noted to occur in this group.

The sands which comprise the Lower Ordovician sandstones were delivered to the Ordovician sea by rivers flowing southward, and by winds that removed clayey components and drifted the sands to the river valleys and locally to the sea (Thiel, 1935, p. 560).

b. Middle Ordovician Series

The stratigraphy of the Middle Ordovician rocks of the Upper Mississippi Valley zinc-lead district has been discussed by Agnew and others (1956).

1) St. Peter Sandstone

The St. Peter Sandstone is exposed along the Wisconsin River about 50 miles north of the district and it covers large areas in Wisconsin, Minnesota, Iowa, Illinois, Missouri and Arkansas (Thiel, 1935, p. 560).

The sandstone consists of clear, fine to coarse, subangular to round quartz grains. Its poor degree of dolomitic, calcareous or siliceous cementation causes moderate porosity (Thiel, 1935, p. 589). The thickness of this bed averages about 40 feet in the area where the writer worked, but it exhibits a variable thickness. At least part of the variation in thickness is due to an unconformity at the base of the St. Peter, which is well exposed in the "glass-sand" quarry south of Clayton, Iowa, in Section 1, T. 93 N., R. 3 W., (Heyl and others, 1959, p. 10).

Zinc-lead minerals generally are uncommon in the St. Peter Sandstone, but sulfides of those metals are locally abundant in the upper few feet of St. Peter sandstone.

2) Platteville Formation

The Platteville Formation is located on the top of the St. Peter Sandstone and consists of four members (See Fig. 3) from the bottom to the top: 1) Glenwood Member, which is locally called a shale with the thickness a maximum of 3 feet. This bed is olive to grayish-brown, and consists of clay with occasional sand grains. Commonly the sand grains of the Glenwood are cemented by pyrite, less commonly by iron oxide. Locally small amounts of lead and zinc minerals have been found in the Glenwood Member. 2) Pecatonica Member, which overlies conformably the Glenwood and locally called Quarry beds. The thickness of this member ranges from 20 to 24 feet. The Pecatonica Member consists of dolomite which is brown colored, medium-grained, and is thin-thick bedded. Grains of quartz sand are common. The Pecatonica Dolomite is

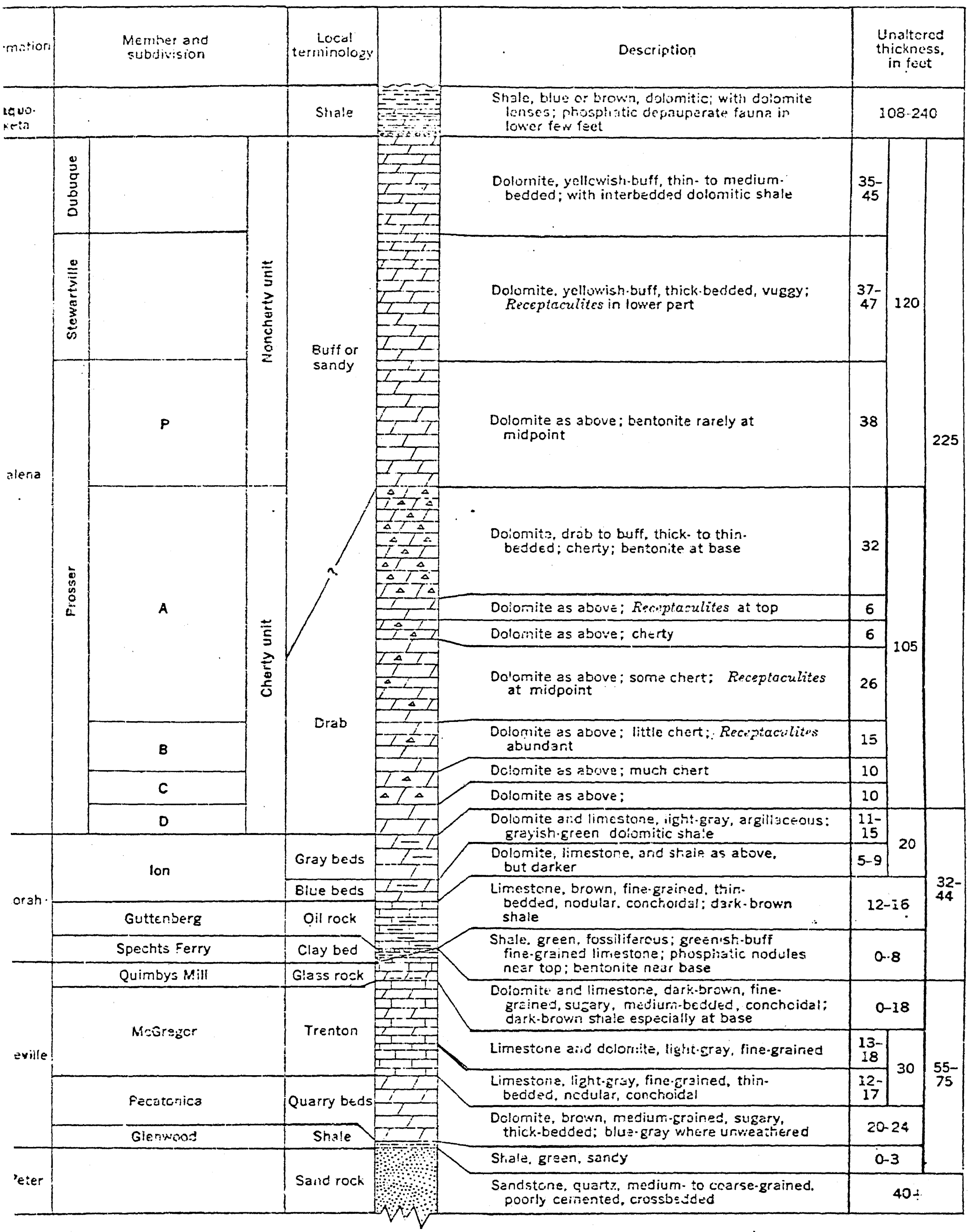


Figure 3. Detailed Middle and Upper Ordovician stratigraphic column for the zinc-lead district (from Heyl and others, 1959).

poor in mineral deposits, but it does contain a small amount of galena and sphalerite. 3) McGregor Member consists of thin to medium-bedded, light-gray to buff limestone and dolomite with shaly partings between beds. It ranges in thickness from 30 to 40 feet (Deinninger, 1964, p. 28). The limestone is commonly white or bluish-white or light gray in color and the dolomite is light gray to light olive gray and stained buff by oxidized iron. Fossils are abundant in the limestone. The McGregor Member is divisible into a lower, thin bedded, light-gray crystalline sublithographic limestone with thin grayish shale partings, and an upper, thin to medium bedded light gray to fine granular less fine grained limestone or dolomite. The McGregor Member, gradational in lithologic character with the Pecatonica Member below, is conformably overlain by the Quimbys Mill Member above.

The McGregor Member, which is called Trenton by miners, contains commercial zinc-lead deposits. Zinc-lead ore is being mined from this member in mines south of Shullsburg, Wisconsin, and south of Galena, Illinois.

4) Quimbys Mill Member, which conformably overlies the McGregor Member of the Platteville Formation, is overlain disconformably by the Decorah Formation. This member, locally called "glass rock", consists of dolomite and limestone, which are dark brown, fine-grained, and medium-bedded. Thin, dark brown, carbonaceous shale marks the base of this unit. Some streaks of organic materials are present in the dolomite and limestone. Conchoidal fracturing is typical of this member. The Quimbys Mill Member is one of the important ore-bearing zones which has been mined since 1940.

3) Decorah Formation

The Decorah Formation rests disconformably on the Platteville. This formation is divisible into three members from the bottom to the top, and consists of: 1) Spechts Ferry Shale, 2) Guttenberg Limestone, and 3) Ion Dolomite. The Spechts Ferry Member is overlies disconformably the uppermost beds of the Platteville Formation and grades upward into the Guttenberg Member. The Spechts Ferry Shale consists of green fossiliferous shale and some greenish buff limestone lenses, 7 to 8 feet in thickness.

Disseminated sphalerite, pyrite and galena are common in this member.

2) Guttenberg Limestone. This member, locally called "oil rock", is a pinkish, thin-bedded, sublithographic, argillaceous, fossiliferous limestone with intercalated thin beds of reddish brown shale, in all totaling 16 feet in thickness. The Guttenberg Limestone grades below into Spechts Ferry Shale, and upward into the Ion Dolomite.

Beds of the Guttenberg Limestone were variously altered by mineralizing solutions that formed the lead-zinc deposits. Dolomitization produced a saccharoidal texture. The Guttenberg Member contains lead and zinc ore in many places as disseminations, fracture fillings, veins, vug fillings, etc.

3) Ion Dolomite. The Ion Dolomite is made up of grayish, medium crystalline limestone and some grayish-green calcareous fossiliferous shale. The thickness of the Ion Dolomite Member is about 20 feet within the district. The Ion Dolomite grades downward into the Guttenberg Limestone and upward into Galena Formation.

Often the beds of the Ion Member are called "Blue" and the upper beds "Gray" because of their colors.

4) Galena Formation

On the basis of lithologic criteria, the Galena Formation has been divided into three members from bottom to top consisting of: Prosser Cherty Member, Stewartsville Massive Member, and Dubuque Shaly Member. On the basis of stratigraphic criteria, this formation has been divided into a lower cherty unit, and an upper non-cherty unit. The cherty unit, called "drab" by the miners, has been further subdivided into beds A, B, C and D (See Fig. 3). Beginning with the lowest bed, the D bed is dolomite with greenish argillaceous material; it contains no chert and locally it is called the "lower buff". It is 10 feet in thickness. The C bed, locally called the "lower chert", is dolomite with bands of chert, with a total of 10 feet in thickness. The B bed, locally called the "lower Receptaculites zone", is brown dolomite with rare chert bands. Receptaculites are common. It is 15 feet in thickness and it grades downward to the C bed and upward to the A bed. The A bed is thick to thin bedded, buff to drab dolomite, with common chert bands and Receptaculites at 35-40 feet from the top. The thickness of the A bed is 70 feet.

The non-cherty units called "sandy" or "buff" by the miners, has been subdivided into three parts, from bottom to top, consisting of: a) the P unit of the Prosser Member, named after Prosser's Ravine, and containing less Receptaculites (Keroher and others, 1966, p. 1453). b) The Stewartsville Member is a yellowish buff, coarsely granular to crystalline, vuggy, medium to thick bedded dolomite with common Receptaculites. Its thickness is about 75-85 feet.

c) The Dubuque Member is yellowish gray, finely granular, argillaceous, thin to medium bedded dolomite and dolomitic limestone with yellowish gray shale. Its thickness is between 35-45 feet. The total thickness of the Galena Dolomite is between 220-230 feet in the mining district.

The Galena Formation is an important host rock for lead and zinc ore.

c. Upper Ordovician Series

1) Maquoketa Shale

The Maquoketa Shale is principally gray, or occasionally blue, dolomitic, silty shale, with some grayish-buff, medium-granular, argillaceous thin-bedded dolomite. The lowest part of this formation is brown in color. The thickness of the formation varies within the district (Heyl and others, 1959, p. 181). The Maquoketa Shale is a poor host rock for ore deposits, but in some of the more dolomitic beds pyrite and phosphatic material has been noted. The Maquoketa Shale as a whole is very fossiliferous. The organic materials are located mostly at the basal part of this unit (Bain, 1906, p. 32). The Maquoketa Shale is underlain by the Galena Formation and overlain by the Silurian System.

4. Silurian System

The Silurian rocks unconformably overlie the Maquoketa Shale. In the ore district they consist of three lower Silurian formations from the bottom to the top: Edgewood, Kankakee, and Hopkinton.

The Silurian rocks in the district are yellowish-buff dolomite, partially vuggy and medium to coarsely granular. The yellowish color of these dolomites serve to distinguish them from the underlying Middle Ordovician Galena Dolomite.

Isolated crystals of sphalerite and galena have been found locally in the dolomites of Silurian age.

5. Post-Silurian Sediments

Additional sediments within the district include Post-Silurian and possibly pre-Pleistocene deposits, Pleistocene glacial and loess deposits, and Recent sediments.

B. Structure

The structural features of the Upper Mississippi Valley may be treated as regional structures, folds, faults, and joints.

1. Regional Structures

The most prominent regional structural features consist of three basins, Michigan, Illinois and Forest City, separated by arches (Fig. 4). The most prominent arch is the Wisconsin Arch, which extends from the Wisconsin Dome to the Oregon Dome and into northern Illinois where it is known as the LaSalle Anticline. The Mississippi River Arch extends to the southwest. The Savanna-Sabula anticline trends east-west in the northern part of Illinois. The Allamakee Anticline trends to the northwest.

The Upper Mississippi Valley zinc-lead district is an uplifted, gently sloping area bounded by the Wisconsin Dome on the north, the

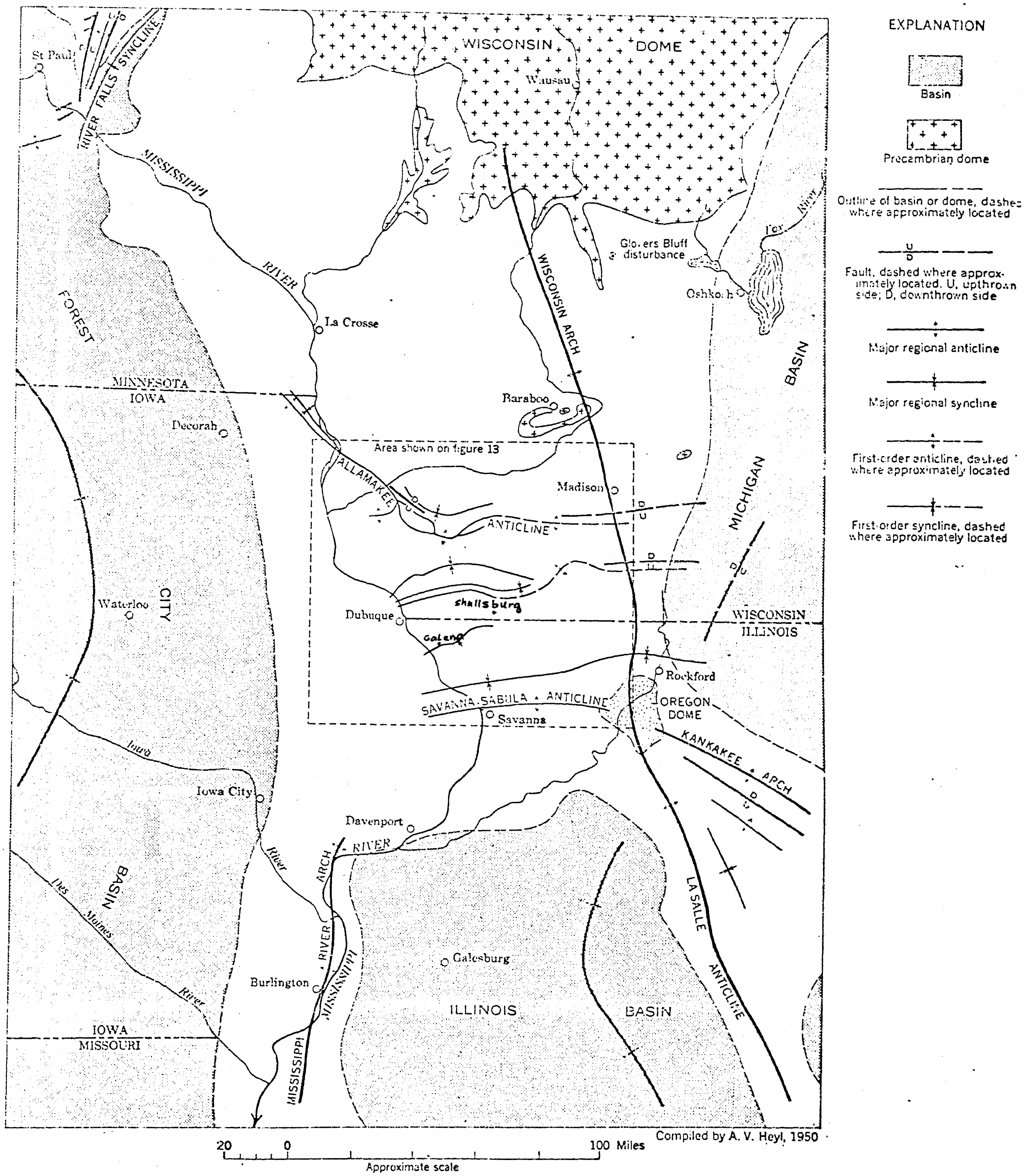


FIGURE 4.—Generalized diagram showing the major structural features of the region bordering the upper Mississippi Valley district (shown by the central square area), and their relations to the principal structures within the district itself.

(from Heyl)

Savanna-Sabula anticline on the south, the Wisconsin Arch on the east, and the Forest City Basin on the west. The regional strike within the district is N. 85° W. (Heyl and others, 1959, p. 27) and dips towards the south about 18 feet per mile. To the west and northwest the regional strike changes to N. 45° W., but the rate of dip remains the same.

2. Folds

The beds in the Upper Mississippi Valley district have been folded into very broad folds. The folds generally have eastward trends, but cross folds are common. Northwest trending folds are most abundant in the west and east portions of the district. The intensity of folding decreases toward the north.

3. Faults

Numerous faults have been recognized in the Upper Mississippi Valley zinc-lead district. Faults are most common along the steeper north limbs of anticlines. Most have vertical displacements of more than 10 feet. Minor faults are important for they may serve as the loci of mineral deposits known as pitches.

4. Joints

In the Upper Mississippi Valley zinc-lead district all of the rock formations contain well developed vertical joints. In many places throughout the district these joints are filled with commercial galena veins.

C. Ore Deposits and Production

The Upper Mississippi Valley district is the oldest known mining area in the United States. The first recorded mining exploration began in 1690. The principal metallic ores in the district are those of lead and zinc, but small amounts of high-grade copper, barite, iron, sulfide, limonite, and hematite have been mined commercially. The ore bodies occur chiefly in Platteville, Decorah and Galena Formations of Middle Ordovician age.

The ore deposits are divisible into: 1) gash-vein, 2) pitch-and-flat, and 3) placer and residual deposits. The gash-vein deposits commonly contain galena, with less abundant sphalerite, and chalcopyrite. The pitch-and-flat deposits are comprised mainly of sphalerite ore, but pyrite and marcasite are abundant. The ores have crystallized in open spaces related to folding. Secondary low grade placer and residual deposits are scattered throughout the district.

Over 50 minerals have been discovered in the district (Heyl and others, 1959, p. 84). Sphalerite is the principal source for zinc in the district. It commonly occurs in symmetrical banded veins. Galena commonly occurs in the gash-vein deposits as well formed cubic crystals in open spaces or as disseminated grains in the host rocks. Marcasite is one of the principal sulfide minerals in the district. It is commonly found in well formed crystals. Chalcopyrite is a rare mineral in most portions of the district and is found in veins and some crystals in pyrite. Small to large amounts of pyrite occur locally with the other ore minerals.

Hematite, limonite and other secondary minerals occur locally in the Upper Mississippi Valley district.

Chapter III

CARBONATE ROCKS

More than 75% of the rocks exposed on the surface of the earth are sedimentary rocks, and carbonate rocks comprise one-fifth of this total (Ham, 1962, p. 2). Thus, carbonates are an important rock type.

Carbonate rocks may provide reservoirs for oil, host rocks for mineral deposits, and they may be used directly for construction materials, agriculatural lime, etc.

A. Study of Carbonate Rocks

Carbonate rocks may be studied by the following means: 1) Hand specimen study. A rock fragment from a sample station is examined by naked eye, hand lens and binocular microscope. Characters which can be determined in this manner include: texture, color, purity, vugs, fossils, stratification, acid reaction, and others. 2) Thin sections. A sawed slice of the rock is mounted on the glass slide and ground to a thickness of 0.03 mm. This method generally yields more information concerning carbonate rocks than other methods. 3) Peels. An acetate impression is made of a slightly etched surface, which subsequently is examined in transmitted light with a petrographic microscope. Only the textural details of carbonate rocks are shown by this method. 4) Staining. Sawed slabs or thin sections of carbonates may be stained by alizarin red S, silver nitrate, etc. Staining with alizarin red S was used by the writer to distinguish calcite from dolomite in thin sections. 5) Insoluble residue. The rock is dissolved in an acid and the insoluble constituents are examined with a petrographic or binocular microscope. 6) Etching. The specimen is immersed in hydrochloric acid for a few minutes, not exceeding five minutes (Folk, 1959, p. 9). This method shows the distribution of such insoluble constituents as sand, silt, clay, quartz, feldspar, chert, opaque minerals, phosphate, dolomite and glauconite. The morphology of the calcite, ooze, spar, microspar and interclast also may be revealed by this method.

B. Classification of Carbonates

It is difficult to find a single classification for carbonates that satisfies all geologists. Classifications have been offered by Folk, Feray, Leighton, Dunham and others.

These carbonate classifications can be divided into two broad groups: descriptive and genetic classifications.

1. Descriptive Classification

Descriptive classifications deal with the visible characters of carbonate rocks, such as composition, texture, and other physical features of the carbonate rocks.

2. Genetic Classification

Genetic classifications deal with the interpretation of the observed features. Genetic and descriptive classifications appear in Ham (1962).

Modern carbonate classifications have been developed during the past 30 years. The most detailed and comprehensive are those by Folk (1959 and 1962) and Powers.

Folk's classification is followed by the writer in classifying the nost rocks of the Upper Mississippi Valley zinc-lead district.

Folk established the following parameters for his classification:

a) Grain size - ratio of large size and small size grains and absolute grain size

b) Composition - skeletal (clastic) and non-skeletal (non-clastic) compositions

c) Transportation - reflects on the grain size, angularity, fragmentation and roundness

d) Sorting - reflects on the environmental conditions under which the carbonate sediment was deposited

e) Porosity and permeability

f) Dolomitization

g) Mode of origin - chemical, physiochemical and mechanical

h) Recrystallization and replacement

i) Diagenesis

3. Major Carbonate Constituents

Pure limestones are composed of three major constituents which Folk terms: a) allochems, b) microcrystalline calcite ooze (micrite), and c) sparry calcite cement.

a. Allochems

The Greek word "allo" means "out of ordinary"; "chem" is short for chemical precipitate. Thus, allochems are not ordinary chemical precipitates, but rather they are complexes and precipitates of a high order of organization which probably have undergone some transportation. The four important allochem types are: 1) interclasts, 2) oolites, 3) fossils, and 4) pellets.

1) Interclasts

This term refers to weakly consolidated material that has been eroded and redeposited in the new form of sediment within the same formation and within the area of deposition. Mud, on the bottom of the ocean, may be picked up by storm action or submarine current and redeposited within the same basin. Those fragments which show transportation are called an interclasts.

2) Oolites

Oolites are small, concentric structures or spherical bodies which may or may not have a nucleus. They are less than 2 mm. in diameter and they are siliceous or calcareous in composition. They must exhibit at least two rings to be called oolites.

3) Fossils

Fragments of a complete fossil, transported or formed in place, and of various sizes are an important type of allochem.

4) Pellets

Pellets are spherical to elliptical or ovoid bodies lacking internal structure. They typically contain concretions of organic matter which are dark brown under inclined reflected light.

b) Microcrystalline Calcite Ooze (Micrite)

Micrite is very fine-grained, milky to colorless carbonate having diameters ranging from 1 to 4 microns.

c) Sparry Calcite Cement

Sparry calcite crystals are 10 microns or more in diameter. They are coarse and more translucent than micrite. While some sparry calcite may be primary, most of it is of secondary origin and fills pore space in the carbonate rock. Microspar is a variety of sparry calcite with a grain size of 10 to 30 microns.

C. Dolomite Classification and Description

For those carbonate rocks in the Upper Mississippi Valley district which exhibit various amounts of dolomite, the classification of Pettijohn (1957) was used in conjunction with that of Folk.

Figure 5 shows the Pettijohn nomenclature with respect to variation in dolomite content.

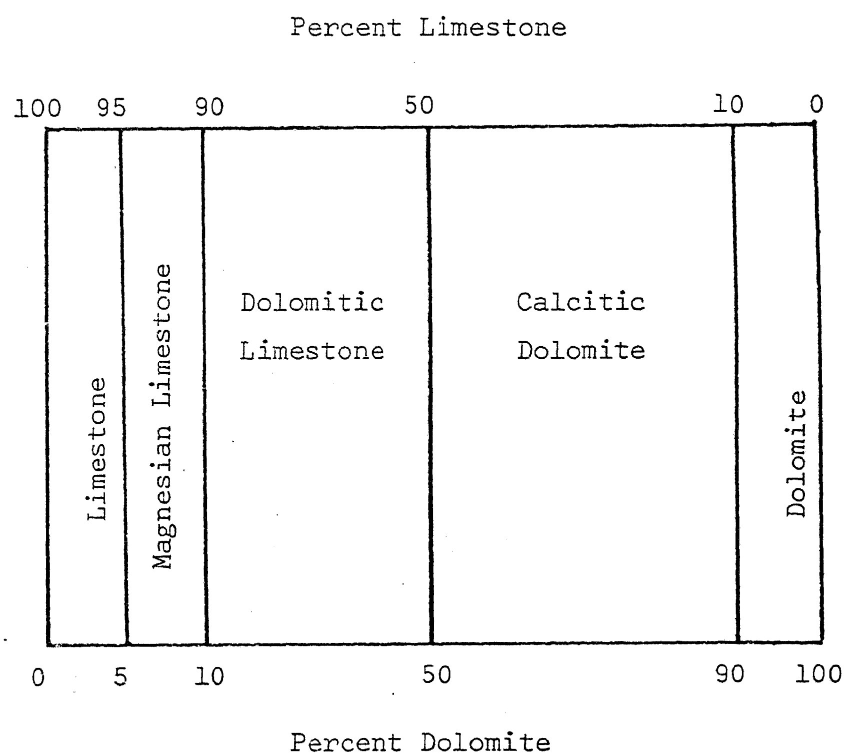
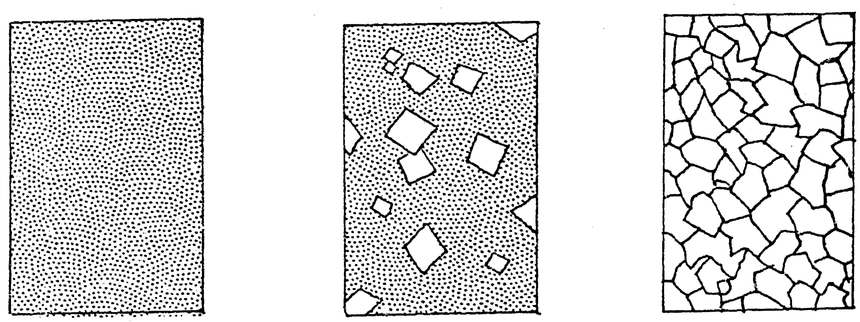


Figure 5. Classification of carbonate rocks based upon their calcite to dolomite ratio. (After Pettijohn).

The texture of dolomitic carbonates may be subdivided into porphyroid and coalesive (Folk, 1965, p. 20-23). Porphyroid texture is that of scattered euhedral dolomite crystals in a matrix of fine micrite grains (Fig. 6b). Coalesive texture refers to that of interlocked recrystallized coarse grains (Fig. 6c).



(a) (b) (c)

Figure 6. Textures exhibited by progressive dolomitization: a) fine-grained mixture of calcite and dolomite micrite, b) porphyroid texture with dolomite rhombs in micrite matrix, and c) coalesive texture of coarse dolomite.

Chapter IV

PETROLOGY OF THE HOST ROCK IN THE UPPER MISSISSIPPI VALLEY ZINC-LEAD DISTRICT

A. Review of Literature

Many geologists have studied and published on the ore deposits and other features of the Upper Mississippi Valley zinc-lead district, but less attention has been given to the host rocks and their alteration. Those references dealing with host rock alteration are reviewed below.

Bain (1905, 155 p.) described the stratigraphic units in the district, but he did not discuss their alteration.

Kay and Atwater (1935, pp. 98-111) indicated that "...some dolomite within the district have resulted from the metasomatism of limestones".

Heyl and others (1959, pp. 101-108) have dealt with alteration of the host rock more than any previous worker. They describe three main types of alteration:

> 1) Solution of the calcareous rocks. They believed this to be the most extensive type of alteration caused by the mineralizing solutions. Its effect was greatest on the limestones of the lower part of Decorah and upper part of Platteville Formations.
>
> 2) Silicification of the rocks within and adjacent to the ore bodies is a prominent feature in the Prairie du Chien Group and, to a lesser extent, in the overlying Platteville, Decorah and Galena strata. Samples collected from the Guttenberg Limestone in the Hoskins Mine were chemically analysed to show that their insoluble content, mostly silica, increases near the ore bodies (see Heyl, 1959, Fig. 66, p. 106).
>
> 3) Dolomitization. Dolomite, deposited during the early part of the period of mineralization, was believed to be a common type of alteration in the district. Dolomitized rock near ore bodies grades into unaltered limestone and shale through a lateral distance of 50 to 100 feet away from the margins of ore. The dolomitization was indicated to be more widespread and intense near the ore deposits in the Prairie du Chien Group than in the overlying Platteville, Decorah and Galena strata.

The present investigation deals with lateral variation of carbonate components in host rocks contiguous to ore deposits in the Platteville Formation.

B. Study of Host Rocks

Several methods of study have been applied to the host rock carbonate specimens collected by the writer: 1) hand specimen study, 2) microscopic study of thin sections, and 3) other methods including acetate peels, etching, and insoluble residue.

1. Megascopic Features of the Host Rock Specimens

The 120 hand samples collected from McGregor and Quimbys Mill host rocks in the Shullsburg Mine were studied initially with a hand lens and a binocular microscope. The megascopic features of those specimens are discussed below.

a. McGregor Member

The McGregor Member of the Platteville Formation is limestone and dolomite fine-grained silt size (see Plate 1A). Its color is light olive gray to light gray*. Stratification is present in some specimens.

Fossils are numerous in this member and several large brachiopods, ostracodes and gastropods were noted.

b. Quimbys Mill Member

The Quimbys Mill Member of the Platteville Formation is dolomitic limestone, and somewhat coarser-grained than the McGregor Member, exhibiting a fine sand to very fine sand size (see Plate 1B).

*For color identification the color chart published by the National Research Council (1948) was used.

Its color generally is light olive gray to pale olive, although some specimens may be dark brown in color. Stratification generally is lacking. Fossils are less abundant than in the McGregor.

2. Microscopic Study of Thin Sections

Petrographic study of thin sections of the McGregor and Quimbys Mill Members in the Shullsburg Mine shows that their average composition is as follows:

70% dolomite, including single, interlocked and disseminated grains.

22% calcite, including micrite, spar and microspar grains.

3% allochems, including various kinds of fossils, some pellets and oolites.

2% quartz, clay, and other silicate minerals.

2% opaque minerals, including galena, pyrite, hematite, limonite, marcasite and some unidentified dark material within some dolomite crystals.

1% pore space, including cracks, veinlets, veins, vugs, fractures, etc.

The size of the carbonate grains varies from 3-4 to about 1,000 microns, averaging about 170 microns.

The microscopic characteristics of the host rock may be treated under three headings: orthochems, allochems, and terrigenous constituents.

a. Orthochems

Orthochems are the most important constituent in the carbonate rocks, forming 92% of the average rock. Orthochems may be dolomite or calcite in composition.

Plate 1. A. Hand specimen of McGregor host rock limestone, Shullsburg Mine.

Plate 1. B. Hand specimen of Quimbys Mill host rock limestone, Shullsburg Mine.

A

B

1) Calcite

Calcite forms 22% of the average. Calcite is readily identified with the Alizarin Red S, by which it becomes stained a red color, while dolomite is unstained.

The orthochemical calcite grains are anhedral to subhedral in shape. They vary from 3µ to 2 mm in size. Those from 3 to 4 µ are termed micrite, those from 10 to 30 µ are microspar, and crystals larger than 10 µ are called spar. Micrite is the most abundant calcite type in the McGregor host rock, but less abundant in the Quimbys Mill.

In dolomitic limestones, calcite exhibits the following relationships to dolomite: 1) calcite grains are concentrated toward the centers of dolomite crystals (Fig. 7B). 2) Calcite grains (which form areas) transgressing the boundaries of dolomite (Fig. 7C). 3) Rare micrite grains scattered throughout dolomite crystals (Fig. 7A). 4) Large calcite crystals which fill vugs, pore spaces, fractures, veins, etc. were noted.

2) Dolomite

Dolomite comprises 70 percent of the average host carbonate and makes up to 96 percent of some specimens. It is present in all thin sections. It occurs in two types: very fine anhedral grains about 3 to 5 µ which are intimately intergrown with calcite grains of similar size, and coarse rhombs about 170 µ across.

The coarser dolomite occurs in two different textures:

(a) Porphyroid texture. In the carbonate rocks studied by the writer prophyroid texture is formed by rhombic grains of dolomite disseminated in a matrix of micrite-size calcite grains (Plate 2A).

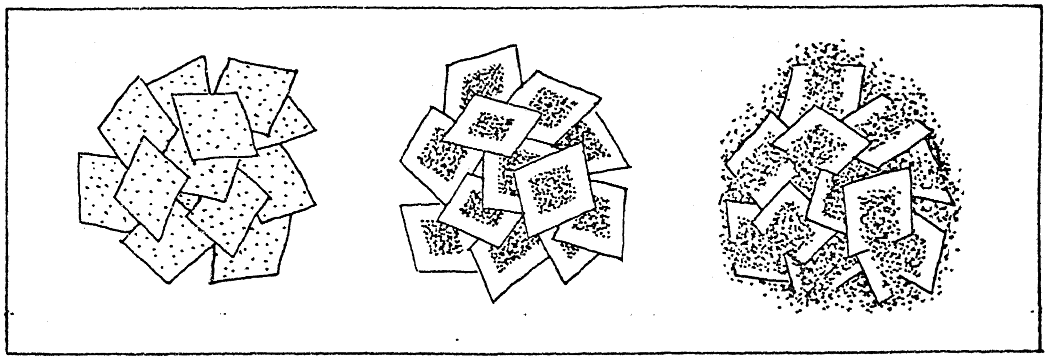


Figure 7. Observed calcite-dolomite textural relationships. Tiny calcite micrite grains may be partly (c) or entirely (b) enclosed as aggregates in dolomite rhomb; more rarely calcite grains are disseminated in euhedral dolomite (a).

Some of the rhombic crystals exhibit compositional zoning which consists of one small rhombic ring within the larger grains.

That the dolomite crystals comprising porphyroid textures have formed by replacement of calcite is shown by the varying degrees of calcite inclusion illustrated in Figure 8. Porphyroid texture may grade into coalesive texture within a single thin section.

(b) Coalesive texture. Observed coalesive textures consist of interlocked grains with an irregular mosaic pattern (Plate 2B). The boundary of these dolomite grains generally are clear, but organic sapropel(?) was noted at the boundaries of some dolomite crystals.

A few isolated circular or ovoidal patches of dolomite observed by the writer may be interpreted as a "product of arrested dolomitization produced by migration of magnesian solution" (Pettijohn, 1957, p. 419) as shown inPlate 3A and B.

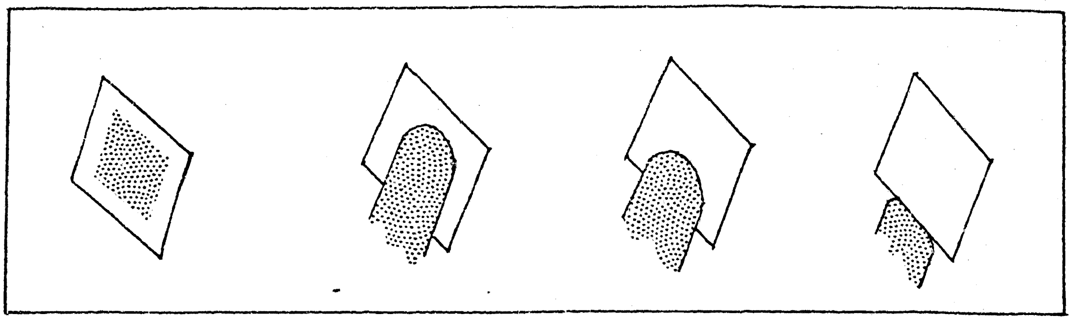


Figure 8. Variable degrees of inclusion of calcite in dolomite crystals.

Dolomite also occurs as clear crystals in vugs, veinlets, veins and fractures. The shells of ostracodes and gastropods may contain large dolomite crystals, 0.040 mm. to 0.137 mm. across.

b. Allochems

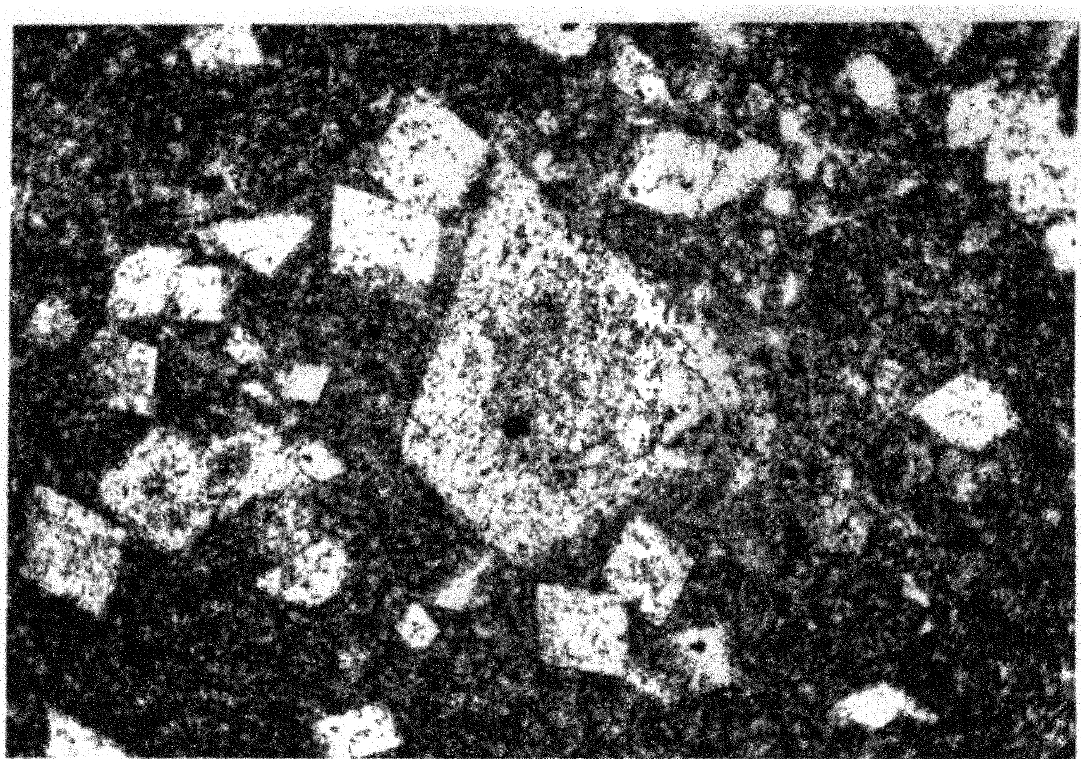
The percentage of allochems in the Shullsburg Mine unit is low. Fossils, the principal type of allochems, are broken, may form geopetal features (Plate 4A), and are very poorly packed (Plate 4B). Allochems constitute only about 3% of the host rock specimens, but some specimens contain over 50% allochems. Fossils noted in this study were: brachiopods, ostracodes, bryozoans, crinoids, gastropods, corals, and trilobites.

Brachiopods, 10 microns to a few millimeters long are the most abundant of the fossils, and rarely they may constitute as much as 30% of the rock. The original fibrous structure of the shell serves to identify it (Plate 5A). The average size of brachiopods is about 1 mm. and maximum size is over 5 millimeters. They occur scattered within the McGregor rather than the Quimbys Mill Member.

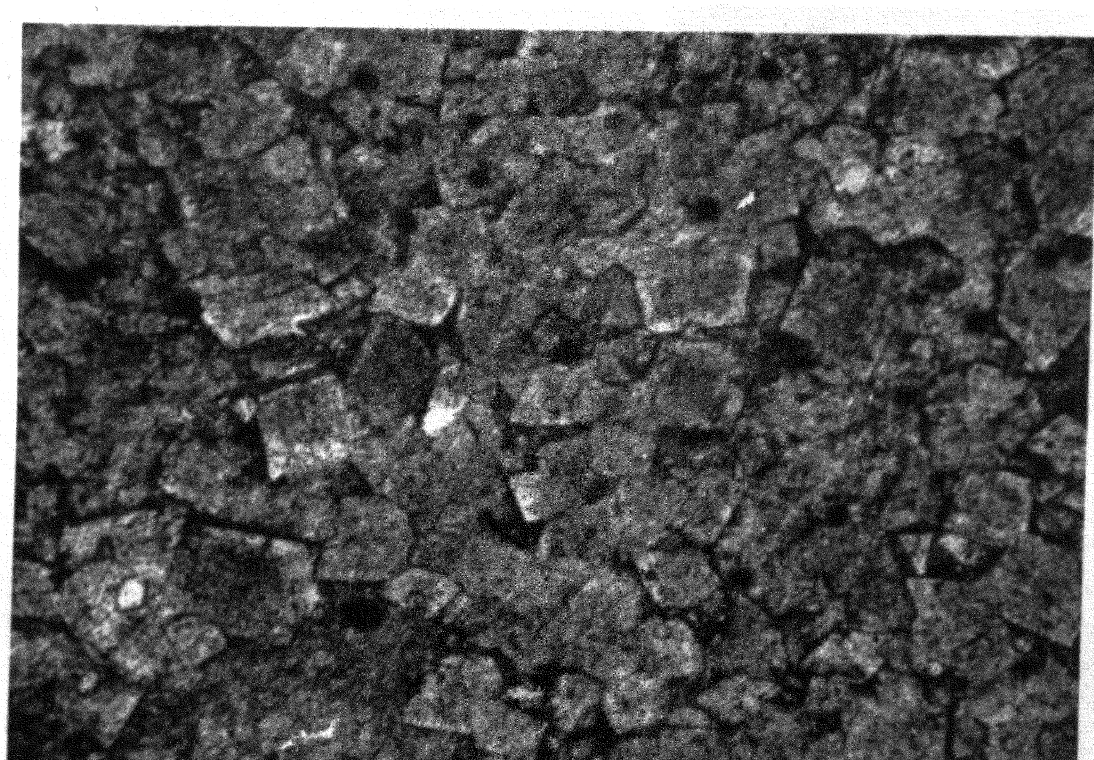
Ostracod shells are the next most abundant type of fossil, and they may constitute 15% of very rare specimens. The typical dome shape of ostracodes aids in their recognition (see Plate 5B). All

Plate 2. A. Photomicrograph of porphyroid texture in which coarse crystals of dolomite (rhombic, light gray) are disseminated in a fine-grained matrix of calcite (dark gray). Plane polarized light. 85X.

Plate 2. B. Photomicrograph of coalesive texture in which the dolomite grains are interlocked and exhibit subhedral to nearly rhombic shapes (medium gray). Scattered calcite and dark material (sapropel?) constitute small amounts in the specimen. Plane polarized light. 30X.



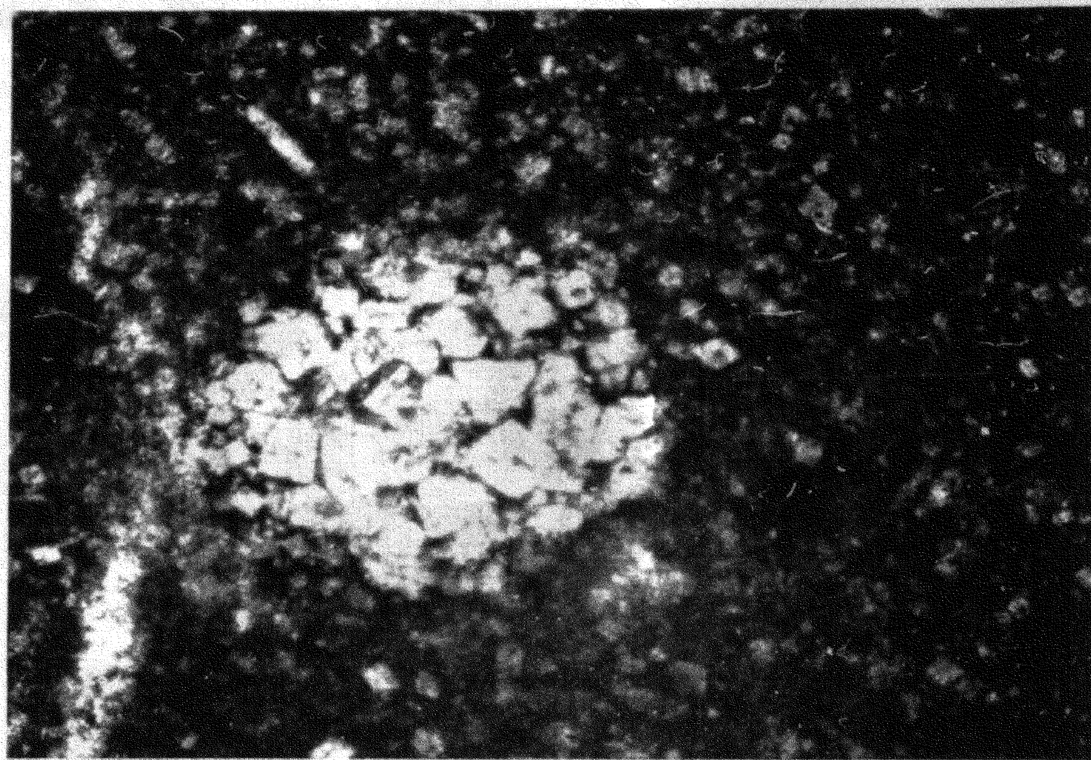
A



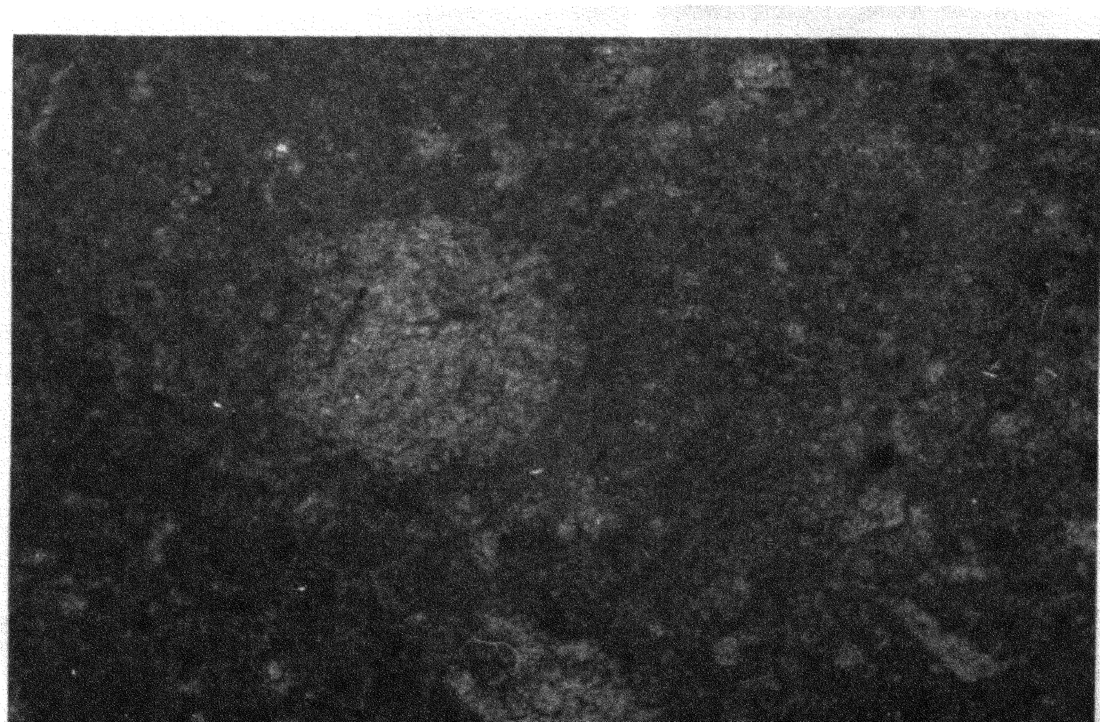
B

Plate 3. A. Photomicrograph of isolated, roughly ovoid, patches of dolomite (white, coarse grains) in a calcite micrite matrix (dark gray). Plane polarized light. 40X.

Plate 3. B. Photomicrograph of isolated, roughly circular, patches of dolomite (gray) in a calcite matrix (dark gray). Plane polarized light. 45X.



A



B

Plate 4. A. Photomicrograph of a thin section showing numerous ostracodes (O), brachiopods (B), and a crinoid (C). The shells are packed with the convex side up, so that they can be used as a geopetal feature. McGregor Member. Plane polarized light. 40X.

Plate 4. B. Photomicrograph showing poor packing of fossils. Trilobite (T) is present in the upper left corner. Plane polarized light. 30X.

A

B

ostracodes observed were dolomitized. Ostracodes are scattered within the McGregor, but some have been noted in the Quimbys Mill Member. The average length of ostracod observed in this section is about 0.1 mm. and their maximum length is 0.5 mm.

Crinoids (Plate 6), bryozoans (Plate 7), corals and trilobite constitute the remainder of the fossils. Sponge and algae are of questionable identification. A single gastropod was observed.

Other allochems include questionable pellets and oolites. Pellets and oolites are very rare and not more than two or three occur in a single thin section.

Dark organic material (sapropel?) was noted within the crystal boundaries of some dark brown dolomite crystals.

The various fossils observed in this petrographic study are illustrated by many photomicrographs because of the general absence of this type of material from the literature of the district.

c. Terrigeneous Constituents

The terrigeneous constituents in the host rocks in the Shullsburg Mine are quartz and clay. They are ubiquitously present in small amounts, generally less than 2 percent.

1) Quartz

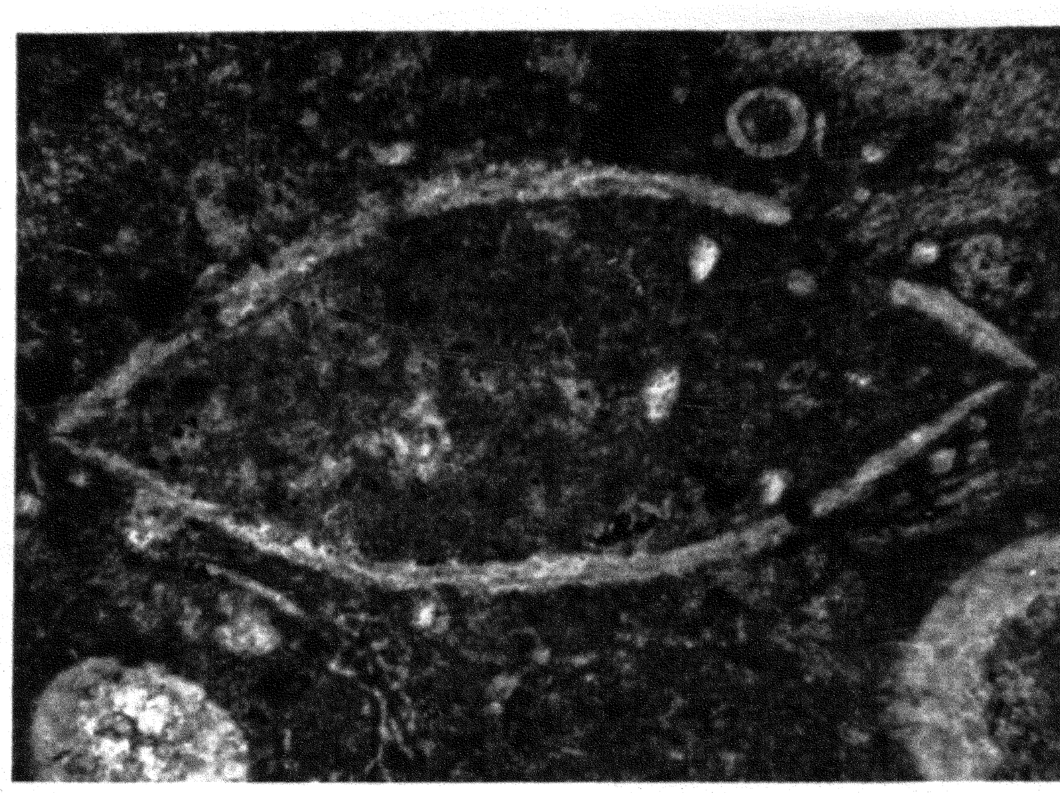
Quartz occurs as rounded detrital grains. The detrital quartz averages 1% and exhibits a size range of about 15 to 100 microns. Such quartz has been noted within thin sections and in insoluble residues.

2) Clay

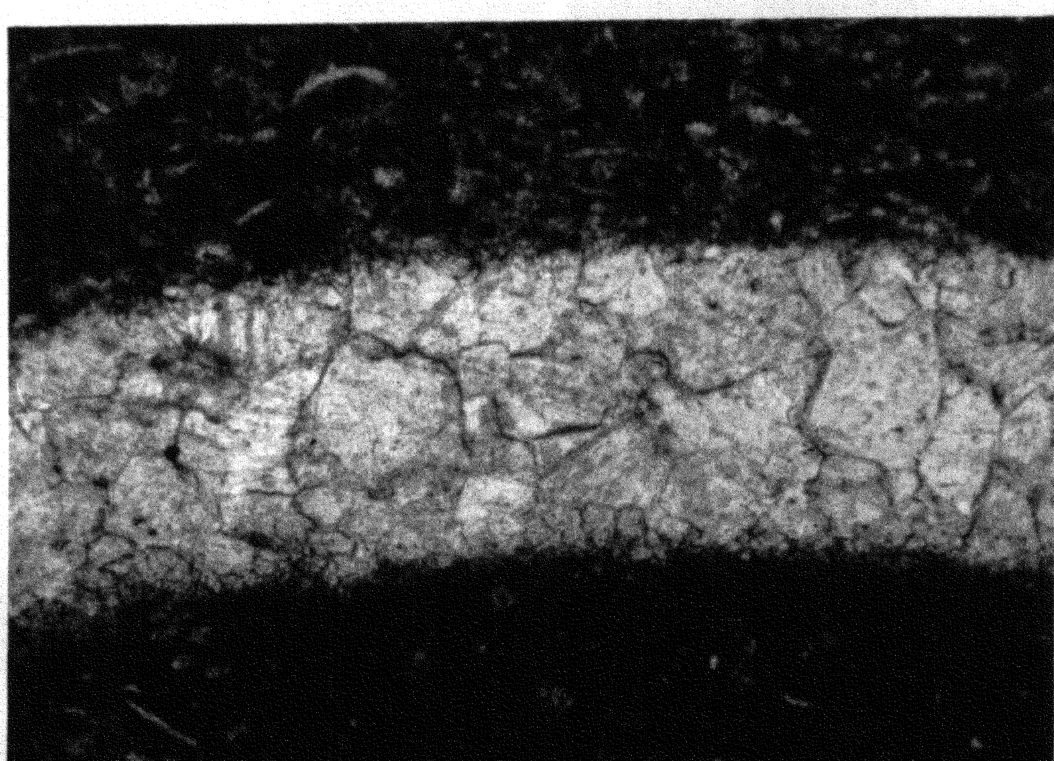
Clay occurs as very fine disseminated grains or it may be concentrated in stylolites, laminations, or rarely within

Plate 5. A. Photomicrograph of brachiopod (lens shaped) in matrix of calcite. Plane polarized light. 95X.

Plate 5. B. Photomicrograph of a portion of a convex dolomitized ostracod shell (light gray) in a matrix of stained calcite (dark) with some small rhombic grains of dolomite. Station 30. Plane polarized light. 40X.



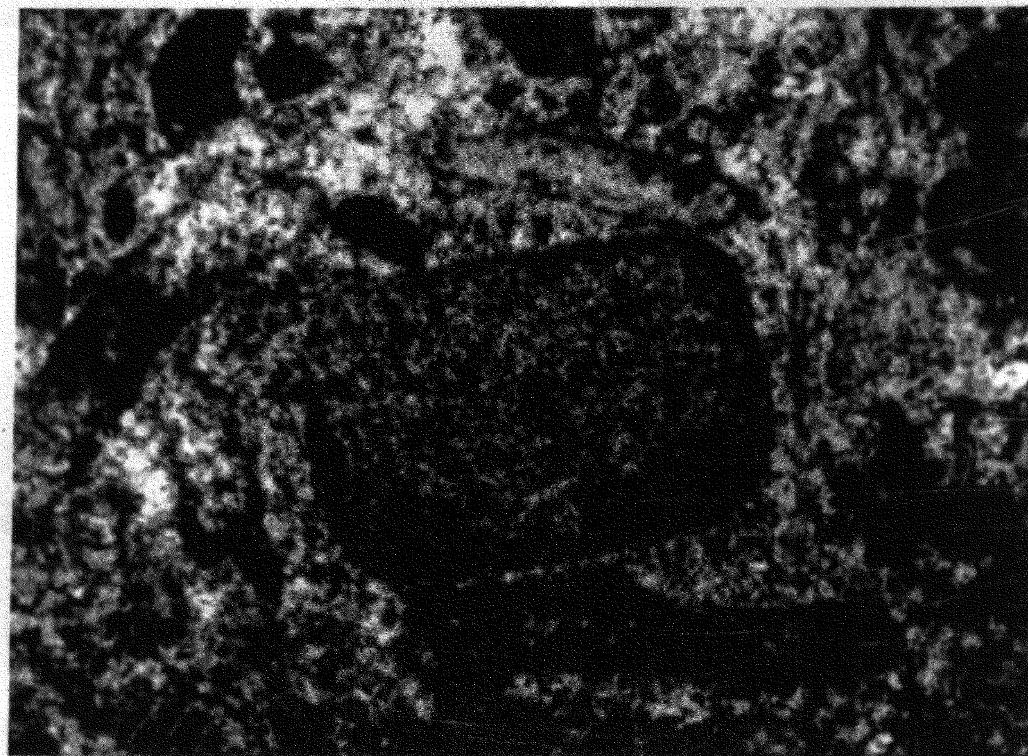
A



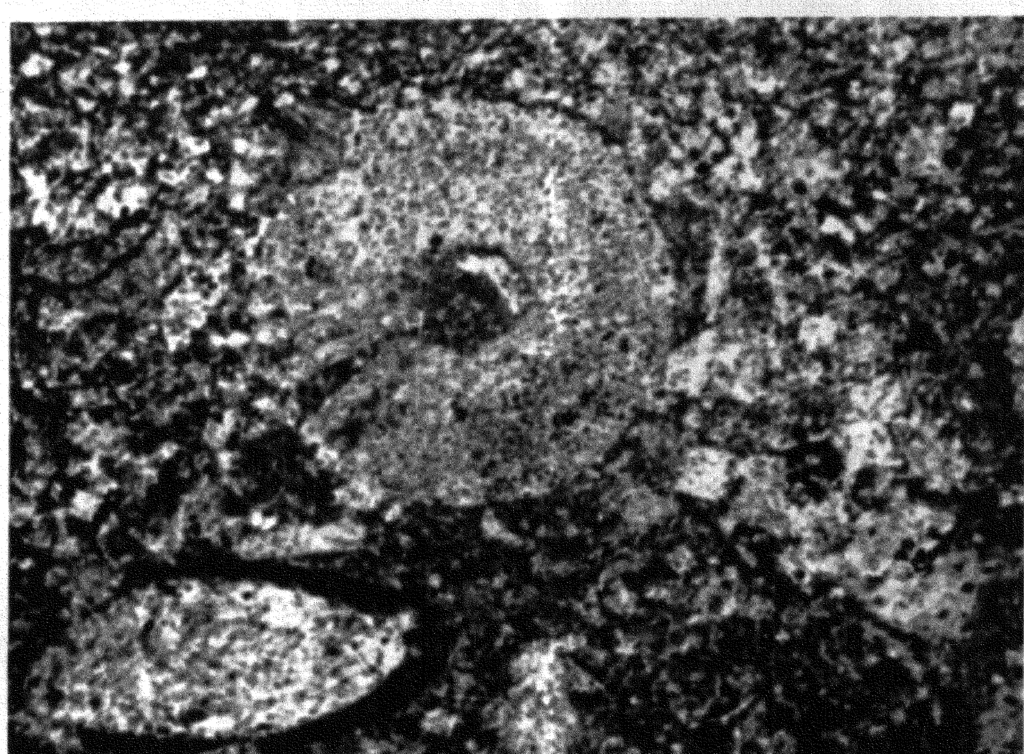
B

Plate 6. A. Photomicrograph of vertical section through a crinoid columnal (center of photograph) in matrix of calcite. Plane polarized light. 40X.

Plate 6. B. Photomicrograph of a horizontal section through a crinoid columnal enclosed in a matrix of calcite. Rhombic grains of dolomite are present in the calcite matrix. Plane polarized light. 40X.



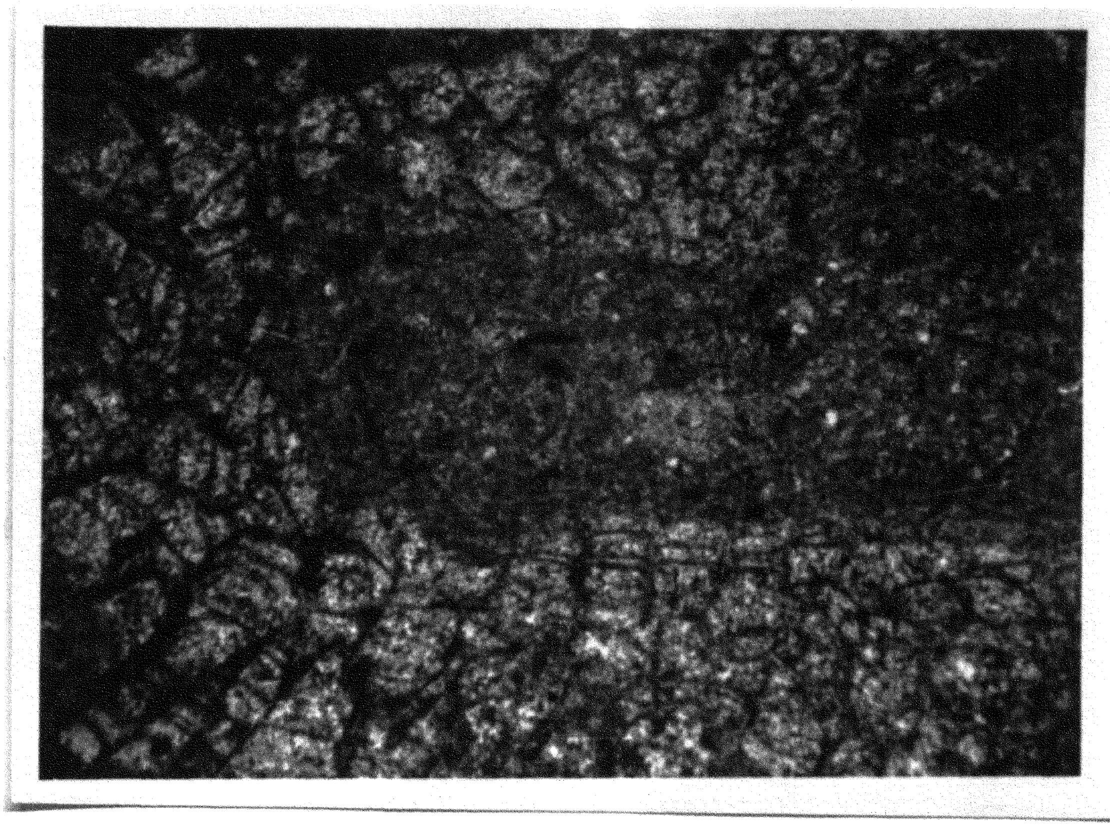
A



B

Plate 7. A. Photomicrograph of colony of bryozoan. Plane polarized light. 40X.

Plate 7. B. Photomicrograph of colony of bryozoan. Dark materials are calcite and lighter ones are dolomite. Plane polarized light. 40X.

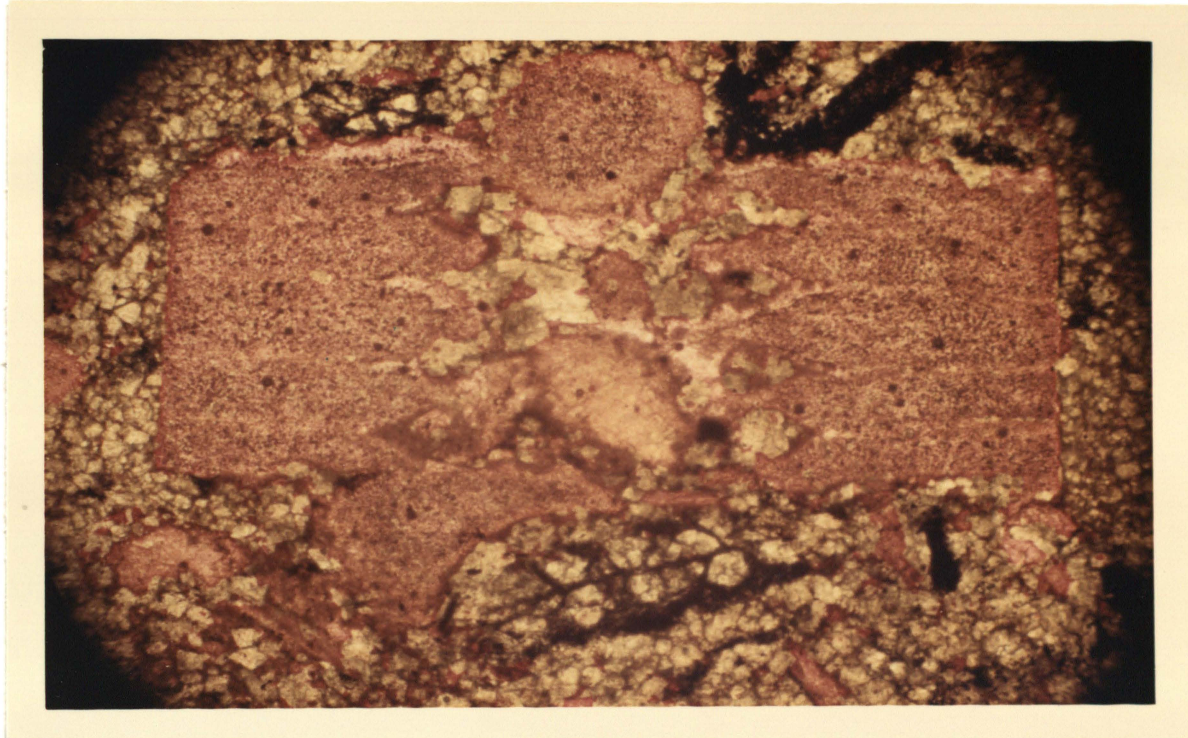


A

B

Plate 8. A. Color photomicrograph of a crinoid columnal in which the calcite in the area of the lumem of the columnal is partially replaced by dolomite. Alizarin Red S has stained calcite red and left dolomite unstained. A single calcitic bryozoan is located beneath the crinoid. Plane polarized light. 25X.

Plate 8. B. Color photomicrograph of calcitic tetracoral (red) partially replaced by dolomite (yellow, rhombic change) and quartz (yellow, fibrous). Crossed nicols. 30X.



A

B

dolomite grains. The color of the clay is dark reddish brown, but when it is concentrated it becomes a dark brownish-black. It constitutes about one-half of the terrigeneous constituents.

d. Opaque Minerals

Small amounts of opaque minerals were noted in specimens near the ore zones. The opaque minerals recognized during this investigation were: pyrite, sphalerite, galena, hematite, chalcopyrite and marcasite.

Pyrite was noted within fractures, stylolites, and dolomite grains. Pyrite occurs as masses of euhedral and irregularly shaped crystals and as disseminated grains in both McGregor and Quimbys Mill members (Plate 9B). The pyrite grains are 0.035 to 0.235 mm in diameter. Rarely pyrite forms anhedral margins against fossils while other crystal faces are euhedral (Plate 9A).

Rare disseminated crystals of subhedral galena, 5 micron chalcopyrite grains, occurs as fan shaped marcasite crystal groups, and a few grains of sphalerite, were noted in some samples. Hematite, recognized in thin sections by its dark red color, is present locally.

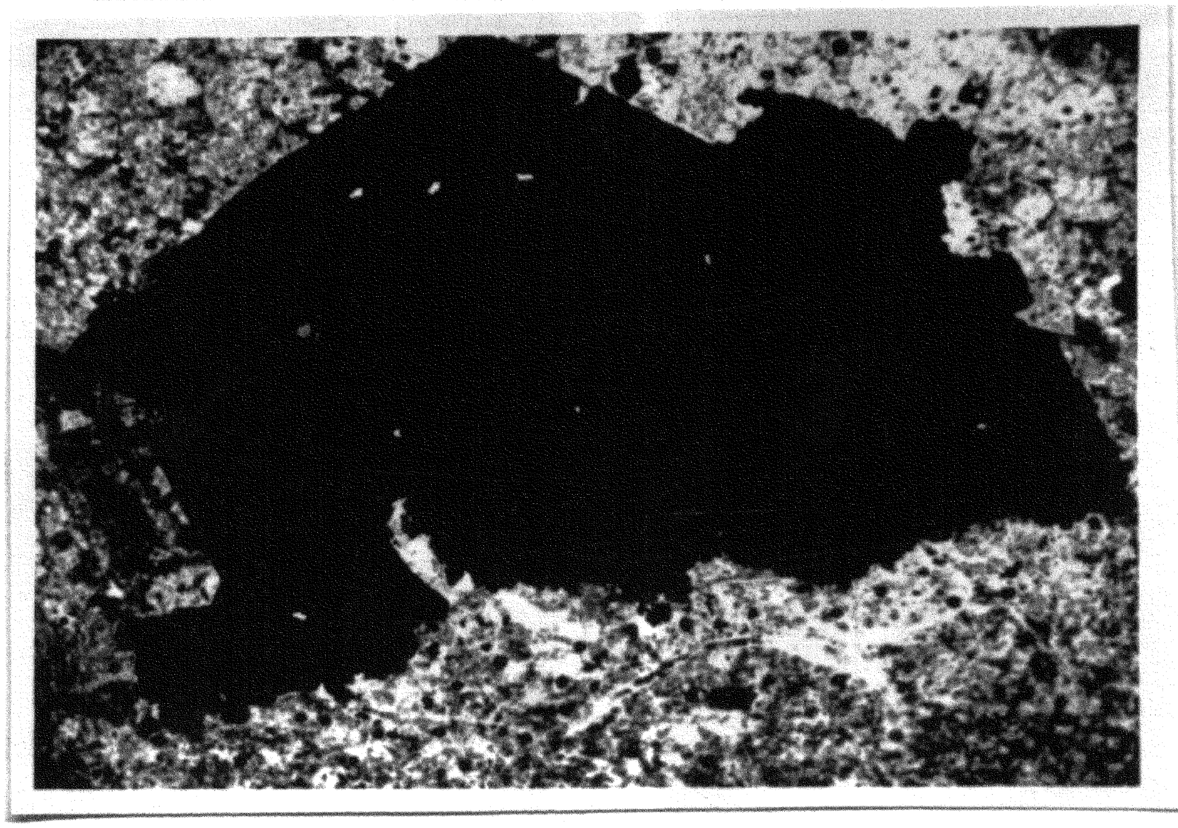
Sulfide specimens collected from the ore zones are shown in Plate 10.

e. Other Microscopic Features

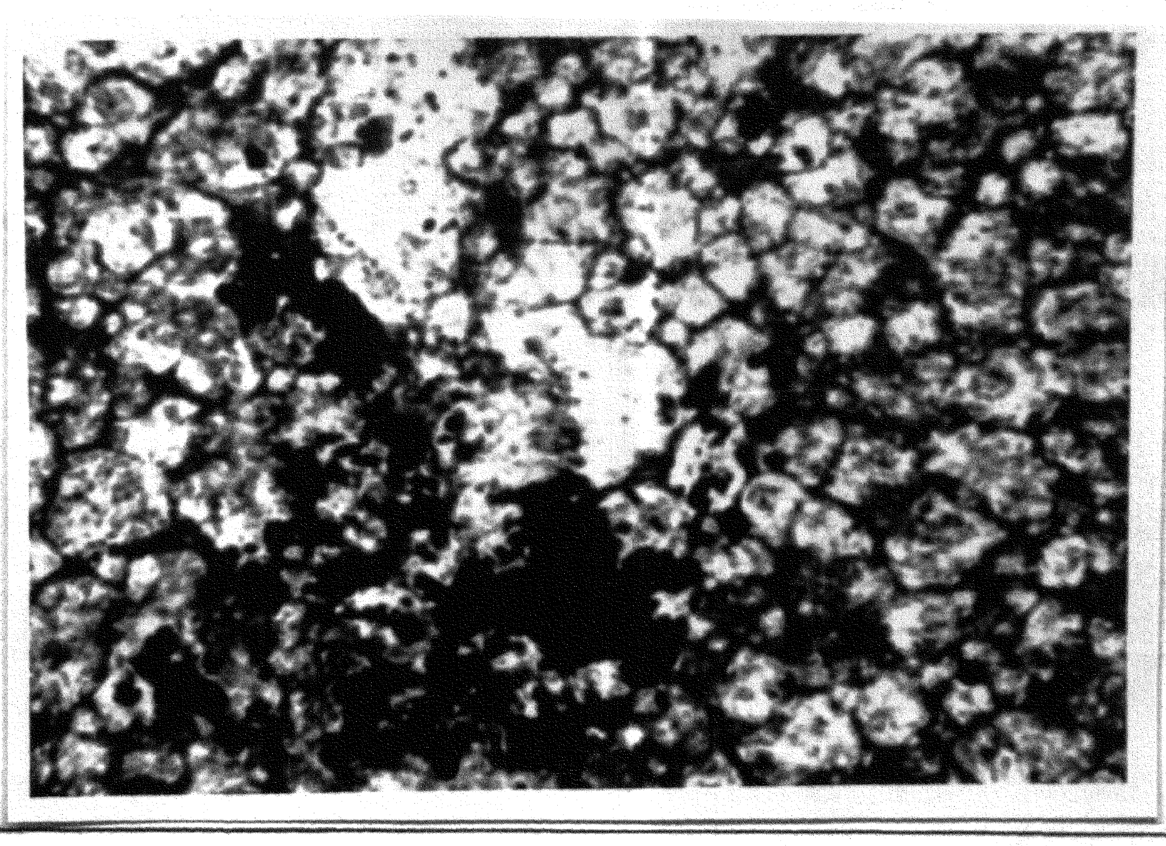
Laminations are not megascopically conspicuous. Microscopically they were observed in both limestones and dolomites, but more commonly in dolomite. They consist of layered concentrations

Plate 9. A. Photomicrograph of a pyrite metacryst which has an irregular base against a fossil and an euhedral to subhedral top. Plane polarized light. 40X.

Plate 9. B. Photomicrograph of dissiminated pyrite closely associated with coalesive dolomite. Plane polarized light. 45X.



A



B

Plate 10. A. Color photograph of a hand specimen of zinc sulfide with calcite (white) and iron sulfide (lighter bands in the colloform structure) from ore zones.

Plate 10. B. Color photograph of hand specimen of zinc sulfide (brown at base of photograph) with calcite (white), galena (bluish gray) and iron sulfide (yellowish-brown area one inch to left of the coin) from an ore body.

A

B

of clay, smaller rhombic dolomite crystals than the surrounding dolomite grains and rarely opaque minerals (Plate 11A).

3. Other Methods of Study Applied to the Carbonate Rocks in the Upper Mississippi Valley Zinc-Lead District

In addition to the above macroscopic and microscopic examinations, a few specimens were studied by acetate peel, acid etching and insoluble residue techniques.

a. Acetate Peels

Acetate impressions of slightly etched flat surfaces of specimens and host rocks were examined under the petrographic microscope. Such peels exhibit many details of texture as shown in Plate 11B.

b. Etching

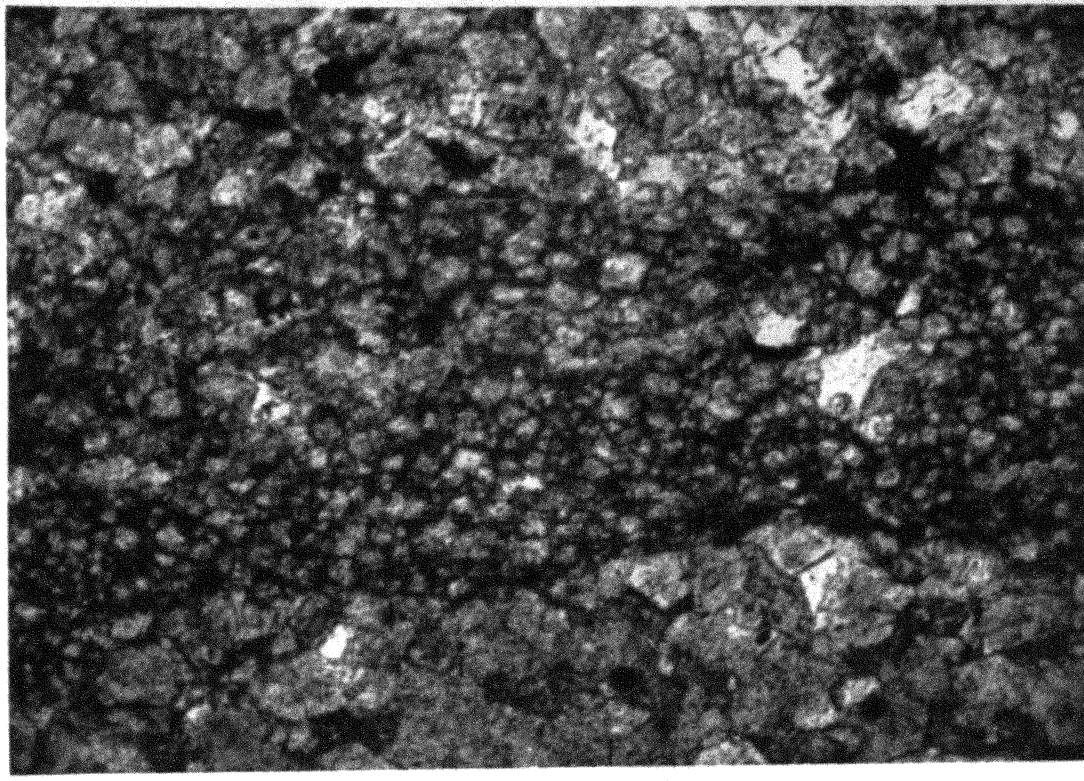
Host rock specimens placed in a 10% hydrochloric acid solution for two minutes revealed the distribution of clay, quartz and other insolubles.

c. Insoluble Residue

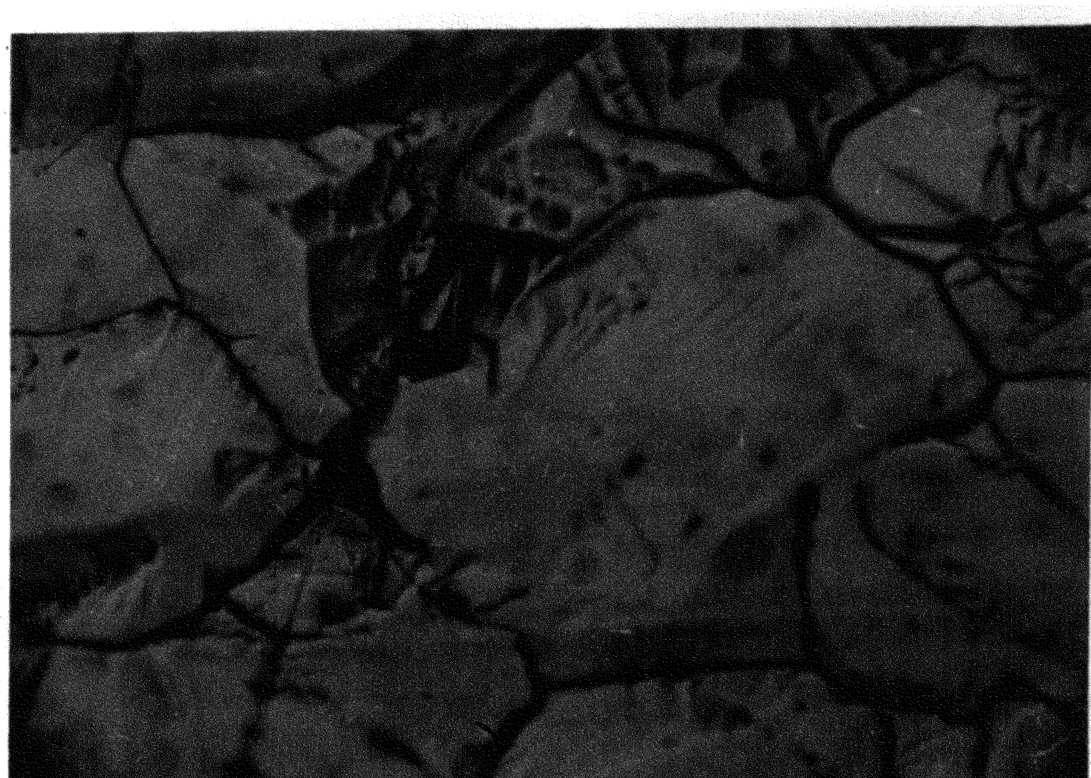
About 5 grams of several host rock specimens were dissolved in concentrated hydrochloric acid and their insoluble constituents were examined under the petrographic and binocular microscopes. The insoluble constituents were quartz, clay and opaque minerals. The quartz is clear to light gray or white, fine-grained (15 to 100 μ) with various shapes. The fine-grained clay is abundant and has a light olive color. Dark unidentified opaque minerals constitute a small percentage of the residues.

Plate 11. A. Photomicrograph of lamination consisting of clay and some opaque minerals (dark gray) at the boundary between fine-grained dolomite and coarse dolomite. Plane polarized light. 90X.

Plate 11. B. Photomicrograph of acetate peel showing the texture of the dolomitic Quimbys Mill Member. Plane polarized light. 170X.



A



B

C. Post-Depositional Changes

The original nature of the sedimentary carbonate may be influenced by endogenous and exogenous forces. Some of the results of these forces were noted in the McGregor and Quimbys Mill carbonates. The post-depositional changes are represented primarily by stylolites and fracture fillings. In addition to these most of the opaque minerals and replacement quartz represent post-depositional crystallization.

Secondary quartz partly replaces calcite and dolomite in some specimens near ore zones. The grains are about 100 μ and generally dessiminated, but some quartz may replace portions of fossil fragments such as brachiopod shells, corals and others (see Plate 8). Up to 8% of some specimens are replaced by quartz.

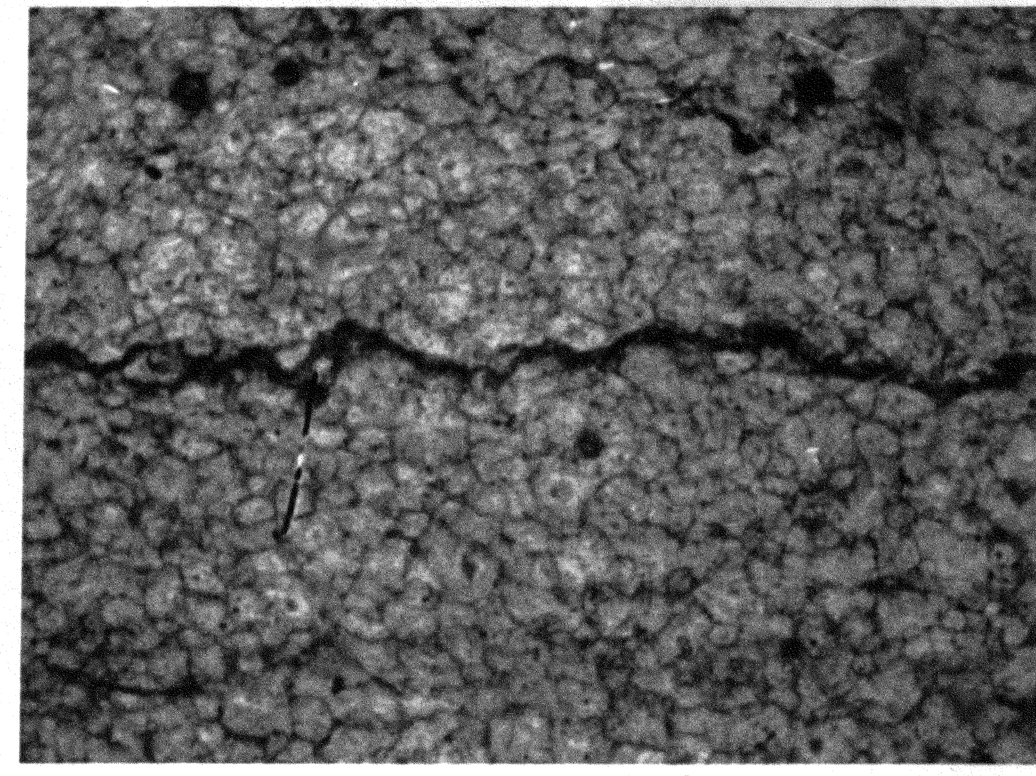
1. Stylolites

Stylolites are not conspicuous megascopically, but in some horizons (e.g., blue bed, lower Ion Member) they have been observed. Microscopically, they are common in the Quimbys Mill and less common in the McGregor. In thin sections the stylolites appear to be zigzag in shape, forming peaks and valleys. The distance between the peaks and valleys measured in several thin sections averaged 125 microns. Their average thickness is 15 microns. Microscopic study of the stylolites showed that they contain clay, opaque minerals (mostly pyrite and iron oxides), and broken crystals and fossils.

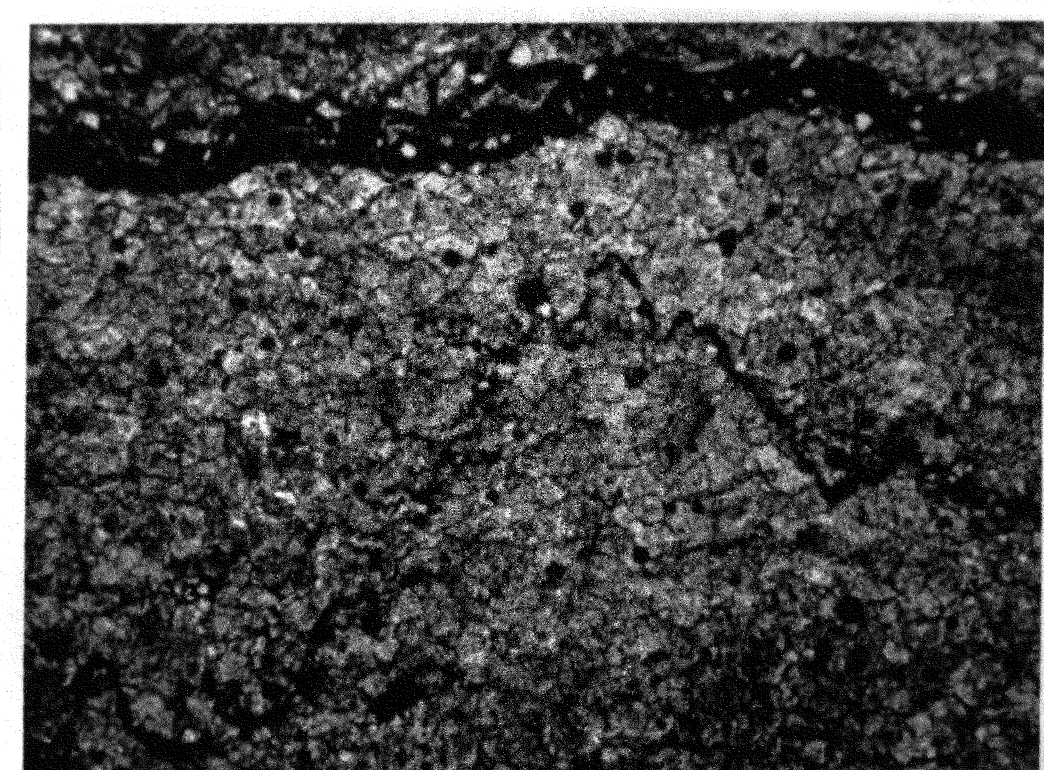
Two types of stylolites are present. One has nearly straight lines with small peaks and valleys with an average separation of 60 microns. This incipient type of stylolite (Plate 12A) is in

Plate 12. A. Photomicrograph of incipient stylolite in dolomite. Dark materials are compacted clay within the stylolite. Plane polarized light. 50X.

Plate 12. B. Photomicrograph of sutured stylolite (lower central part of photo) in dolomite grains. The heavy line on the upper part of the picture is an incipient stylolite. Plane polarized light. 50X.



A



B

contrast with the sutured type (Plate 12B) which has relatively thick accumulations of clays in its crests and valleys (Park, 1962, p. 92 to 94).

2. Fracture Fillings

Fractures of various attitudes were observed underground in the Shullsburg Mine. Since these fractures provide excellent conduits for the passage of solutions, some are filled by ore and gangue minerals to form veins and veinlets. Irregular shaped vugs (Plate 13) may also be filled or partly filled with minerals such as calcite, dolomite and sulfides. Coarse-grained calcite crystals may be scalenohedral (Plate 14A) or rhombohedral (Plate 14B).

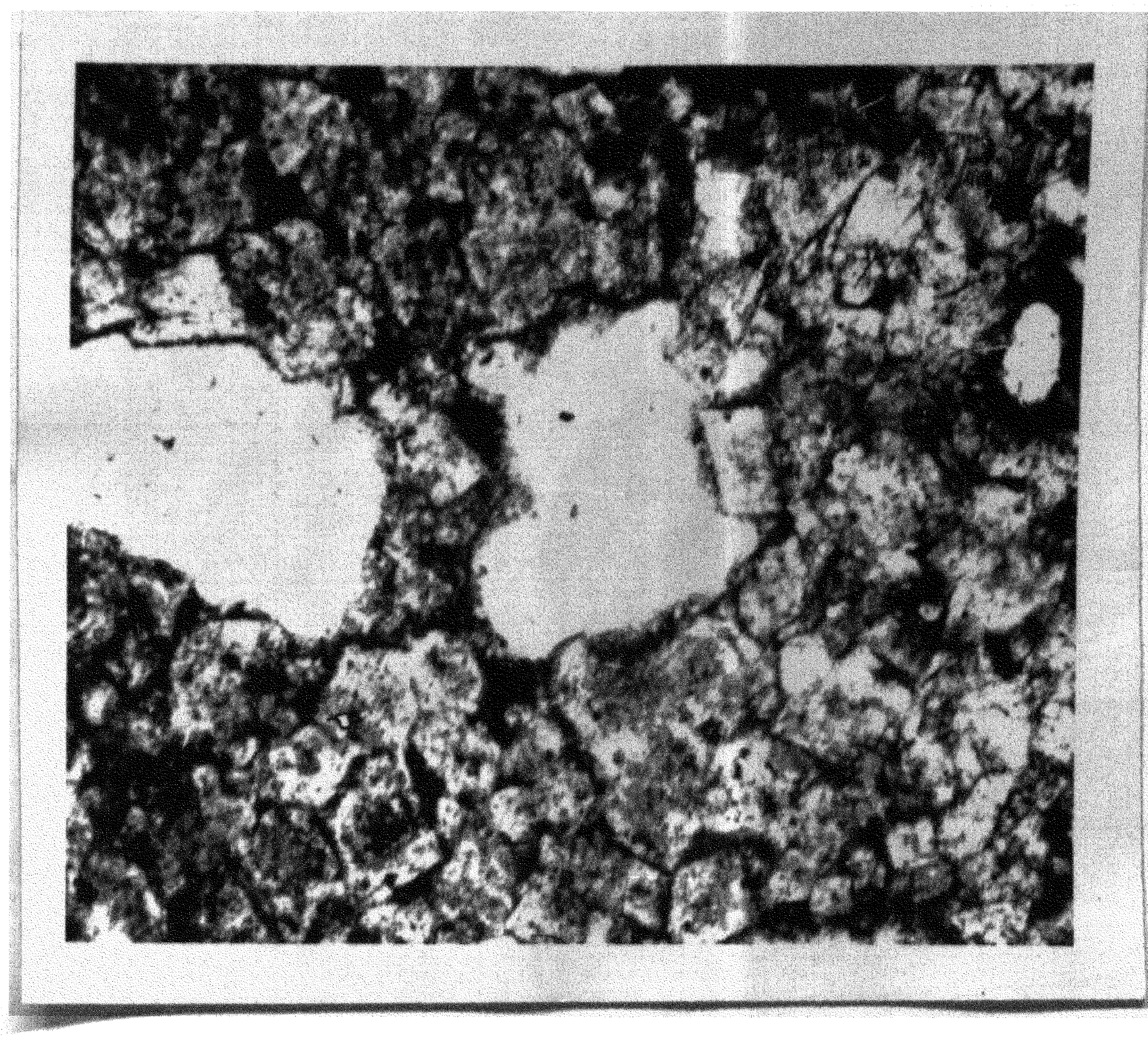


Plate 13. Photomicrograph of microvugs (white), crystals in coalesive dolomite (gray). Plane polarized light. 95X.

Plate 14. A. Color photograph of a scalenohedral calcite crystal found in a vug.

Plate 14. B. Color photograph of a rhombohedral calcite crystal found in a vug.

A

B

Chapter V

LATERAL VARIATION IN HOST ROCKS

The principal purpose of this study was to investigate the lateral variation in host rock carbonates contiguous to lead-zinc ore deposits in the Upper Mississippi Valley district.

The Shullsburg Mine was selected for this investigation because a series of pull drifts connecting eight ore bodies afforded access to the host rock. Specimens were collected at an approximate interval of 100 feet from 86 stations along the pull drifts, from the Edgarton and Wheeler deposit in the south to the Hendrickson deposit in the north (Fig. 9). Duplicate specimens were collected from some stations. From these specimens 132 thin sections were prepared for study. An additional 41 hand specimens and thin sections were available from an earlier study of the south part of the mine by R. D. Hagni.

A special effort was made to obtain all of the specimens in a given pull drift from the same stratigraphic horizon. Structural conditions, however, necessitated the collection from the McGregor Member (Trenton) in pull drifts from the Edgerton and Wheeler deposit to the South South Leona Hayden deposit. From that deposit northward to the Hendrickson deposit, the samples were collected from the Quimbys Mill (glass rock) Member of the Platteville Formation. Since the samples available from Dr. Hagni belong to the Quimbys Mill, both stratigraphic members are represented in the southern portion of the Shullsburg Mine. A summary of the specimens collected is given in Table 1.

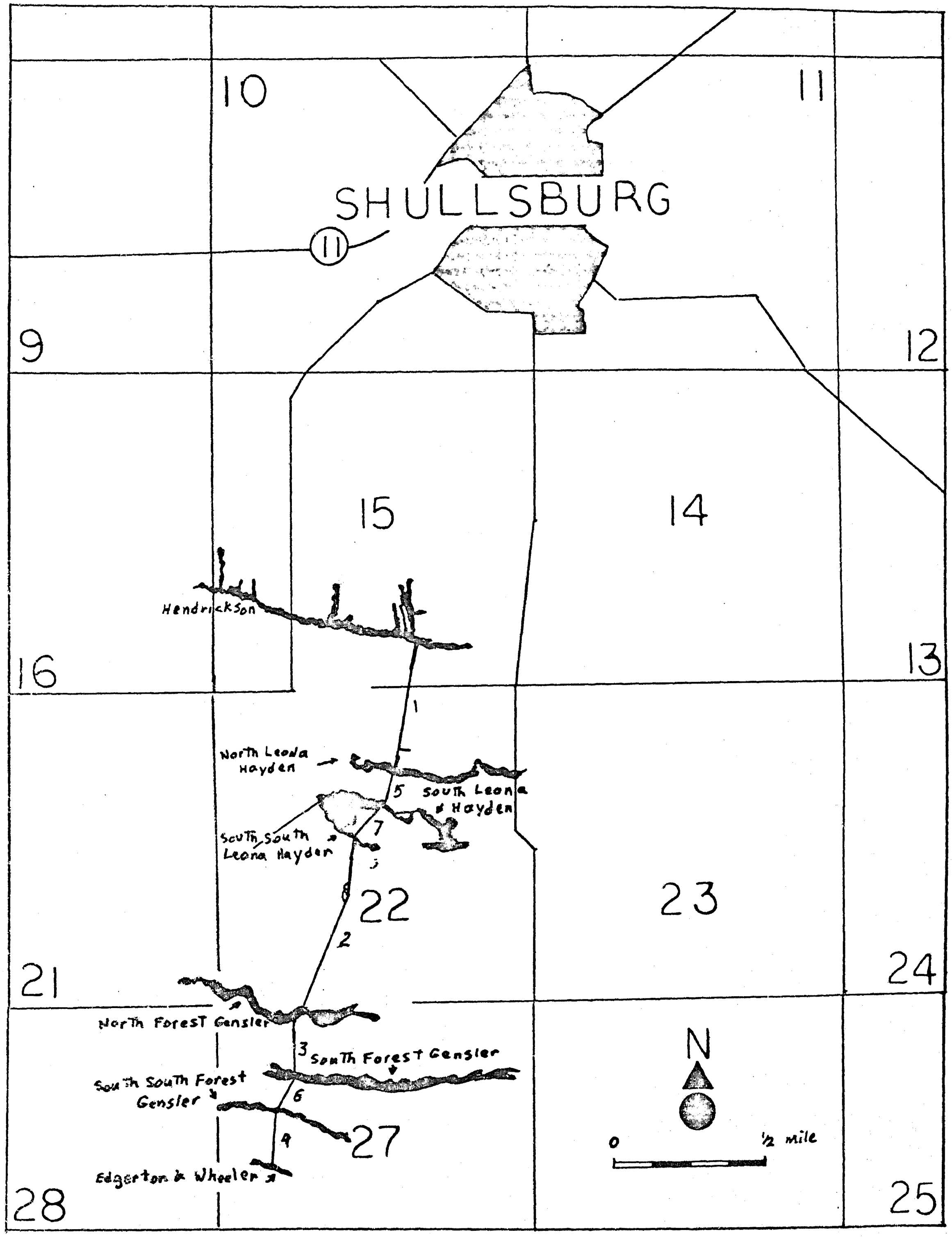


Figure 9. Index map showing location of ore deposits in the Shullsburg Mine, Wisconsin.

A similar study in the Tri-State district (Hagni and Saadallah, 1965) showed that host rock limestone consisting primarily of allochems was replaced by sparry calcite at distances of 40 to 80 feet from the zinc-lead ore bodies. In the Upper Mississippi Valley district, Heyl and others (1959, p. 101-108) indicated that the wall rock alterations there consisted of solution of the calcareous rocks, silicification and dolomitization. To study these lateral variations in more detail, the Shullsburg Mine was selected.

A. Lateral Variation of Host Rock Within Individual Pull Drifts

The seven pull drifts selected for this investigation are discussed in the order given in Table 1.

1. Pull Drift Between the North Leona Hayden and Hendrickson Ore Deposits

Nineteen host rock carbonate samples of Quimbys Mill were collected from a pull drift 2,000 feet long between the North Leona Hayden and the Hendrickson deposits in the northern portion of the Shullsburg Mine. The specimens were numbered from 72 adjacent to the North Leona Hayden (specimens 70 and 71 are not shown in the profile in Fig. 10 because they were from a different stratigraphic horizon) to 90 near the Hendrickson ore zone.

Close megascopic study of the hand specimens shows no consistent lateral color variations.

A total of 19 thin sections were prepared from hand specimens. These sections exhibit some marked differences in the compositions of carbonate rock. The rock in most of the central portion of the pull drift (specimens 74-77 and 83-85) has an average composition of 48% orthochem and allochem calcite and 50% dolomite. As the

	PULL DRIFT BETWEEN DEPOSITS FROM	TO	LENGTH (Feet)	STRATIGRAPHIC BED UNITS	NUMBER OF SPECIMENS
1	North Leona Hayden	Hendrickson	2,000	Quimbys Mill	19
2	North Forest Gensler	South South Leona Hayden	3,200	McGregor	33
3	South South Forest Gensler	South Forest Gensler	400	McGregor	5
	South South Forest Gensler	South Forest Gensler	400	Quimbys Mill	11
4	South Forest Gensler	North Forest Gensler	900	McGregor	10
	South Forest Gensler	North Forest Gensler	900	Quimbys Mill	22
5	South South Leona Hayden	South Leona Hayden	600	Quimbys Mill	7
6	Edgarton Wheeler	South South Forest Gensler	600	McGregor	6
	Edgarton Wheeler (Halfway on pull drift)	South South Forest Gensler	400	Quimbys Mill	8
7	South Leona Hayden	North Leona Hayden	500	Quimbys Mill	6
					TOTAL...127

TABLE 1. Host rock carbonate specimens collected from the Shullsburg Mine.

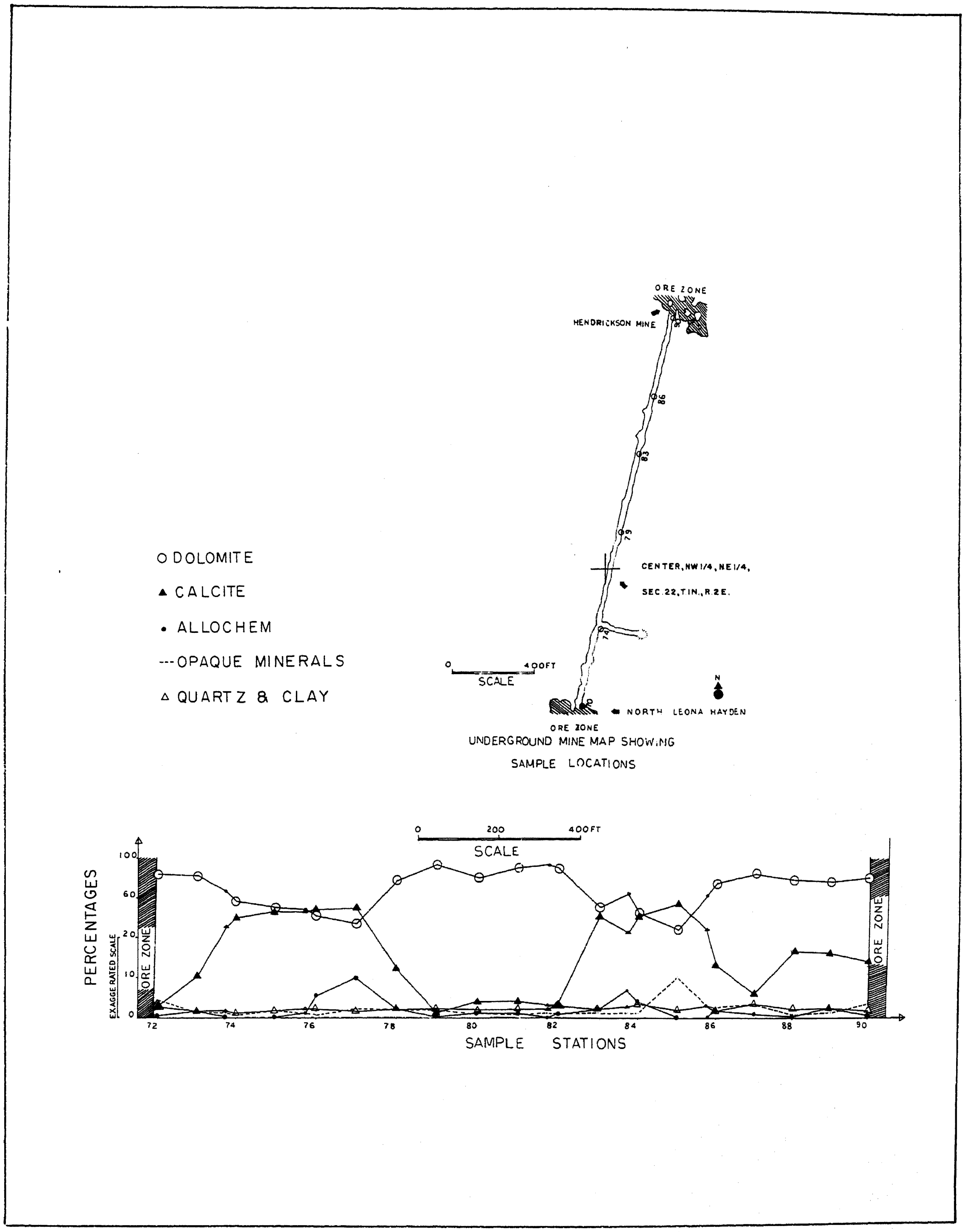


Fig. 10. Chart showing sample location, distance from ore zone, and percentages of carbonate constituents. Smaller symbols indicate duplicate samples. Pull drift between North Leona Hayden and Hendrickson ore deposits, Shullsburg Mine, Wisconsin. Quimbys Mill Member.

Hendrickson ore zone is approached the calcite content drops to 16% and the dolomite increases to 76%. Adjacent to the North Leona Hayden ore deposit the calcite content is diminished to 3% and the dolomite content rises to 80%. The point at which the dolomite component begins to increase is about 400 feet from the former deposit and 150 feet from the latter ore zone.

The increase in dolomite content is accomplished by replacement of fine-grained anhedral calcite and dolomite by coarser-grained rhombic dolomite as shown in Plate 15A and B. Remnant areas of fine-grained calcite and dolomite remain in the central portions of some dolomite rhombs, averaging about 170 μ.

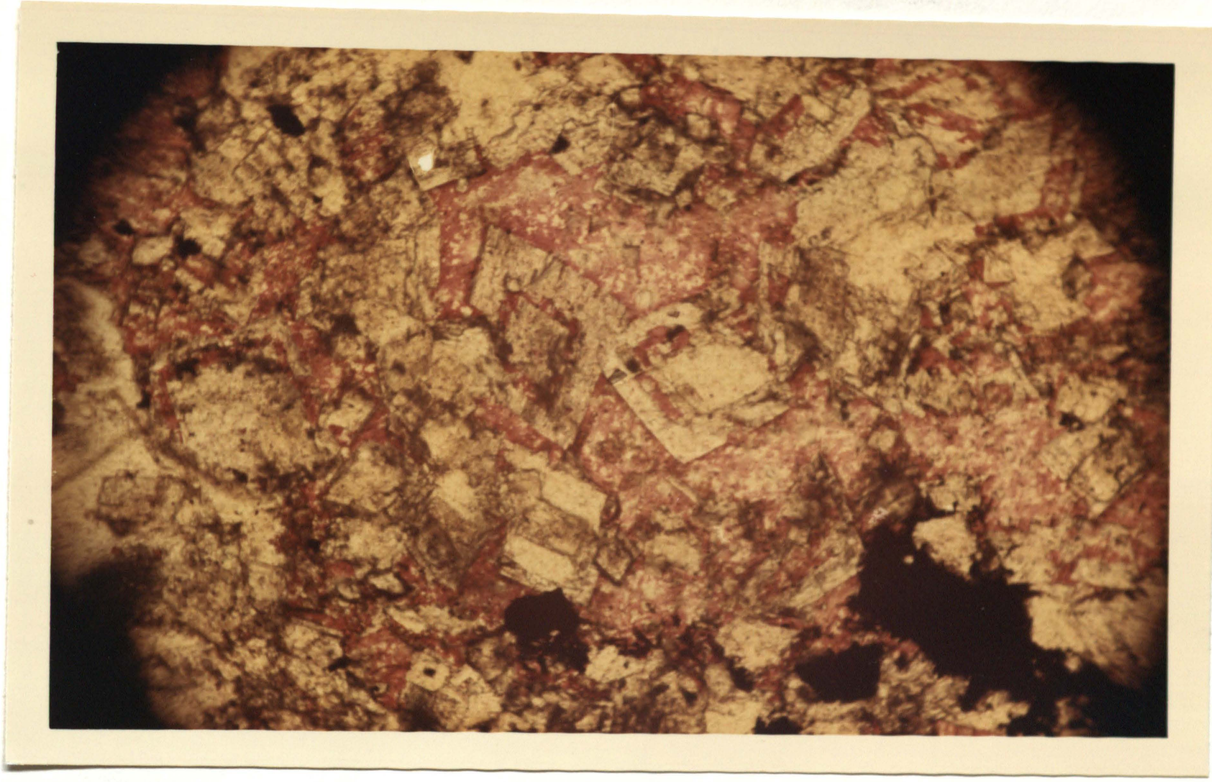
A local marked decrease in the calcite content of the carbonate rock in the middle of the pull drift (specimens 79 to 82) suggests that another east-trending mineralized zone may be located in an intermediate position between the two ore zones. Some drilling to the east of the pull drift apparently was directed at such mineralization.

2. Pull Drift Between the North Forest Gensler and South South Leona Hayden Ore Deposits

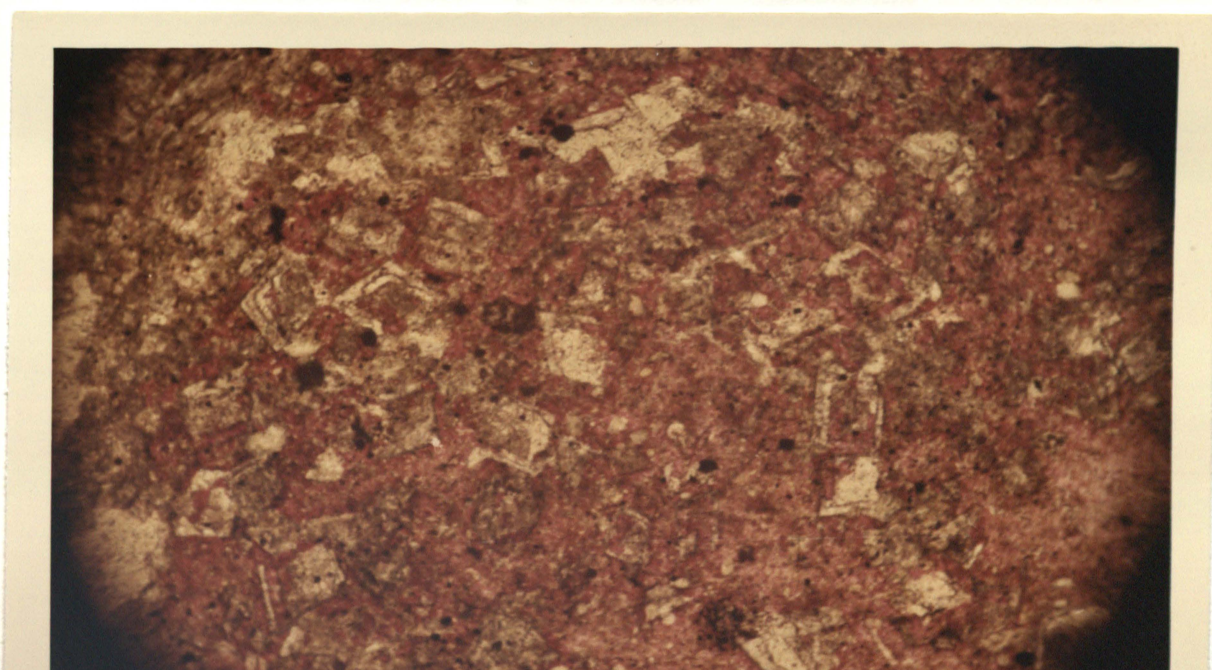
Thirty-three specimens of McGregor host rock carbonate were collected from a 3,200 foot pull drift, between the North Forest Gensler and South South Leona Hayden in the Shullsburg Mine (Fig. 11). Close megascopic study of the hand specimens show that the single specimen or two immediately adjacent to the ore zones are lighter (yellow gray) while the bulk of the specimens exhibit a darker color (light gray). Fossils are megascopically visible in some of the specimens.

Plate 15. A. Color photomicrograph of fine-grained calcite (red) and dolomite (yellow) replacement remnants in coarser dolomite crystals (rhombic). Partly altered carbonate rock, Station 17, and North Forest Gensler and South Forest Gensler ore deposits, Quimbys Mill Member. Plane polarized light. 40X.

Plate 15. B. Color photomicrograph showing replacement of fine-grained calcite (red) and fine-grained dolomite (yellow) by coarser dolomite (rhombic). Partly altered carbonate rock Station 28, pull drift between North Forest Gensler and South South Leona Hayden ore deposits, McGregor Member. Plane polarized light. 25X.



A



B

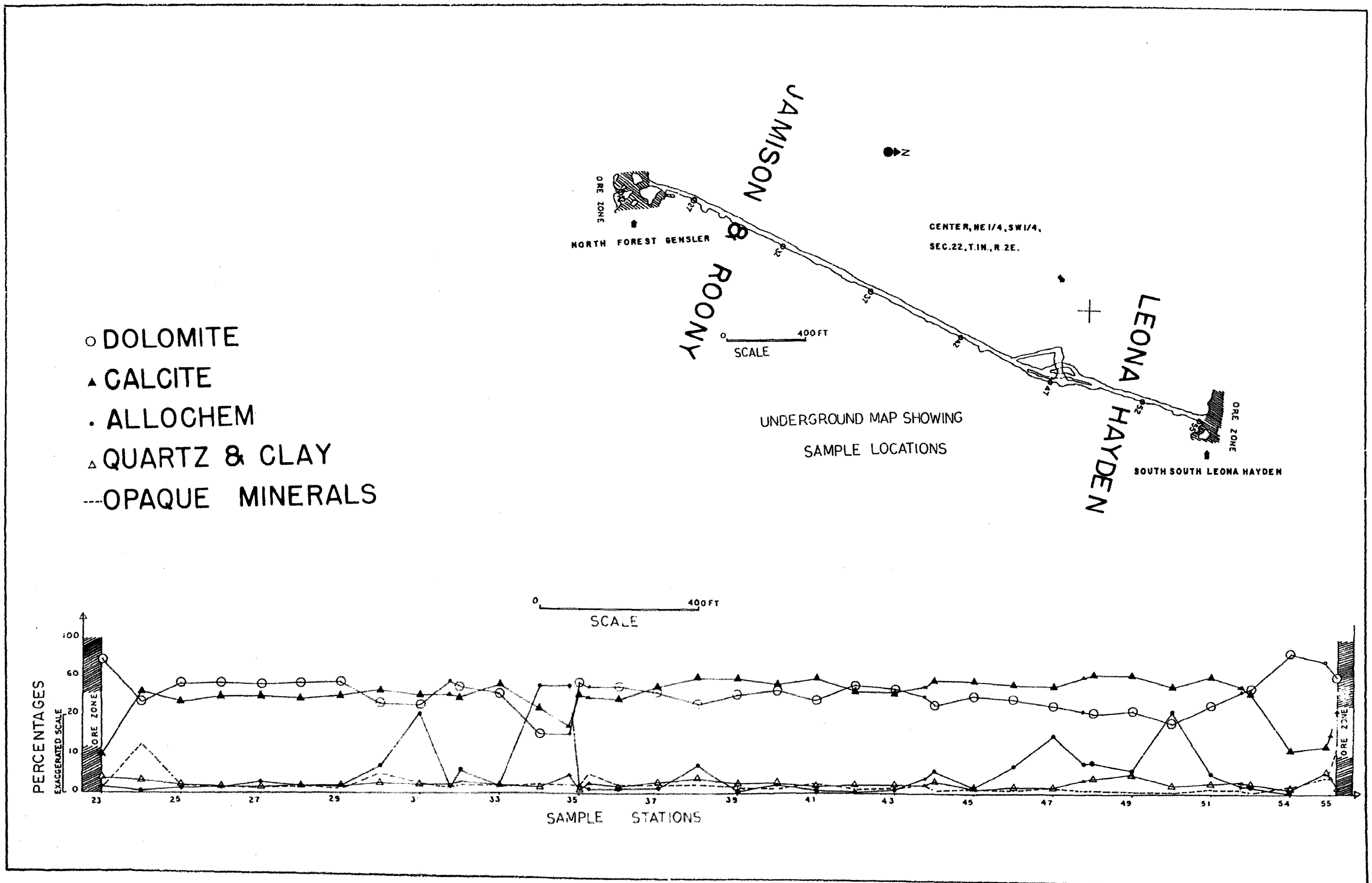


Fig. 11. Chart showing sample location, distance from ore zone, and abundance of carbonate constituents. Smaller symbols indicate duplicate samples. Pull drift between North Forest Gensler and South South Leona Hayden ore deposits, Shullsburg Mine, Wisconsin. McGregor Member.

Thin sections prepared from the carbonate specimens show marked differences in the constituents near the ore zones. In the central portion of the pull drift, where the carbonate is least altered, the average composition is 56% calcite, 42% dolomite, with minor amounts of quartz, clay and opaque minerals. Calcite and dolomite are predominantly of micrite size. The allochem content varies greatly from 1% to over 50%, but exhibits no apparent systematic lateral variation. Toward the North Forest Gensler ore deposit, the calcite content decreases to 10% while dolomite increases to 78%. Toward the South South Leona Hayden ore deposit calcite decreases to about 10% near the ore zone, where dolomite increases to 72%. The dolomite crystals near the ore bodies average 170 µ. The point at which the dolomite component begins to vary is about 90 feet to the North Forest Gensler ore deposit, and 200 feet toward the South South Leona Hayden ore deposit.

3. Pull Drift Between the South South Forest Gensler and South Forest Gensler Ore Deposits

Five host rock carbonate specimens were collected from a pull drift 400 feet long between the South South Forest Gensler and South Forest Gensler ore deposits (Fig. 12). The specimens are from McGregor Member. The specimen collected immediately adjacent to each ore zone is lighter (yellowish gray to light brownish gray) than the others which are light gray to medium gray.

Thin sections prepared from the five specimens show very little variation in composition. The carbonate specimens average 50% dolomite, 39% calcite, and 11% allochems and other materials. The dolomite grains are principally coarse-grained, averaging 200 µ in size. Thus, the McGregor appears to be partly dolomitized

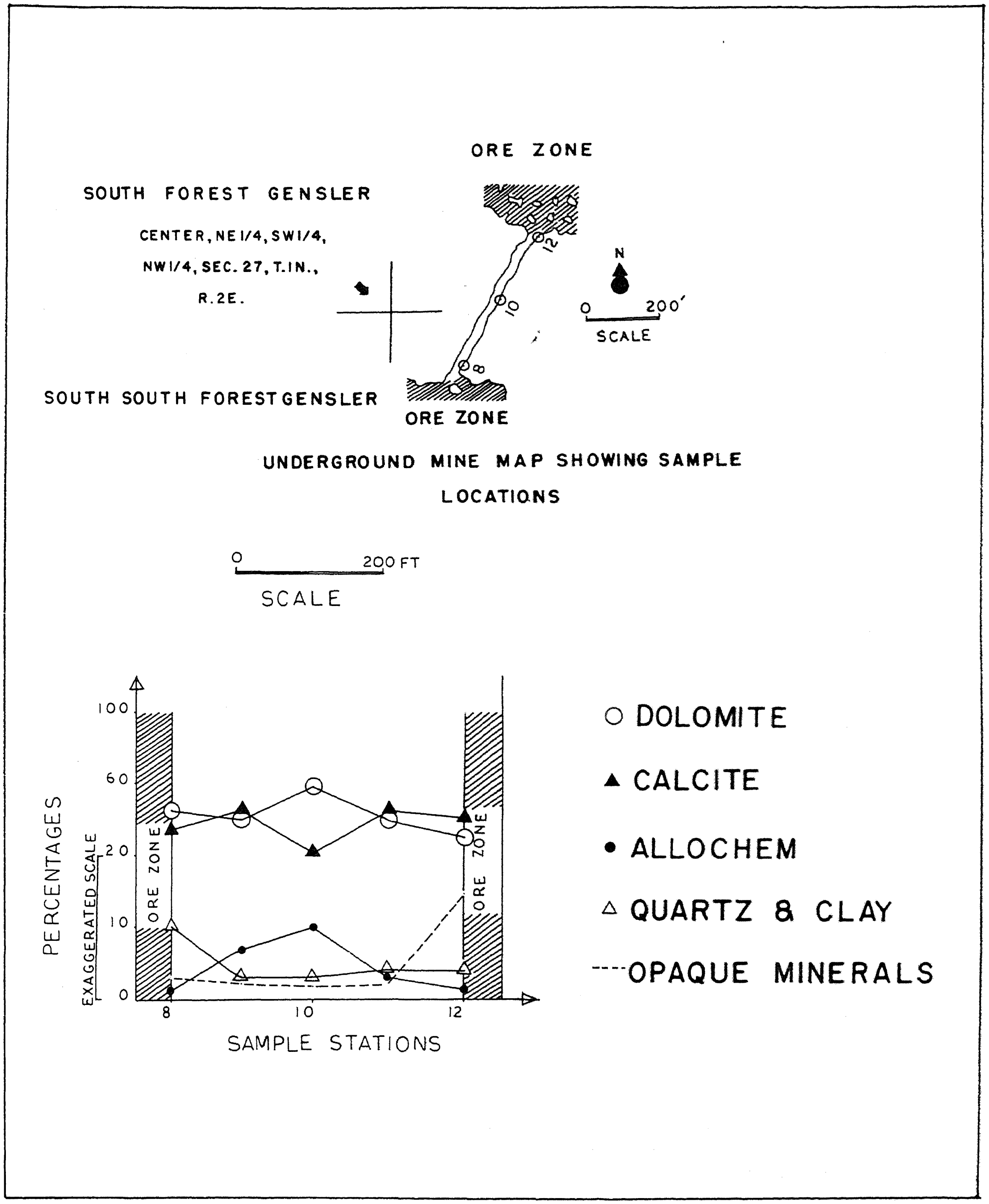


Fig. 12. Chart showing sample location, distance from ore zone, and abundance of carbonate constituents. Pull drift between South South Forest Gensler and South Forest Gensler ore deposits, Shullsburg Mine, Wisconsin. McGregor Member.

throughout the length of this pull drift. The allochems appear to show a slight but systematic increase away from the ore zones toward the central portion of the pull drift.

In contrast to the McGregor, eleven specimens collected from the overlying Quimbys Mill in the same pull drift, available from an earlier study by Hagni, show marked lateral variations in composition (Fig. 13). In the central portion of the pull drift the host rock averages 72% calcite and 18% dolomite, but near the ore bodies the rock is 93% dolomite and only 3% calcite. Specimen 23 does not fit this pattern, for reasons unknown to the writer. The intense dolomitization begins about 190 feet from the South Forest Gensler ore body and 90 feet from the South South Forest Gensler.

The rocks show lateral textural variations in addition to the composition variations. In the central portion of the pull drift calcite and dolomite are very fine grained, ranging about 3-5 μ. Toward the ore bodies, specimens 27 and 31 exhibit small amounts of coarse dolomite; while closer yet, the dominant dolomite constituent is almost entirely composed of coarse rhombic crystals averaging 165 u.

4. Pull Drift Between the South Forest Gensler and North Forest Gensler Ore Deposits

Ten specimens of McGregor host rock carbonate were collected from a pull drift, about 900 feet long, between South Forest Gensler and North Forest Gensler in the Shullsburg Mine (Fig. 14). Most of the hand specimens exhibit a medium gray color, but the two specimens closest to each of the ore zones are lighter (light olive gray to

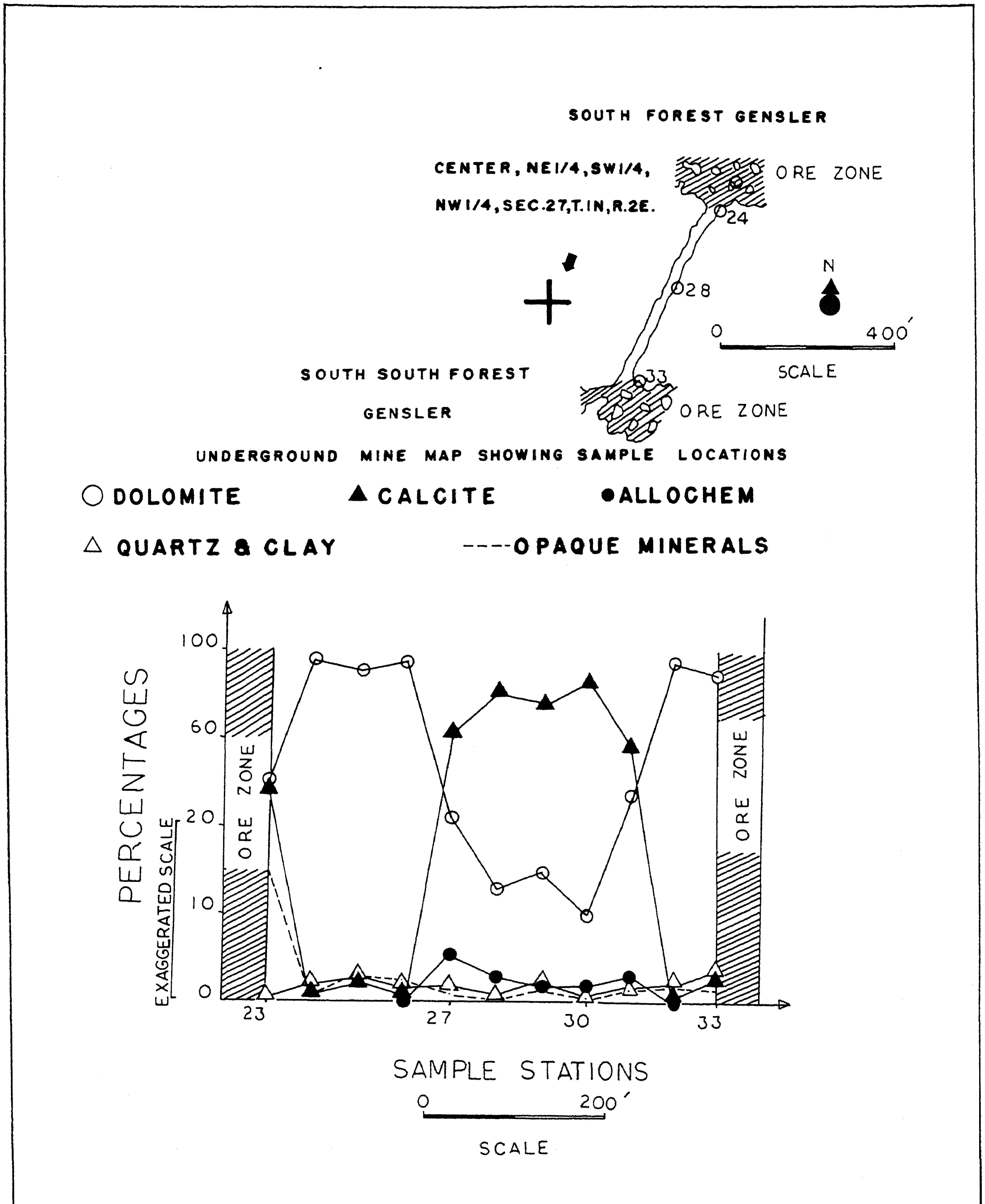


Fig. 13. Chart showing sample location, distance from ore zone, and abundance of carbonate constituents. Pull drift between South South Forest Gensler and South Forest Gensler ore deposits, Shullsburg Mine, Wisconsin. Quimbys Mill Member.

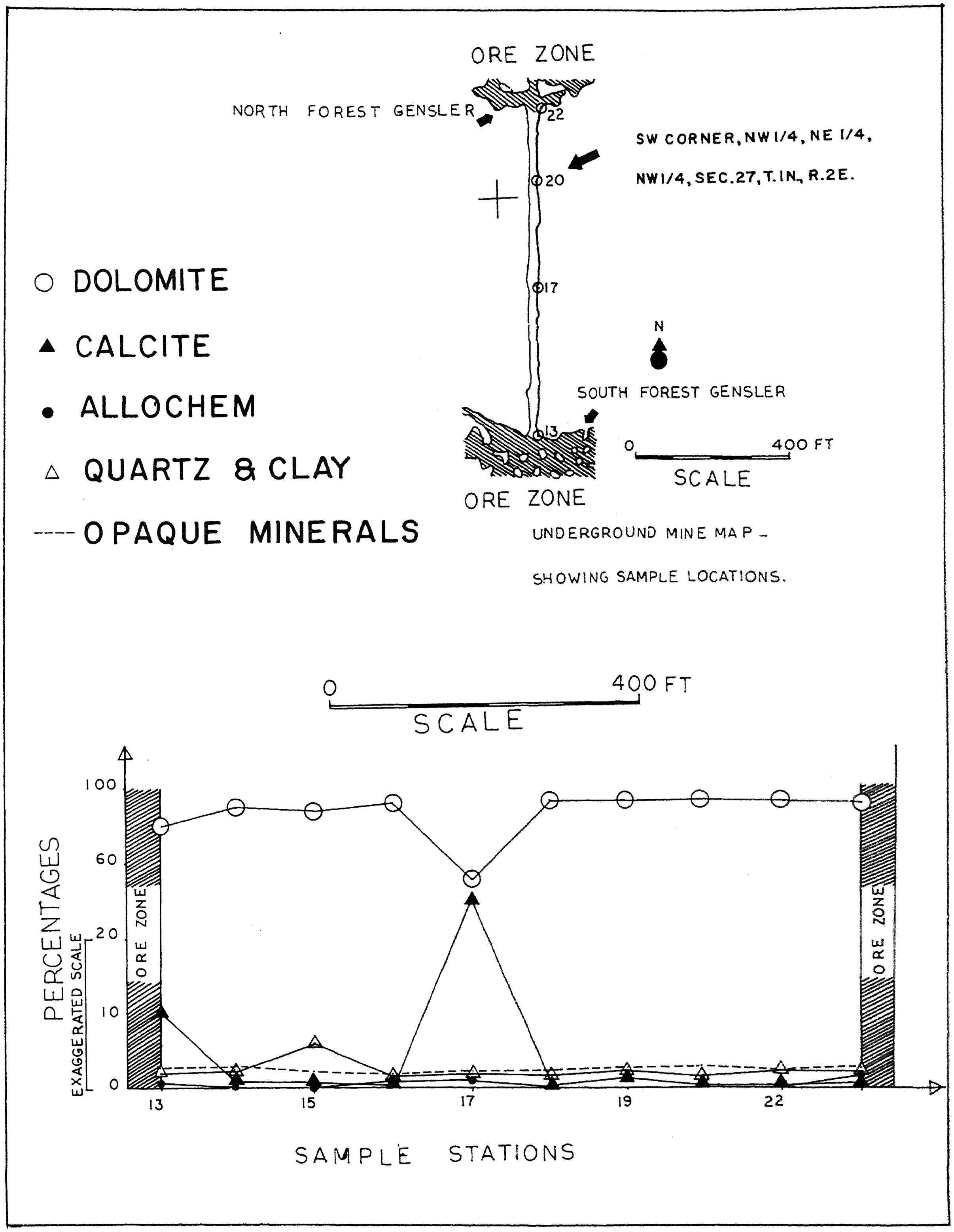


Fig. 14. Chart showing sample location, distance from ore zone, and abundance of carbonate constituents. Pull drift between South Forest Gensler and North Forest Gensler ore deposits, Shullsburg Mine, Wisconsin. McGregor Member.

yellowish gray) and specimen 17 also is light colored (yellowish gray). Thus, in contrast to the previous suites, the central specimen is lighter in color than carbonate rocks closer to the ore zones.

All of the ten thin sections prepared from the specimens exhibit a low calcite content, except one centrally located specimen (no. 17) 400 feet from the South Forest Gensler deposit and 500 feet from the North Forest Gensler deposit. That single host rock specimen contains 42% calcite while carbonate rocks closer to the ore zones average only 3% calcite. Essentially all of the dolomite in this pull drift is coarse grained. The presence of mineralization in the overlying Quimbys Mill may have contributed to the large distance at which dolomitization occurs from these ore bodies.

Twenty-two host rock specimens collected at 50 foot intervals from the Quimbys Mill member in the same pull drift were available from an earlier study by Hagni (Fig. 15). These specimens were restudied to compare the lateral variation of carbonate constituents in the Quimbys Mill with that of the McGregor. Megascopically the carbonate specimens are light olive gray, except the two specimens at each end of the pull drift, which are yellow gray. The thin sections show little or no significant lateral differences in composition. All of the specimens have dolomite contents of about 96% and an average calcite content of less than 1%. The dolomite grains have nearly the same size, averaging about 160 μ. However, in the middle portion of the pull drift, at about the same position as specimen 17 in the McGregor Member, there is a small drop in the dolomite content to 88%. Thus, the Quimbys Mill is intensely

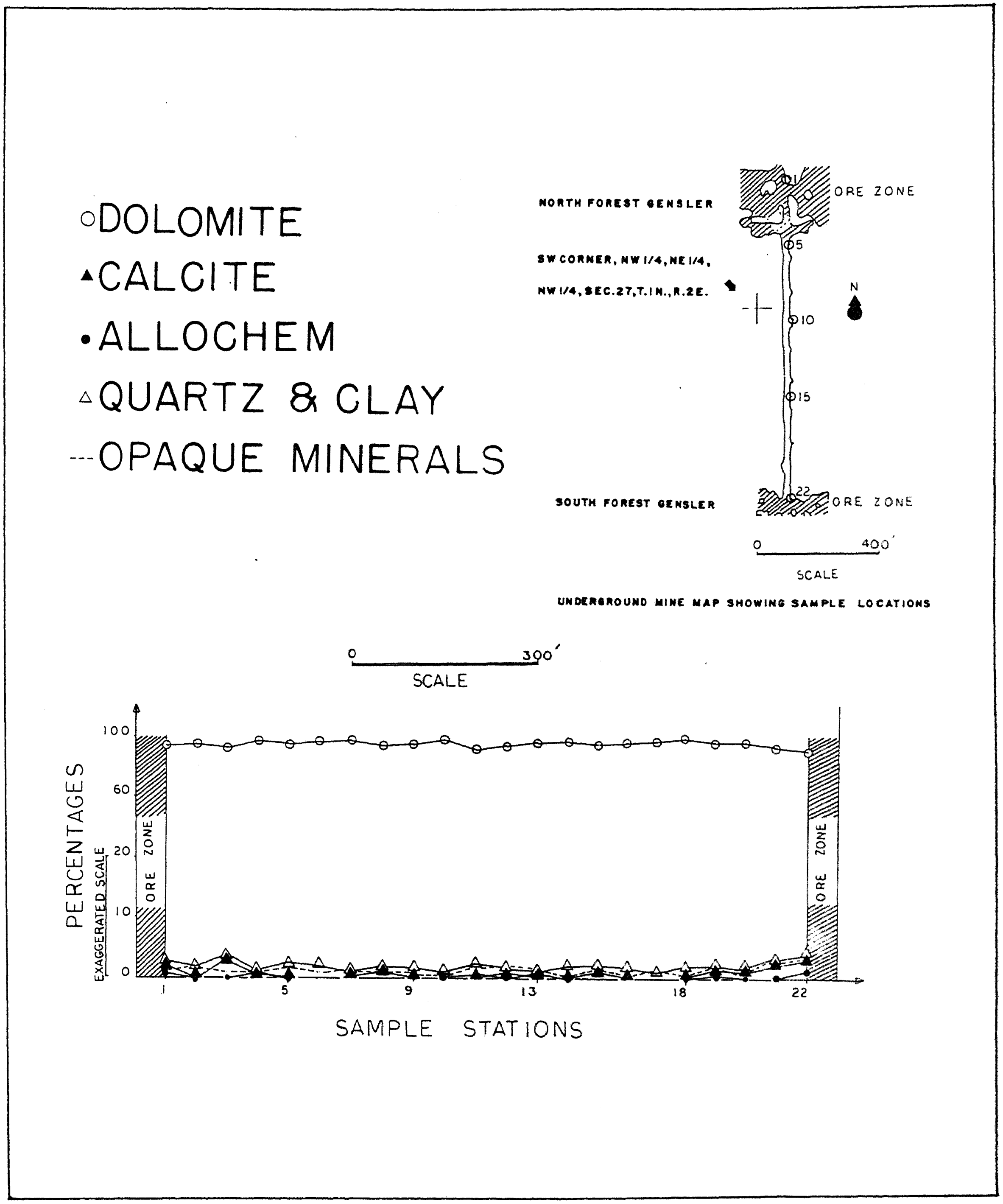


Fig. 15. Chart showing sample location, distance from ore zone, and abundance of carbonate constituents. Pull drift between South Forest Gensler and North Forest Gensler ore deposits, Shullsburg Mine, Wisconsin. Quimbys Mill Member.

dolomitized but may exhibit a very restricted area of slightly less altered carbonate host rock in the central portion of the pull drift distant from the ore bodies.

5. Pull Drift Between the South South Leona Hayden and South Leona Hayden Ore Deposits

Seven Quimbys Mill specimens were collected at seven stations in a 600 foot long pull drift (Fig. 16), between two ore runs, named here the South South Leona Hayden and the South Leona Hayden, which form one ore body to the northwest of the pull drift. All of the hand specimens are light to medium grey, except a single specimen adjacent to the South Leona Hayden ore zone, which is light yellow gray. Thin sections prepared from the specimens exhibit little or no significant lateral variations in composition. The specimens average about 93% dolomite and 4% calcite with small amounts of other constituents. All of the dolomite is coarse-grained, averaging 170 μ. Only an occasional specimen, such as numbers 58 and 60, in the central portion of the pull drift exhibit slightly higher calcite contents, up to 12%. The fact that the ore zones connected by this pull drift are joined to form a single ore body immediately to the northwest of the pull drift (see Fig. 9) suggests that the high degree of dolomitization may be due to the closeness of that single ore body.

6. Pull Drift Between the Edgarton and Wheeler and South South Forest Gensler Ore Deposits

Six host rock carbonate specimens were collected at 100 foot intervals from the McGregor in a pull drift, about 600 feet long, between Edgarton and Wheeler, and South South Forest Gensler

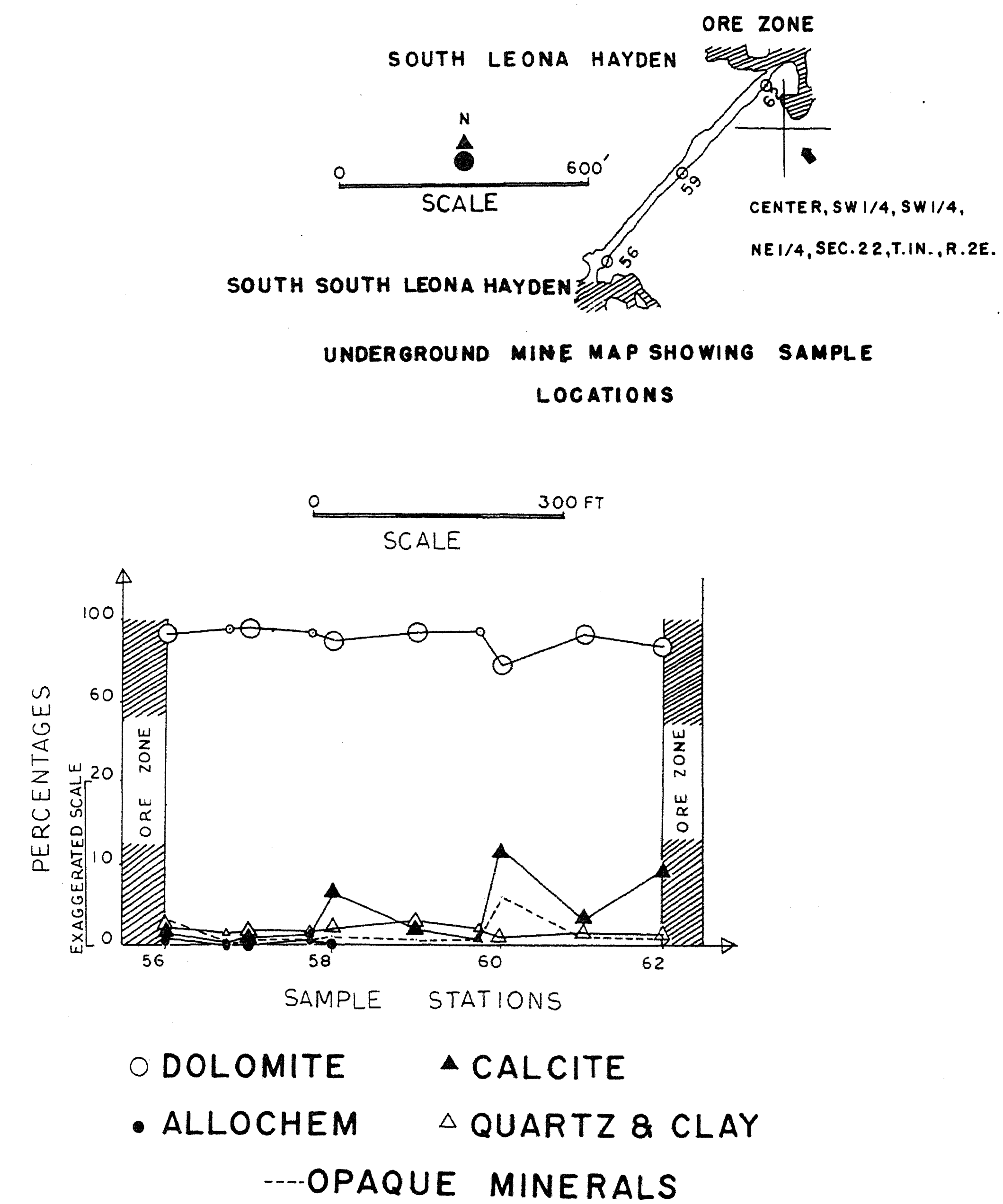


Fig. 16. Chart showing sample location, distance from ore zone, and abundance of carbonate constituents. Smaller symbols indicate duplicate samples. Pull drift between South South Leona Hayden and South Leona Hayden ore deposits, Shullsburg Mine, Wisconsin. Quimbys Mill Member.

ore deposits (Fig. 17). The hand specimens are light to medium gray in color, and exhibit no significant lateral variations.

The six thin sections prepared from the carbonate specimens exhibit no significant lateral compositional variations. The carbonate specimens average about 90% dolomite, 4% calcite and 6% other materials. The short distance between the two ore zones apparently has allowed dolomitization to progress the entire distance of the host carbonate rock exposed in this pull drift. The coarse grain size of the dolomite present, averaging about 170 μ, supports this conclusion.

Eight specimens collected at 50 foot intervals from the Quimbys Mill and in the same pull drift were available from a study by Hagni (Fig. 18). The hand specimens are light olive gray, except a single lighter specimen adjacent to South South Forest Gensler ore zone, which is a yellowish gray. Thin sections exhibit no significant lateral differences in carbonate composition. The carbonate specimens average about 93% dolomite, 2% calcite and 5% other materials. The dolomite rhombs average about 170 μ. Thus, both the McGregor and Quimbys Mill Members appear to have been strongly dolomitized the entire length of this pull drift.

7. Pull Drift Between the South Leona Hayden and North Leona Hayden Ore Deposits

Six specimens were collected from the Quimbys Mill member in a pull drift about 500 feet long between the South Leona Hayden and North Leona Hayden ore zones (Fig. 19). Megascopically the carbonate specimens are gray to light to medium gray, but the

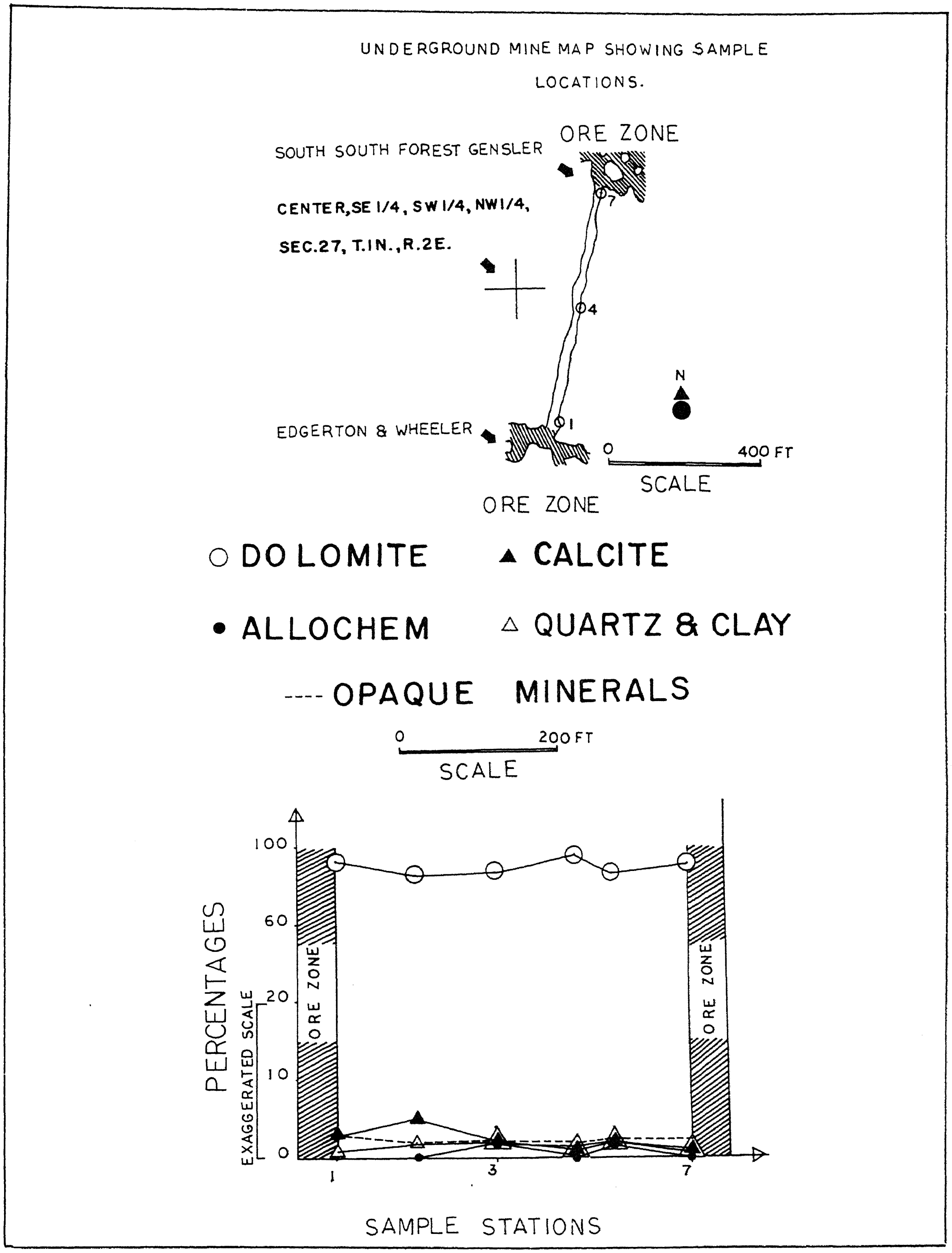


Fig. 17. Chart showing sample location, distance from ore zone, and abundance of carbonate constituents. Pull drift between Edgarton and Wheeler and South South Forest Gensler ore deposits, Shullsburg Mine, Wisconsin. McGrègor Member.

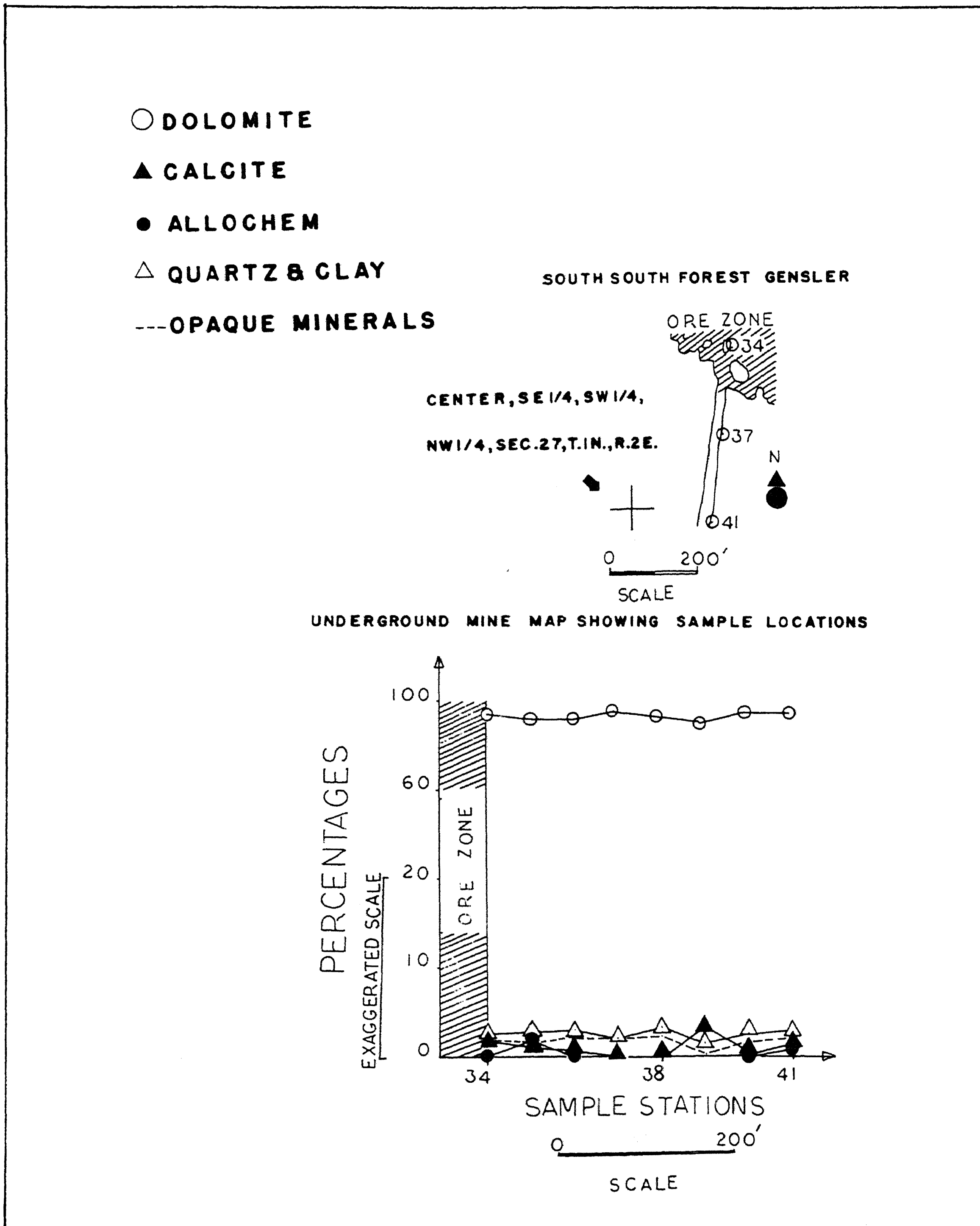


Fig. 18. Chart showing sample location, distance from ore zone, and abundance of carbonate constituents. Pull drift between Edgarton Wheeler (half way of pull drift) and South South Forest Gensler ore deposits, Shullsburg Mine, Wisconsin. Quimbys Mill Member.

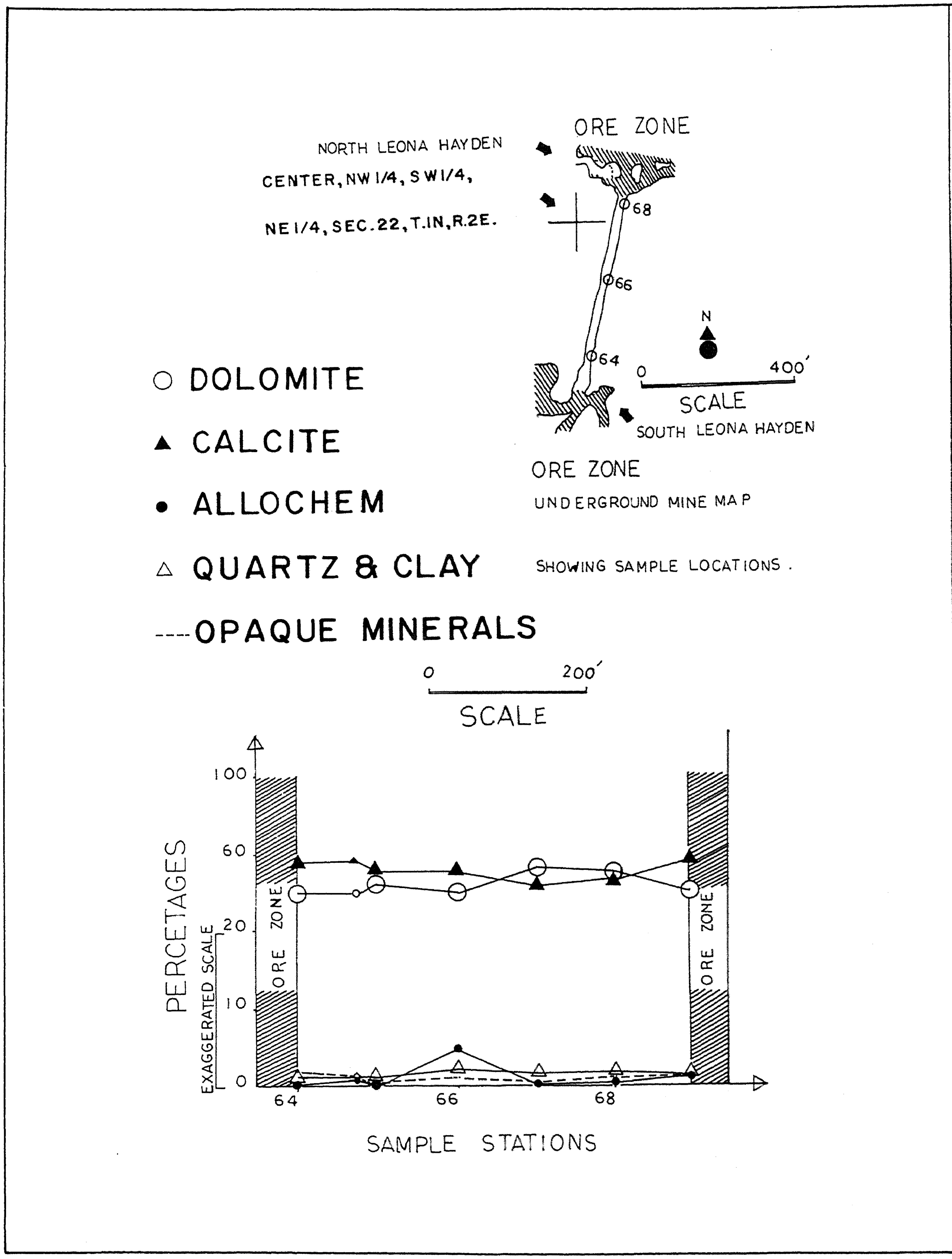


Fig. 19. Chart showing location, distance from ore zone, and abundance of carbonate constituents. Smaller symbols indicate duplicate samples. Pull drift between South Leona Hayden and North Leona Hayden ore deposits, Shullsburg Mine, Wisconsin and Quimbys Mill Member.

specimen immediately adjacent to the North Leona Hayden ore zone is yellowish gray. Thin sections prepared from the specimens showed no significant lateral variations in composition. Their average composition is about 50% dolomite, 46% calcite, and 4% other materials. The calcite and a small proportion of the dolomite are fine-grained, averaging 3-5 μ, but most of the dolomite is present as coarser rhombs about 165 μ across. This short pull drift appears to have been partly dolomitized its entire length.

B. Summary

Quimbys Mill and McGregor host rock carbonate specimens collected from seven pull drifts connecting eight ore bodies in the Shullsburg Mine, Wisconsin, were examined megascopically and microscopically for lateral variations in color, texture and composition. These variations are summarized below.

1. Color

The Quimbys Mill and McGregor host rock carbonate specimens vary in megascopic color from light gray to light olive gray. Those specimens collected immediately adjacent to many of the ore zones are lighter in color (yellowish gray) than those specimens more distant. However, many exceptions to this generalization were noted in the 10 suites studied by the writer and such megascopic color variations are much more restricted laterally than is that of microscopic compositional variations.

2. Composition

The Quimbys Mill was sampled in six pull drifts. The carbonate rock in two of the pull drifts exhibited marked lateral compositional variations. The Quimbys Mill Member contains about 50% or more calcite distally from ore bodies, but adjacent to ore bodies it becomes progressively more dolomitic until little or no calcite remains in the rock. The two suites which best illustrate the lateral variations are from the longest and the shortest of the pull drifts. In the shortest pull drift the increment in dolomite content begins at 50 to 150 feet from the ore zones; in the longest pull drift it commences at 150 to 400 feet. In one suite the rock has been partly dolomitized the length of the pull drift, and it consists of about equal portions of fine-grained calcite and coarse dolomite rhombs. In two of the suites only small amounts of remnant calcite remain in carbonate specimens in the central portions of those pull drifts. The carbonate rock in the last pull drift has been completely dolomitized along its entire length.

The McGregor member was sampled in four pull drifts. It exhibits lateral variations similar to those in the Quimbys Mill. The two longest pull drifts (900 and 3200 feet) exhibit marked lateral composition variations. Carbonate specimens distal from ore bodies are composed of approximately equal portions of calcite and dolomite, while those closer to ore become progressively more dolomitic. The increment in dolomite content begins at 100 to 200 feet in the one pull drift, and at 300 to 400 feet in the second pull drift. The carbonate rock in one of the shortest two pull drifts (400 and 600 feet) has been partly dolomitized, so that it consists of fine-grained calcite with about the same amount of coarse dolomite rhombs. Allochems (fossils) are more abundant in the central portion of that pull drift. The rock in the other short pull drift has been completely dolomitized.

The range of composition of the carbonate host rocks studied by the writer is shown in Figure 20. Figure 21 illustrates graphically the compositional differences between the least altered and altered host rocks.

Highly dolomitic host rock specimens immediately adjacent to some ore zones may contain small amounts of introduced, scattered, subhedral to euhedral quartz crystals averaging about 100 μ long.

3. Texture

Megascopic examination of the Quimbys Mill and McGregor host rock carbonate specimens is not sufficient to detect the lateral variations in grain size present. Microscopic study reveals that the least altered carbonate specimens distal from ore zones are composed primarily of very fine-grained (about 3-5 μ) calcite and dolomite. Specimens with moderate amounts of coarse-grained dolomite exhibit a porphyritic texture, and those carbonates very near the ore bodies which contain abundant coarse-grained dolomite exhibit a coalesive texture.

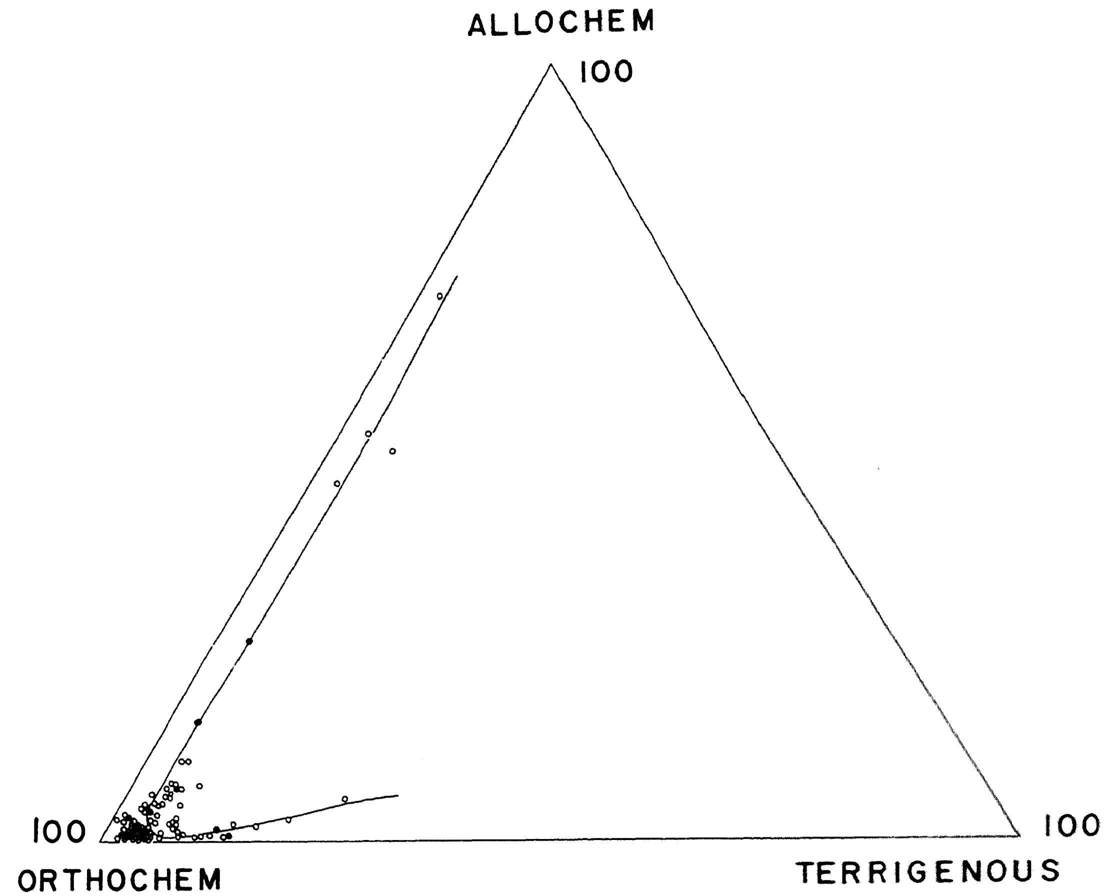


Fig. 20. Ternary diagram showing the distribution of carbonate host rock constituents. The approximate trend of the average composition is given by the line. Quimbys Mill and McGregor Members of the Platteville Formation, Shullsburg Mine, Wisconsin.

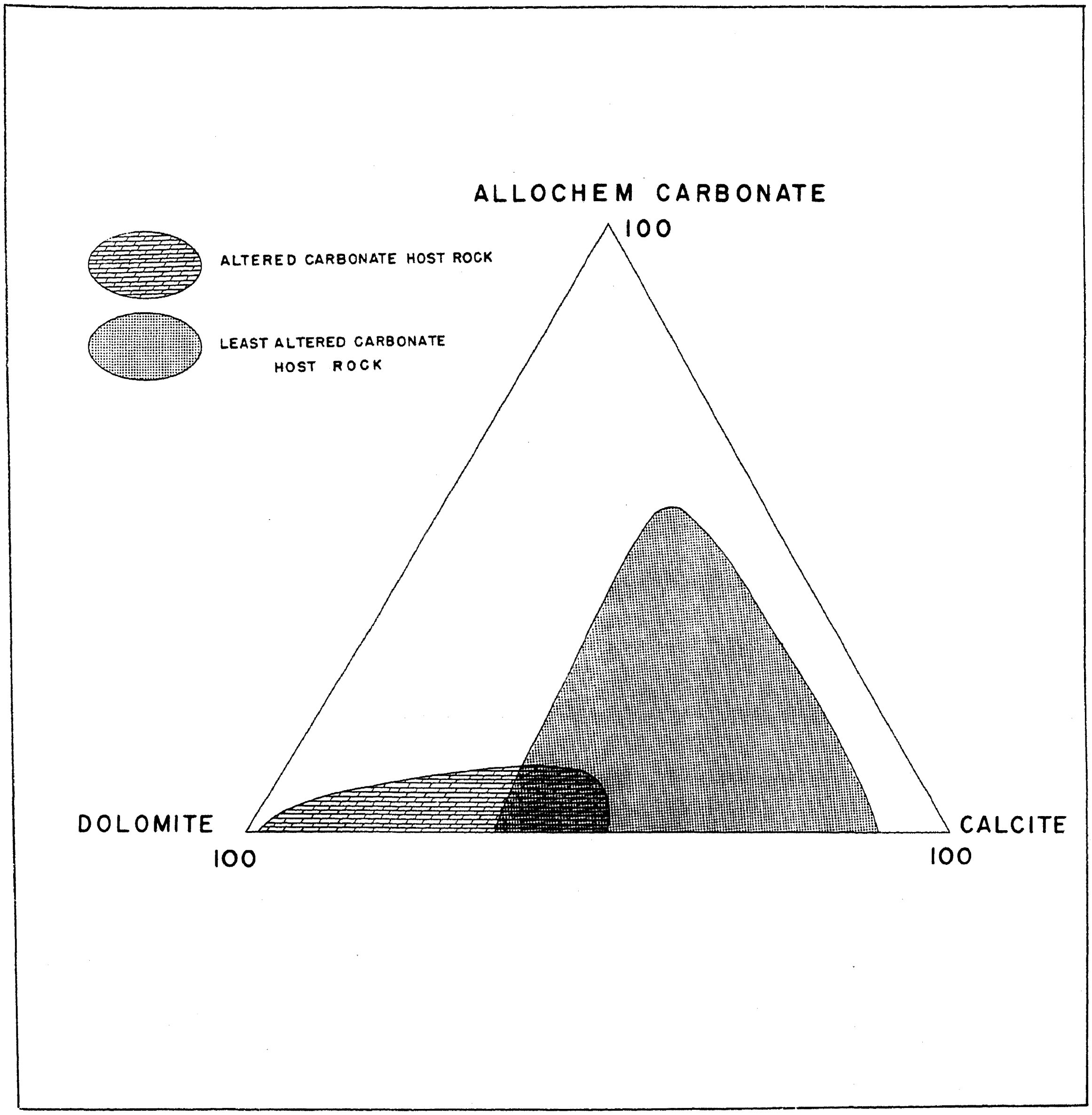


Fig. 21. Ternary diagram showing altered and least altered Quimbys Mill and McGregor carbonate host rocks. Shullsburg Mine, Wisconsin.

Chapter VI

CONCLUSIONS

The carbonate rocks of the McGregor and Quimbys Mill Members of the Middle Ordovician Platteville Formation in the Upper Mississippi Valley zinc-lead district in southwestern Wisconsin, northwestern Illinois and northeastern Iowa, are light to medium gray and fine-grained away from the ore zones. Carbonate specimens collected immediately adjacent to some ore bodies are somewhat lighter in color (yellowish gray) but they exhibit no apparent megascopic differences in texture.

Detailed petrographic study of thin sections often reveals a difference in carbonate composition and texture between carbonate specimens collected distant from ore bodies and those collected near ore. The carbonate specimens far from the ore zones generally are composed of 50% or more calcite with intimately intergrown fine-grained dolomite. Calcite is present primarily in the form of fine-grained orthochems but with generally minor quantities of allochemical calcite. Orthochemical calcite and dolomite have grain sizes which average about 3-5 microns. Brachiopods, ostracodes and bryozoans are the most abundant allochems, but crinoids, gastropods, corals, and trilobites were present in minor quantities. Clay forms a minor constituent in these carbonate specimens.

Thin sections of Quimbys Mill and McGregor carbonate specimens occurring progressively closer to ore bodies exhibit compositions and textures which contrast to those distal from ore. The calcite content gradually decreases, often to the point at which it is absent or nearly absent, while the dolomite content increases. This change in composition takes place as close as 50 feet and as far as 400 feet, but averages about 200 feet from the ore bodies. The additional dolomite content occurs as coarser grained, euhedral dolomite rhombs about 170 μ on a side. Initial increments of dolomite form a porphyritic texture in which the coarse dolomite rhombs are set in a matrix of fine-grained calcite and dolomite. Irregularly shaped remnant inclusions of fine-grained calcite and dolomite within some of the coarse dolomite rhombs attests to the replacement of the former by the latter. Closer yet to the ore zones, the rock consists entirely of coarse-grained dolomite in a coalesive texture. Carbonate specimens immediately adjacent to some ore zones contain small amounts of introduced quartz.

Since the coarse-grained dolomite is spatially associated with the ore zones and since those dolomite rhombs have formed by replacement of primary or diagenetic fine-grained calcite and dolomite, the observed changes are believed by the writer to have been brought about by the lateral extensions of the mineralizing solutions which deposited the ores.

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