1959

Geology of the northeast portion of Des Arc Quadrangle, Iron and Madison Counties, Missouri

Wesley Dean Weixelman

GEOLOGY OF THE NORTHEAST PORTION OF DES ARC QUADRANGLE

IRON AND MADISON COUNTIES, MISSOURI

BY

WESLEY DEAN WEIXELMAN

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE, GEOLOGY MAJOR

Rolla, Missouri

1959

Approved by

Paul Dean Proctor (advisor) J C Amstutz

R. A. Black C. Christiansen

TABLE OF CONTENTS

	PAGE
INTRODUCTION	1
Acknowledgements	1
Location of Area	2
Objectives	4
Previous Work	4
Field Methods	5
Geography	5
Regional Geologic Setting	7
PRECAMBRIAN IGNEOUS ROCKS	9
Rhyolites	9
Purple rhyolite porphyry	9
Tile-red rhyolite porphyry	11
Basalts and Interlayered Tuff	12
Undifferentiated basalts	13
Blue School basalts and interlayered tuff	13
Dacite-Andesite	14
Diabase Dike	16
Quartz Veins	16
UPPER CAMBRIAN SEDIMENTARY ROCKS	19
Lower Brown Dolomite	19
Light Gray Dolomite	21
The Arkosic beds	24

PAGE

Tom Sauk limestone beds 25

Channel-like structures in the Light Gray dolomite 29

Upper Brown Dolomite 30

QUATERNARY SEDIMENTS 33

Quaternary (?) Conglomerate 33

Residuum 33

Alluvium 34

STRUCTURE 35

Precambrian Structures 35

Flow structures 36

Joints 37

King fault 40

Upper Cambrian Structures 41

Buried hill structures 41

Joints 42

CORRELATION OF THE PRECAMBRIAN ROCKS WITH AEROMAGNETIC DATA . . . 47

ECONOMIC POSSIBILITIES OF THE AREA 51

Tom Sauk Limestone 51

Other Economic Possibilities 54

GEOLOGIC HISTORY AND SUMMARY 56

CONCLUSIONS 59

APPENDIX: THIN SECTION DESCRIPTIONS OF REPRESENTATIVE IGNEOUS ROCKS 63

BIBLIOGRAPHY 72

LIST OF ILLUSTRATIONS

PLATES PAGE

I. Index to map area 3

II. Idealized east-west section up Marble Creek valley 32

III. Geologic map of the northeast portion of Des Arc Quadrangle, Iron and Madison Counties, Missouri, with overlays 44

A. Structural overlay.

B. Aeromagnetic overlay.

IV. Geologic cross sections AA', BB', and CC' 45

V. Geologic cross sections DD' and EE' 46

FIGURES

1. Boxwork in the Light Gray dolomite member of the Bonneterre formation 23

2. Channel-like structures in the Light Gray dolomite member of the Bonneterre formation 23

3. Joint pattern in the Precambrian extrusive rocks 38

4. Idealized joint pattern in the Bonneterre formation 38

ABSTRACT

A geological investigation of the northeast portion of Des Arc Quadrangle in southeast Missouri was completed during the summer of 1958. Exposed Precambrian rocks include, from oldest to youngest, undifferentiated purple rhyolites with an interlayered tile-red rhyolite, andesine basalts with interlayered tuff, and an andesite. A diabase dike intrudes the lower purple rhyolites. The purple rhyolites account for about ninety-seven percent of the Precambrian exposures.

Exposed Paleozoic rocks belong to the Bonneterre formation and include three members: (1) Lower Brown dolomite; (2) Light Gray dolomite with Tom Sauk limestone and arkosic sandstone and conglomerate facies; and (3) Upper Brown dolomite. These members correlate with zones 2, 3, and 4, respectively, of McQueen and Stewart for the Bonneterre formation of the Fredericktown area. Residuum derived from the Davis, Derby-Doerun, Potosi, Eminence, Gasconade, and Roubidoux formations covers much of the area.

The Precambrian rocks show gentle dips, possibly of primary origin. Locally the tile-red rhyolite is inclined forty degrees. Primary structures include flow layering and poorly developed bedding in the rhyolites, plus contraction joints in all the Precambrian rock units. At least one fault occurs in the purple rhyolites. Initial dips off Precambrian knobs are the main structures in the Paleozoic rocks. Joints related to differential compaction occur around these knobs.

Aeromagnetic data appear to correlate well with the calculated susceptibilities for the various exposed igneous rock types of the area, using Slichter's method of calculation.

Possible economic use might be made of the Tom Sauk limestone exposed in Marble Creek valley for agricultural lime, in manufacture of portland cement, or for terrazzo. Small quartz veins in the Precambrian rhyolites show no apparent metallic values. Aeromagnetic positive anomalies in the area are not considered indicative of buried iron-ore bodies. A tuff exposed near the Blue School, however, shows a relatively high hematite content and might constitute low-grade iron ore of not more than 5,000,000 tons reserves. Lead ores in the Bonneterre formation are unlikely in the area since the favorable stratigraphic horizon of the nearby Fredericktown area (zone 1 of McQueen and Stewart) is missing.

INTRODUCTION

To date the Des Arc Quadrangle, covering approximately 242 square miles in southeast Missouri, has never been completely mapped geologically. This investigation of the northeast portion of the quadrangle is a contribution toward that goal. It also adds to the Missouri Geological Survey's over-all objective of complete geological coverage for the state. The investigation has revealed a number of misconceptions and errors in previous work. It presents new interpretations of some data gathered by earlier workers and adds geologic detail to a previously unmapped area.

The report includes introductory data on location, objectives, previous work, field methods, geography, and regional geology; details of the Precambrian and Upper Cambrian rocks, Recent sediments, and geologic structure; a brief resume' on aeromagnetic data in the area; data on economic possibilities; a geologic history and summary; and conclusions of the writer. An appendix of thin section descriptions of representative igneous rocks and a bibliography complete the report.

Acknowledgements

This study was made possible through the generous support of the Missouri Geological Survey which paid field expenses and furnished topographic map and aerial photo coverage for the project. Well logs and insoluble residue analyses were also made available.

The writer especially wishes to express his sincere thanks to Dr. P. D. Proctor, Chairman of the Department of Geology at the Missouri

School of Mines and Metallurgy, for his advice and guidance in the compilation and writing of this report and for his helpful suggestions concerning field methods. He is indebted to Dr. A. C. Spreng for his suggestions concerning the sedimentary rocks of the area and to the other members of the School of Mines Department of Geology staff who gave freely of their time in discussion of various problems.

The writer also expresses his thanks to Dr. William C. Hayes, Assistant State Geologist of the Missouri Geological Survey, for his wholehearted cooperation with the project. Besides making the Geological Survey's facilities available, Dr. Hayes spent three days in the field during which time he made many useful suggestions.

Mr. Douglas Stark, chief draftsman of the Missouri Geological Survey, gave invaluable aid in planning and drafting the plates and figures in this report.

Thanks are due Mr. R. A. Black of the Mining Department at the Missouri School of Mines and Metallurgy for his suggestions concerning interpretation of aeromagnetic data for the area.

Location of Area

The area mapped consists of forty-seven square miles in the northeast portion of Des Arc Quadrangle in southeast Missouri. The north and east boundaries coincide with the north and east boundaries of the quadrangle. The southern boundary extends due east along the section lines from the SW corner, sec. 5, T.31N., R.4E., to the eastern edge of the quadrangle. The western boundary is a straight line extending from the southern boundary to the point at which the northern edge of the quadrangle crosses the middle of R.4E. (See index map, Plate I.)

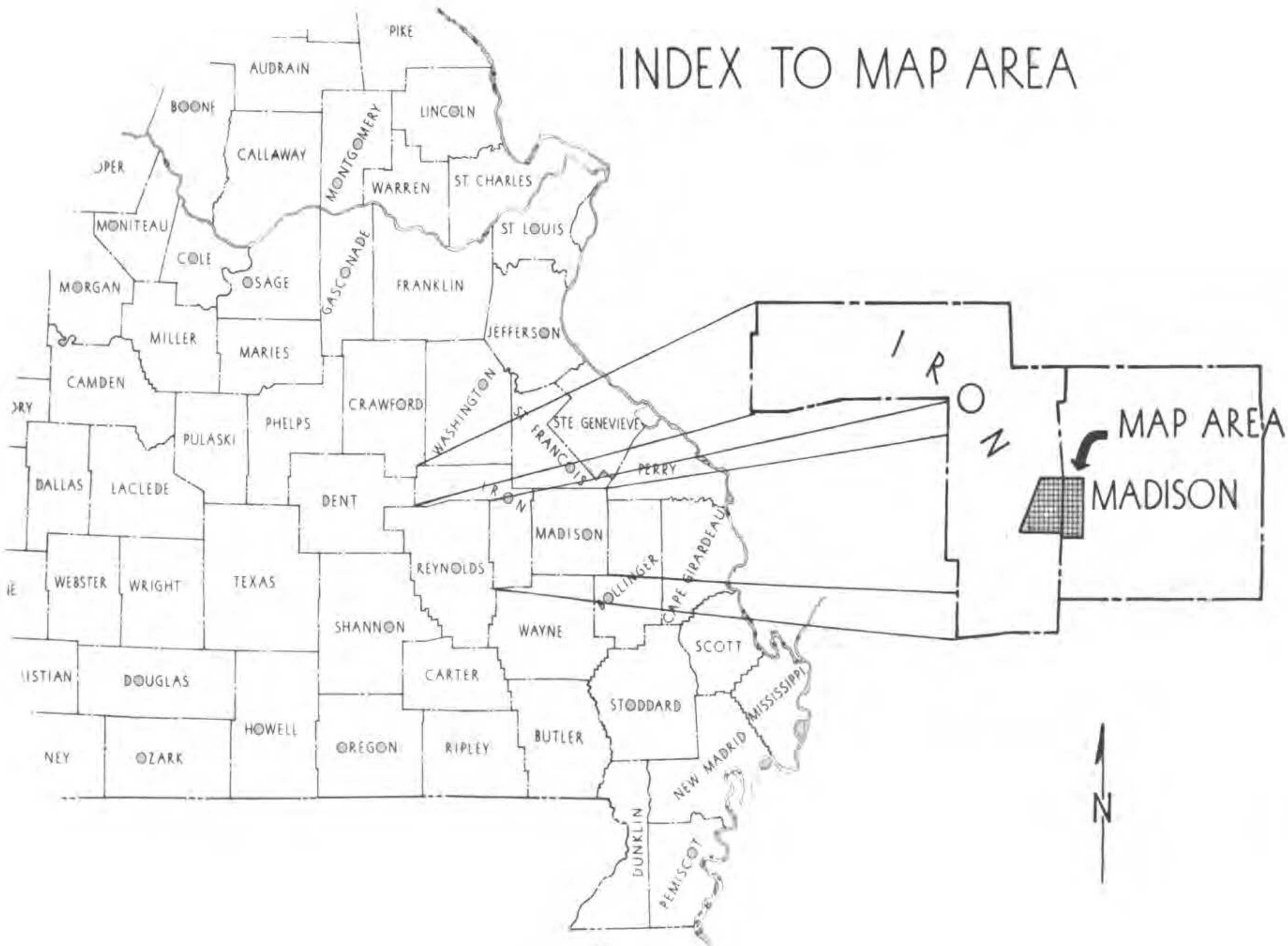

INDEX TO MAP AREA
MAP AREA
MADISON
IRON
PIKE
AUDRAIN
BOONE
CALLAWAY
MONTGOMERY
LINCOLN
WARREN
ST. CHARLES
MONITEAU
COLE
OSAGE
GASCONADE
ST LOUIS
MORGAN
FRANKLIN
JEFFERSON
MILLER
MARIES
CAMDEN
CRAWFORD
WASHINGTON
ST. FRANCOIS
STE GENEVIEVE
PULASKI
PHELPS
PERRY
DALLAS
LACLEDE
DENT
WEBSTER
WRIGHT
TEXAS
REYNOLDS
BOLLINGER
CAPE GIRARDEAU
SHANNON
WAYNE
SCOTT
DOUGLAS
CARTER
MISSISSIPPI
STODDARD
HOWELL
OREGON
RIPLEY
BUTLER
OZARK
NEW MADRID
DUNKLIN
PEMISCOT
N

Plate I

Objectives

Major objective of the investigation was to obtain geologic data on a little-known area. This included classifying, subdividing, and, if possible, correlating the Precambrian igneous rocks of the area; subdividing and correlating the Paleozoic stratigraphy; preparing geologic and structural maps; and relating structure and stratigraphy to possible mineralized zones.

Previous Work

Few geological data are available for the area. Dake (1930, pp. 62-78)[1] several times mentions the "marble" beds of the Bonneterre formation which are widespread in the northeast portion of the area of this report.

Forbes Robertson (1949) compiled a map and manuscript on the igneous rocks of the St. Francois Mountains. Most of the igneous rock exposures for the area of this study are roughly outlined on this map. Although some errors and omissions occur, his work is fairly accurate considering its comprehensive nature. The Missouri Geological Survey plans to publish his material.

An aeromagnetic survey map of the entire Des Arc Quadrangle has been published by the United States Geological Survey (1949) at a scale of one inch to one half mile. Level of flight was approximately 1,000 feet above the ground.

Herbst (1952) mapped the northwestern portion of the Des Arc Quadrangle. His map adjoins the area under discussion on the west.

---

1. All references are in bibliography.

For better geologic correlation, the areas were overlapped about nine to ten square miles.

Richard Zimmerman (1959), a graduate student at the Missouri School of Mines, mapped the adjoining area to the south.

Field Methods

The summer of 1958 was devoted to field work in the area. Headquarters were the small town of Annapolis, Missouri. Field work consisted of searching for and describing outcrops. Lithology, joint orientation, planar and linear structures of the igneous rocks, and strike and dip of the sedimentary beds were the main features described.

A United States Geological Survey fifteen minute topographic map (scale, 1:62,500) served as a base map. Department of Agriculture aerial photos (approximate scale, 1:20,800) were used to determine location and to suggest possible outcrops.

Geography

The area mapped consists of a series of knobs and ridges of igneous rocks separated by valleys cut into sedimentary rocks. Total relief exceeds 880 feet. Maximum local relief is about 670 feet cut into rhyolite in the SW$\frac{1}{4}$, sec. 2, T.32N., R.4E. North of Marble Creek, average relief is considerably greater than elsewhere in the area. Here is exposed the bulk of the igneous rocks. South and west of Marble Creek, the topography is an undulating surface of moderate-sized hills and narrow valleys. A number of stream narrows, locally called "shut-ins," have formed where streams cut across the exposed igneous rocks.

The present drainage system has many features in common with the Precambrian drainage system, but in places it has departed radically. For instance, Marble Creek now appears to flow up a former Precambrian valley, cutting through the Precambrian rocks at the head of the valley through recently formed narrows. This is probably the result of the stream being superimposed during uplift.

Three principal streams drain the area. Marble Creek is the most important and drains the northern and central portions. Crane Pond Creek drains the southwest and Leatherwood Creek the southeast. These streams flow generally southeast to east and eventually empty into the St. Francois River. Lower Rock Creek drains a small area along the northern border and flows to the northeast. Little Rock Creek drains a small portion in the northeast. These and a number of other small, nameless streams in the eastern portion also empty into the St. Francois.

The area is in a region of temperate forests and supports a dense stand of trees. The tree cover consists chiefly of oak, though pine predominates in some places. Maple, hickory, cedar, and walnut are present in smaller numbers. Thick undergrowth causes many problems in access for field work.

Some farming is done along the stream valleys. The narrowness of these valleys, together with heavy, leaching rains and cherty soils, relegates the industry to a minor economic position.

The region is sparsely populated and has few improved roads. Highway E, which parallels Marble Creek, is black-topped in Iron County but has a gravel surface in Madison County. It is the only hard surface road in the area. Note that it has been rerouted from its position on the map in Madison County (see Plate III). Two other roads, one connecting Highway E with Minimum to the south, and the other connecting Highway E with Chloride to the west, have gravel surfaces. These are passable most of the time. None of the roads, including Highway E, are passable during very heavy rainstorms. Many roads shown on the United States Geological Survey topographic map have been abandoned. Numerous logging trails are present throughout the area.

No towns exist within the mapped area. Arcadia and Ironton, with a combined population of 1,562 (1950 census), are about seven miles north. Annapolis, population 490 (1950), lies an equal distance to the southwest.

The Rural Electrification Administration has brought electricity to most of the area's farms.

Regional Geologic Setting

The mapped area is in the Ozark Plateau province on the southwest flank of the St. Francois Mountains. Precambrian granites, felsite flows, and diabase dikes make up the basement rocks. The granites intrude the felsites, and the dikes intrude both the felsites and the granites. Precambrian erosion formed a series of knobs and ridges separated by deep valleys. Early Paleozoic seas inundated the area, and sedimentary rocks formed in this environment. Present physiography represents exhumed Precambrian hills and eroded Paleozoic sediments.

Paleozoic stratigraphy includes the Upper Cambrian Lamotte, Bonneterre, Davis, Derby-Doerun, Potosi, and Eminence formations and the Ordovician Gasconade, Roubidoux, and Jefferson City formations. With the exception of the Lamotte sandstone, these formations are predominantly dolomite. Locally sandstone is dominant in the Roubidoux and shale in the Davis. Maximum thickness of the formations is unknown because of variability in thickness from place to place. However, if the tops of the Precambrian knobs were covered by the end of Roubidoux deposition (Dake, 1930, p. 196), the total thickness must have been over 2,000 feet. Lack of later Paleozoic sediments in the St. Francois Mountains area makes it uncertain whether they were ever deposited there.

Known Precambrian structures in the region consist of gently dipping felsite flows and tuffs intruded by stock-like to batholith-like granite masses.

Structural features of the Paleozoic sedimentary rocks include initial dip on the Precambrian knobs and ridges; the northwest trending Farmington anticline; several large, northwest trending faults; and minor northeast trending faults.

PRECAMBRIAN IGNEOUS ROCKS

The Precambrian rocks in the mapped area are igneous. Likewise, the igneous rocks are all Precambrian. Three general groups are recognized according to lithology: rhyolites, basalts, and dacite-andesites. In addition, a tuffaceous rock is interlayered with the basalts in the vicinity of Blue School. The rhyolites are separated into tile-red and purple varieties.

Together these rocks are exposed over some forty percent of the mapped area's surface. They cover nearly the whole northern portion of the area and form scattered knobs and ridges through the remainder of the area. As a group the igneous rocks produce more and larger outcrops than the sedimentary rocks.

Rhyolites

The rhyolites form numerous large outcrops. On the basis of color and the number of phenocrysts present, they are divided into two separate types. These include purple rhyolite porphyry and tile-red rhyolite porphyry. The purple rhyolites are distinguished on the map (Plate III) by three different colors. These three divisions are made on the bases that one purple rhyolite underlies the tile-red rhyolite, another overlies the tile-red, and the third is undifferentiated. The latter includes the bulk of the Precambrian rocks exposed in the area.

Purple rhyolite porphyry. Undifferentiated purple rhyolite porphyry is exposed across the large upland area north of Marble Creek and along the eastern border of the area. It also forms a number of scattered knobs in the south central and northwestern portions of the area. Special mention is made of two small areas that might be overlooked on the map. One occurs as a small mound in a field north of Highway E in the center of the N$\frac{1}{2}$, NW$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 24, T.32N., R.4E.; the other is a small exposure north of a road in the SW corner, sec. 4 and the SE corner, sec. 5, T.31N., R.4E. The lower purple rhyolite is the oldest rock exposed in the area.

Purple porphyry underlies the tile-red variety in two places: on Crane Pond Creek in the S$\frac{1}{2}$, sec. 33, T.32N., R.4E., and on a stream in the NW$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 35, T.32N., R.4E. Purple porphyry overlies the tile-red rhyolite in the NE$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 28, the SW$\frac{1}{4}$, sec. 34, the center of the W$\frac{1}{2}$, W$\frac{1}{2}$, sec. 35, and the SE corner, sec. 36, T.32N., R.4E., and in the NW$\frac{1}{4}$, sec. 3, and the NE$\frac{1}{4}$, sec. 1, T.31N., R.4E.

The various purple rhyolite porphyries exposed in the area are all very similar in appearance, in some cases almost indistinguishable one from another. They vary from pinkish to reddish purple to very dark purple. They contain from ten to forty percent phenocrysts of plagioclase and potash feldspars and quartz. Magnetite phenocrysts are also commonly visible in the hand specimen. Flow bands are common but not universal.

Microscopic inspection reveals that the largest (about 3 mm. by 1.5 mm.) and most numerous phenocrysts are usually plagioclase (Ab_{60-66}). Potash feldspar (perthites and orthoclase) and quartz phenocrysts are about equally abundant. Together they constitute from five to thirty percent of the rock. The quartz phenocrysts average somewhat smaller than the potash feldspars (about 0.8 mm.) Magnetite phenocrysts (1.8 mm. to less than 0.1 mm.) form from two to eight percent of the rock and average about four percent. Accessory piedmontite is occasionally present. Minor secondary calcite sometimes partially replaces the feldspars.

No definitive features were found by which the various purple porphyries might be distinguished from each other. This is true even of those that underly and overly the tile-red rhyolite porphyry. The subdivision is made merely on the basis of their spatial relationships to the tile-red rhyolite.

Tile-red rhyolite porphyry. Tile-red[2] rhyolite porphyry is exposed in the shut-ins on Crane Pond Creek in the NW$\frac{1}{4}$, sec. 3 and Leatherwood Creek in the NE corner, sec. 1, T.31N., R.4E., and on the hills in the SW$\frac{1}{4}$, sec. 33, the SW$\frac{1}{4}$, sec. 35, and the NE$\frac{1}{4}$, sec. 28, and the NW$\frac{1}{4}$, sec. 27, T.32N., R.4E. Purple rhyolite lies both above and below the tile-red variety. This relationship can best be seen in the SW$\frac{1}{4}$, sec. 35, T.32N., R.4E.

The tile-red rhyolite porphyry is tile-red in color. Phenocrysts of perthites, plagioclase (Ab_{64-70}), magnetite, and occasionally quartz average from three to five percent of the rock.

Perthites form the largest phenocrysts, about 2 mm. by 1 mm., average about 1 mm. by 0.5 mm. They consist of about forty percent albite and sixty percent potash feldspar.

Plagioclase phenocrysts are about the same size as the perthites but much less numerous. They seldom constitute over one percent of the rock.

Accessory (less than one percent of the rock) magnetite phenocrysts average about 1 mm. across. Rare quartz phenocrysts are about

2. This color approximates the dark reddish brown (10R3/4) of the National Reasearch Council Rock Color Chart (1948).

the same size, but thin sections sometimes reveal up to ten percent quartz phenocrysts about 0.1 mm. across.

The matrix is preponderantly potash feldspar. Plagioclase and quartz together make up some thirty percent. Because of the extremely small grain sizes involved, it is impossible to distinguish between the plagioclase and the quartz of the matrix by optical means. The potash feldspar can readily be determined by staining techniques. Spherulite structures are abundant and indicate that much of the rock was originally glass.

Orbicular structures occur in this rhyolite in the Leatherwood Creek shut-in in the NE corner, sec. 1, T.31N., R.4E. Many of the structures are as much as four inches in diameter. In this same locality, the rock contains numerous inclusions of purple porphyry.

Color and scarcity of phenocrysts are the bases for mapping the tile-red rhyolite separately. It is possible that all the tile-red rhyolite is not the same flow. It may even be a phase or phases of one or more purple rhyolite flows.

Basalts and Interlayered Tuff

The basalts cover much less area and produce much poorer and more discontinuous outcrops than do the rhyolites. They are restricted to five areas in the Marble Creek drainage system. These include the base of a large hill in the center of sec. 9; the Blue School area in sec. 14 and 15; the knob just north of Highway E in the NE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 24; the base of a knob in the SW$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 24, T.32N., R.4E.; and the knob in the NW$\frac{1}{4}$, sec. 19, T.32N., R.5E. With the exception of the exposures in the vicinity of Blue School, the basalts are not subdivided.

Undifferentiated basalts. The undifferentiated basalts are rather typical. They consist of plagioclase feldspar laths in an augite groundmass. Magnetite constitutes up to ten percent of the rock. The plagioclase and augite are present in approximately equal amounts. Four-tenths millimeter hornblende grains are present in amounts up to two percent. Basalt exposed on the knob south of Highway E in the NW$\frac{1}{4}$, sec. 19, T.32N., R.5E., contains epidote that appears to have replaced feldspar. Much of the feldspar has a coating of very fine grained material (white in reflected light), probably a clay.

Blue School basalts and interlayered tuff. In the vicinity of Blue School are two basalt flows separated by a layer of tuff. All rest on a purple rhyolite porphyry. Outcrops are poor, and these relationships were determined on the basis of float materials.

The lower basalt crops out just across Highway E from Blue School in the SW$\frac{1}{4}$, NE$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 15, T.32N., R.4E. It contains 3 mm. quartz-filled amygdules and tiny 1 mm., horizontal quartz veinlets. Thin section study shows that about sixty percent of the rock consists of lath-like plagioclase grains generally parallel to one another. Interstitial augite constitutes some twenty-five percent of the rock, magnetite another fifteen percent. Accessory hornblende is present.

The tuff lies above the lower basalt and crops out on the side of the hill above Blue School in the SW$\frac{1}{4}$, NW$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 14, T.32N., R.4E., where it is approximately thirty feet thick. It is very dense and dark purplish with a slightly speckled appearance due to patches of white calcite that react vigorously with hydrochloric acid. Thin section study shows that hematite constitutes some thirty-seven percent of the rock, calcite about thirty-five percent, quartz five percent, and magnetite three percent. The rest of the rock consists of a very fine matrix that appears to be made up of plagioclase laths less than 0.01 mm. in length. The calcite occurs in rounded grains about 1 to 2 mm. across separated from one another by matrix or interstitial hematite. The quartz is generally associated with the matrix and occurs in grains about 0.05 mm. across. In thin section, the rock shows very definite layering, with alternating bands in which hematite, calcite, and matrix predominate, respectively.

Small scattered outcrops of basalt occur on the same hill above the tuff bed. The hand specimen is dull blue-gray and amygdaloidal. Thin section shows the rock consists of some fifty percent plagioclase laths about 0.1 mm. long, four percent plagioclase phenocrysts (Ab_{60})[3] with an average length of about 1.0 mm. by 0.2 mm., fifteen percent magnetite, twenty-four percent interstitial augite, and seven percent amygdules containing plagioclase largely replaced by augite and calcite. The magnetite is mostly in the matrix, but some is found in phenocrysts up to 0.4 mm. across. Magnetite occasionally replaces the edges of the plagioclase phenocrysts.

<u>Dacite-Andesite</u>

Dacite and andesite appear to be the youngest of the Precambrian rocks. A distinction between the dacite and the andesite may not be valid since the quartz in the dacite occurs in amygdules and tiny connecting veinlets and might be considered distinct from the rock itself.

Taken as a unit, the dacite-andesite is found in three places: on the crest of the hill just east of Blue School in the NW$\frac{1}{4}$, NE$\frac{1}{4}$, SW$\frac{1}{4}$,

---

3. Plagioclase composition suggests the name andesine basalt. The rock was noted as a basalt on the basis of its color index.

sec. 14, T.32N., R.4E., and on the knob in the center of the E$\frac{1}{2}$, sec. 30, and the nose in the center of the E$\frac{1}{2}$, W$\frac{1}{2}$, sec. 29, T.32N., R.5E. It crops out in only two places: at the crest of the hill east of Blue School and on the south side of the nose in the center, E$\frac{1}{2}$, NE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 29, T.32N., R.5E. The knob in sec. 30, T.32N., R.5E., is covered with float but has no outcrops.

The rock is dark purple to wine colored and contains from five to thirty percent pink and gray plagioclase phenocrysts (Ab_{63-69}) averaging about 3.5 mm. in length. A few magnetite grains are present. Tiny quartz veinlets from 1 mm. to 0.1 mm. thick connect numerous quartz-filled amygdules which comprize from thirty percent of the rock on the hill above Blue School, through five percent at the outcrop in the center, E$\frac{1}{2}$, NE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 29, T.32N., R.5E., to zero percent in most of the float material. The amygdules are sometimes as much as 30 mm. across but average about 4 mm. Chlorite is commonly associated with the quartz in the amygdules. Calcite, too, is sometimes found with the quartz but never with the chlorite. Potash feldspar is present in the matrix and constitutes around eighteen percent of the rock. It forms no phenocrysts. Most of the matrix is composed of plagioclase laths. Chalcopyrite, chalcocite, and galena were found filling an amygdule in andesite from the top of the igneous nose in the center, E$\frac{1}{2}$, W$\frac{1}{2}$, sec. 29, T.32N., R.5E. In polished section, galena appeared to be present in numerous very small blebs (about 0.01 mm. across) as well as in the amygdule with the copper sulfides.

It is possible that the dacite-andesite rock is a late differentiation product of the same magma that produced the basalts.

Diabase Dike

A single diabase dike occurs in the stream bed in the center, NW$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 35, T.32N., R.4E. It occurs in the purple rhyolite beneath the tile-red variety and can be followed for some 100 feet along the stream bed. A maximum width of about four feet was observed.

The diabase is dark greenish-gray with minute plagioclase laths seldom over one millimeter long immersed in a greenish-black pyroxene groundmass. No thin section was made of this rock. The chief difference between it and the basalts appears to be that its ophitic texture can readily be seen with the unaided eye while that of the basalts is visible only under a microscope.

The dike is probably the same age as the basalts. If so, it very likely penetrated the overlying rhyolites which have since been eroded away. The stream found the dike less resistant than the heavy chert residuum and cut down through the dike rather than along the rhyolite-residuum contact.

Quartz Veins

Quartz veins of from less than one sixteenth inch to nearly four feet thick are found locally in the rhyolites and lower basalt. Individual veins have been traced for as much as a hundred feet before disappearing beneath cover. Where present, they generally occur in a parallel vein pattern but are often connected to each other by thin stringers. Sometimes, as in the stream in the E$\frac{1}{2}$, SW$\frac{1}{4}$, sec. 7, T.32N., R.5E., they form a branching vein pattern. The locations of these various vein systems and their general dip and strike is given on the aeromagnetic overlay (Aeromagnetic Overlay to Plate III). The largest of these veins, about four feet thick, is found in the upper end of Lower Rock Creek in the SW corner, NW$\frac{1}{4}$, NW$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 6, T.32N., R.5E. It strikes generally N.47E., and dips between 85 and 90 degrees S.43E. Its length cannot be ascertained due to cover. A zone of quartz breccia parallels the vein on its northwest side. A prospect pit about ten feet square has been dug into the vein and breccia, possibly in an attempt to explore the reddish brown staining associated with the hematite cement of the breccia.

Another vein about three feet wide and with a N.40E. trend occurs in a stream cut into the rhyolite in the SE corner, NW$\frac{1}{4}$, sec. 7, T.32N., R.4E. This vein zone varies from siliceous rhyolite to nearly pure quartz and can be traced for nearly 150 feet up the stream. Many lesser veins of similar trend are also present here.

Yellow quartz veinlets less than one sixteenth inch thick occur in the lower of the Blue School basalts at the outcrop just across Highway E from Blue School in the SW$\frac{1}{4}$, NE$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 15, T.32N., R.4E. These veinlets are horizontal. Since the veins in the rhyolites consist of white quartz and are generally vertical or steeply dipping, they may be unrelated to the veinlets in the basalt.

The veins are all post-rhyolite, and at least some are post-early basalt. They may all be later. The general north-east trend of these veins, if extended, would pass through the Silver Mine area which lies five miles N.35E. from the northeast corner of the area under discussion.

This raises the possibility that they are genetically related to the Silver Mine veins. However, the Silver Mine veins trend east-west and dip steeply to the south, though prominent joint sets strike northeast (Stevens, 1958, p. 6). Further, emplacement of the Silver Mine veins was accompanied by greisen-type alteration of the wall rock (*ibid.*, p. 17-23). No such alteration accompanies the veins described in this report.

UPPER CAMBRIAN SEDIMENTARY ROCKS

Paleozoic sedimentary bedrock exposed in the area belongs to the Upper Cambrian Bonneterre formation. Three distinct members are recognized. These include a Lower Brown dolomite, a Light Gray dolomite, and an Upper Brown dolomite. The Light Gray member is further subdivided into a number of facies. (See the geologic map, Plate III.) According to James (1951, p. 24), the earlier Lamotte formation was not deposited in this area. Post-Bonneterre formations have apparently been removed.

Lower Brown Dolomite

The Lower Brown dolomite is named for its brown color and for its position at the base of the sedimentary rocks in the area. The unit is confined almost entirely to Marble Creek valley and its tributaries in the northwest portion of the area. The single exception is in the NW$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 3, T.31N., R.4E., west of the bridge crossing Crane Pond Creek. It often forms low bluffs along the streams. The best exposure is a fifty foot bluff on the west bank of Marble Creek in the NE$\frac{1}{4}$, SE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 10, T.32N., R.4E. At this exposure, the overlying Light Gray dolomite is in direct contact with it. Other good exposures occur on the northeast bank of Marble Creek in the NE$\frac{1}{4}$, SE$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 15, T.32N., R.4E.; about 1,400 feet upstream on the southwest bank of the creek; and about 4,000 feet of nearly continuous outcrop in the bed and along the banks of the small tributary to Marble Creek in the southern parts of sections 9 and 10, T.32N., R.4E. The contact with the overlying Light Gray unit is again exposed along the west edge of Highway E in the NE$\frac{1}{4}$, NE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 3, T.32N., R.4E.

The Lower Brown dolomite unconformably overlies the Precambrian rocks. The exact contact between the two is not visible in the area, but near-contacts occur on the west bank of Marble Creek in the SE$\frac{1}{4}$, SE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 10, T.32N., R.4E., and on the northeast bank of Marble Creek near Blue School in the NE$\frac{1}{4}$, SE$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 15, T.32N., R.4E. In both cases the Precambrian rock is rhyolite.

Maximum thickness measured is about fifty feet at the bluff on the west bank of Marble Creek in the NE$\frac{1}{4}$, SE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 15, T.32N., R.4E.

Lithologically, the Lower Brown unit is a uniformly brown, fine-grained, dense, slightly vuggy dolomite. Beds vary in thickness from less than an inch to about four feet. Beds from one to two feet thick predominate. Abundant cross-bedding indicates a clastic origin, as do numerous included pebbles and sand grains apparently derived from the felsites. Dolomite grain sizes range from microscopic to about 0.4 mm. Average size is about 0.1 mm. Small pockets of crystalline calcite are common. At one outcrop, about 400 feet west of the bridge on Crane Pond Creek near the center of the N$\frac{1}{2}$, N$\frac{1}{2}$, sec. 3, T.31N., R.4E., quartz druse is exposed.

This unit weathers sharp and blocky. The weathered surface is usually faintly striated, sometimes showing cross-bedding. Closely spaced vertical joints characterize the member. Erosion along the well developed joints often forms small rounded pinnacles in the beds. The joints are sometimes enlarged by solution, and small springs issue from many of them.

Since no fossils were found in this unit, it is correlated on the basis of its lithologic character and its stratigraphic position. On this basis, it seems to correlate best with Stewart's (1944, p. 2) and McQueen's (1943, p. 9) zone 2 of the Bonneterre formation.

Light Gray Dolomite

The Light Gray dolomite conformably overlies the Lower Brown dolomite. The member is named for its distinctive and persistent light gray to nearly white color throughout the area. In addition to its normal occurrence, the unit contains two other prominent facies: (1) the Tom Sauk limestone beds, and (2) the Arkosic Beds. Plate II shows the general relationships between the various facies of this member.

In its normal occurrence, the Light Gray dolomite is more widespread in the area than all the other sedimentary rocks. It outcrops in all the major stream valleys and in most of the minor ones. Good outcrops occur along Marble and Crane Pond Creeks. The best exposures crop out on the east bank of Marble Creek in the NW corner, SW$\frac{1}{4}$, SW$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 14, T.32N., R.4E., and again about 400 feet downstream; on the north bank of Marble Creek in the NE$\frac{1}{4}$, SE$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 10, T.32N., R.4E.; and on the west bank of Marble Creek in the SW$\frac{1}{4}$, SE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 34, T.33N., R.4E.

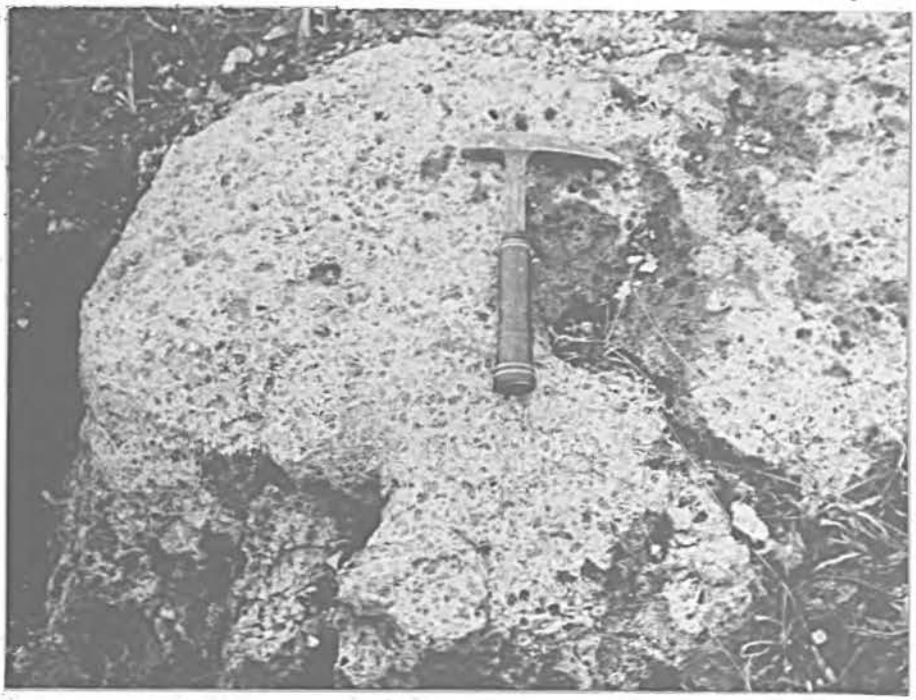
Although the Light Gray dolomite member conformably overlies the Lower Brown dolomite, it overlaps in places and rests directly on Precambrian rocks. In such areas of outcrop, the facies generally changes from dolomite through sandy dolomite to arkosic sandstone and conglomerate. Elsewhere, the Light Gray dolomite directly overlies the porphyry. Examples occur in the small tributary to Leatherwood Creek in the NW corner of sec. 6, T.31N., R.5E.; on the southwest bank of Leatherwood Creek in the SE$\frac{1}{4}$, SW$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 36, T.32N., R.4E.; in the small stream in the NW corner, sec. 17, T.32N., R.5E.; and in Crane Pond Creek, NE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 33, T.32N., R.4E. In lower Marble Creek valley, the dolomite is interbedded with Tom Sauk limestone.

The contact between the Light Gray dolomite and the overlying Upper Brown dolomite is exposed on the north bank of Marble Creek in the NE$\frac{1}{4}$, SE$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 10, T.32N., R.4E., and also on the southwest bank of Patterson Creek near its confluence with Marble Creek in the NE$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 3, T.32N., R.4E. Patterson Creek has changed its channel from that shown on the map and now parallels Marble Creek for some 1,200 feet in this vicinity.

Coarsely crystalline, calcareous, very vuggy, light gray dolomite with numerous patches of green shale characterize the Light Gray unit. It often shows a boxwork or honeycomb pattern both on the fresh and on the weathered surface (see Figure 1). One-half inch to one inch pockets of white, crystalline calcite are common. Occasionally these pockets are much larger and range to seventeen inches long and five inches wide. The many vugs in the dolomite are usually lined with brown to orange-stained calcite. The brown stain is due to limonite and argillaceous material. Felsite and quartz pebbles and sand grains are present locally near Precambrian rock exposures. Insoluble residue analysis of the Light Gray dolomite shows small amounts of shaley residues.

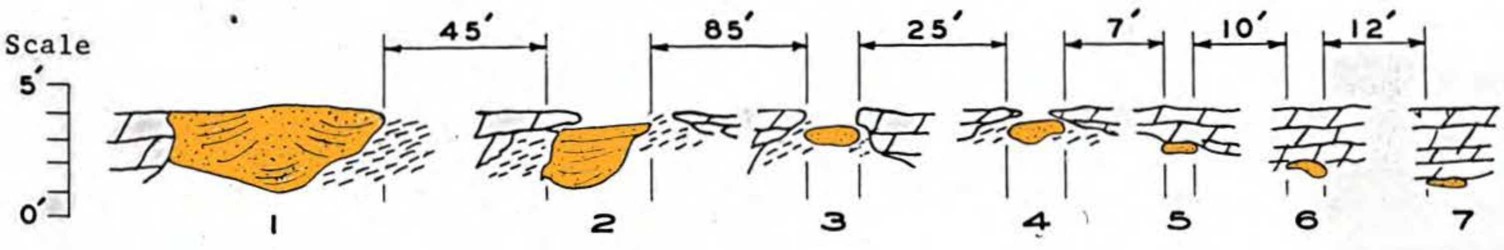
Beds range from less than half an inch to more than three feet in thickness. Green shale partings are common. These change laterally to coarse nodular appearing dolomite containing many pockets of green shale.

Figure 1



Boxwork in the Light Gray dolomite member of the Bonneterre formation.

Figure 2



Outcrop of channel-like structures in the Light Gray dolomite member of the Bonneterre formation along the east side of Highway E in the NW¼, NE¼, NE¼, sec. 15, T.32N., R.4E. The structures are numbered in order from north to south. Vertical and horizontal scales are equal, but the horizontal scale is broken between the channel-like structures.

Beds up to ten feet thick of finely crystalline, laminated, buff dolomite commonly occur within the more typical, coarsely crystalline dolomite of this unit. This is especially true in lower Marble Creek valley, where they occur above the Tom Sauk limestone beds. An example may be seen along the north edge of Highway E in the SW corner of sec. 17, T.32N., R.5E.

No fossils were found in the Light Gray dolomite. However, on the basis of its lithology, stratigraphic position, and the occurrence of Tom Sauk limestone beds within it, it is considered part of the Bonneterre formation and is correlated with zone 3 of McQueen (1943, p. 9) and Stewart (1944, p. 2).

The Arkosic beds. Where the Light Gray dolomite member laps onto the Precambrian knobs, it commonly changes from coarsely crystalline dolomite to arkosic sandstones and conglomerates. These arkosic beds are distributed about the flanks of the exposed igneous rocks, especially in sheltered areas away from the open Upper Cambrian seas. On the map the arkoses appear as narrow bands between the Light Gray dolomite and the exposed Precambrian rocks. (Plate III.) Good exposures occur in the bed and on the west bank of the small stream in the SW$\frac{1}{4}$, sec. 9, T.32N., R.5E.; on the south flank of a hill some 400 feet due east of the center of the E$\frac{1}{2}$, sec. 11, T.32N., R.4E.; and in a small stream bed in the NW$\frac{1}{4}$, NE$\frac{1}{4}$, NW$\frac{1}{4}$, sec. 35, T.32N., R.4E. The last two mentioned outcrops also show the arkose-porphyry contact as do several outcrops on the side of the hill in the NW corner of sec. 18, T.32N., R.5E.

That these arkosic beds represent facies of the Light Gray dolomite member and not the underlying Lamotte sandstone is shown at the outcrops along the north bank of Marble Creek near the center of the W$\frac{1}{2}$, NW$\frac{1}{4}$, sec. 11, T.32N., R.4E.; in a stream bed in the SE corner, NE$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 3, T.32N., R.4E.; and in a stream in the NW$\frac{1}{4}$, SW$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 36, T.32N., R.4E., where they directly overly dolomite and where gradational beds of sandy dolomite and dolomitic sandstone are present. Sandstone is also found interbedded with dolomite in the Marble Creek tributary in the SE$\frac{1}{4}$, NW$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 11, T.32N., R.4E.

These sandstones and conglomerates vary from medium to coarse-grained quartz sandstone to boulder conglomerate. Coarseness generally increases down section and towards the knobs. The sand and gravels which formed these beds were apparently derived from the porphyries. Color is commonly reddish to orange-brown, but is sometimes green, purple, or gray. Cross-bedding is not generally present but does occur on some outcrops. Current-ripple marks were noted at one exposure.

The maximum exposed thickness of individual units is eighteen feet along the west bank of the stream in the NW$\frac{1}{4}$, NE$\frac{1}{4}$, NW$\frac{1}{4}$, sec. 18, T.32N., R.5E. This includes thirty-three inches of dark gray to brown, fissile shale at the top of the outcrop. Here it is directly overlain by Light Gray dolomite.

On the basis of their stratigraphic position and their interfingering relationships with the Light Gray dolomite, these beds are considered facies of that unit.

Tom Sauk limestone beds. The Tom Sauk limestone was named from the type section along Little Tom Sauk Creek in the E$\frac{1}{2}$, sec. 25, T.33N., R.2E., and sec. 30, T.33N., R.3E., on the Reynolds-Iron county line, by G. F. Brightman (1938 p. 248). Dake (1930, p. 62) called it the "Marble

Phase of the Bonneterre," and referred to several outcrops within the area of this report. These include outcrops near the center, S½, sec. 17,; near the center of the N½, sec. 20, and near the center of the N½, sec. 19, T.32N., R.5E., in Madison County. Good outcrops in Iron County are mentioned in the S½, sec. 24, T.32N., R.4E.

In the area of this study, known occurrences of Tom Sauk limestone are restricted to the lower part of Marble Creek valley and its tributaries. Based on the distribution pattern of the Precambrian rocks, this area appears to have been the upper reaches of a Precambrian valley, more or less sheltered from the open sea on three sides. Actual outcrop areas are shown on the aeromagnetic overlay to Plate III.

The limestone forms two distinct units within the coarsely crystalline dolomite of the Light Gray member. The lower of these two units locally rests directly upon the Precambrian basement. Examples are known in the small stream valley in the S½, S½, sec. 17, T.32N., R.5E.; along Highway E in the NW¼, SE¼, SW¼, sec. 24, T.32N., R.4E.; on the southeast slope of the small hill in the center of the S½, S½, sec. 24, T.32N., R.4E.; and in the small stream bed in the SE¼, NW¼, sec. 19, T.32N., R.5E.

The lower limestone attains a maximum thickness of about twenty-five feet along the west bank of Marble Creek where old Highway E crossed in the SW¼, NE¼, sec. 19, T.32N., R.5E. In this same area and slightly downstream, the upper limestone develops a thickness of about twenty feet. Two feet of coarsely crystalline dolomite lies above this, then ten feet of cover and three and a half feet more of limestone. The upper and lower limestones are separated by about twenty-one feet of coarsely crystalline, pinkish-gray dolomite containing numerous patches of green shale.

On the east bank of a small tributary of Marble Creek near a bend in the stream, in the SW$\frac{1}{4}$, NE$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 23, T.32N., R.4E., an outcrop of about 200 square feet appears to be gradational between Light Gray dolomite and the upper limestone unit. This is the main basis for calling the limestone a facies of the Light Gray member.

Lithologically, the two limestone units are very similar. Following is a description of a typical exposure of the lower unit. The section was measured along the southwest side of Highway E near the center of the SW$\frac{1}{4}$, sec. 24, T.32N., R.4E.

Typical Exposure of Tom Sauk Limestone

	Description	Thickness (inches)
	Top	
1.	Dense, blue-gray limestone with brown veinlet network. Massive. Weathers gray with velvet-like appearance.	21
2.	Covered.	12
3.	Medium to massive, very dense limestone. Upper 19 inches are slightly pinkish; lower 44 inches are gray. Weathers smooth with velvet-like appearance.	63
4.	Similar to 3, but reddish throughout.	10
5.	Reddish to greenish-gray limestone containing green shale.	5
6.	Similar to 3, but gray throughout.	18
7.	Very dense, reddish limestone containing green shale. Weathers irregularly. Breaks off in small chunks when hit by hammer. Bedding is medium, bedding surface irregular. Veinlets of brown calcite run in all directions through rock. Upper surface marked by small, long, and narrow troughs (about 5 to 6 inches long, 1 inch wide) trending in all directions.	17

8. Very dense, blue-gray, massive limestone with pockets of green shale. Contains some pinkish limestone. Weathers smooth to rough, with many tiny ridges on surface. Weathered color is blue-gray. In places it chips off in chunks as 7 does. 32

9. Very dense, blue-gray limestone containing green shale. Pinkish in places. Weathers irregularly and light gray. Thin bedded with irregular bedding surface. Chunks off like 7 and 8. 13

Bottom of outcrop

Dip: 9° S.65W.

The limestone breaks with a conchoidal fracture and often weathers with a nodular appearance. This description bears striking resemblance to that of Brightman for typical Tom Sauk limestone:

> The typical Tom Sauk limestone is light gray or white in color and so fine grained as to appear dull on a broken surface, like lithographic stone. It has well-developed conchoidal fracture and an almost chertlike appearance.... The dense gray limestone is very commonly cut by irregular veinlets and patches of coarser grained, clear, secondary calcite. Thin wavy discontinuous veinlets of green clay occur in many of the specimens, and some of these clay veinlets contain coarse brown dolomite crystals, obviously secondary.
>
> Many of the limestone varieties differ from the normal type only in color. There is a continuous variation from the very light-gray limestone through the faintest flesh-pink colors to deep reds and browns. Other variations from the normal are dark grays with a faint purple tinge, light-greenish grays, and dark-purple browns. The colored beds of the Tom Sauk are frequently mottled or varigated.... (Brightman, 1938, pp. 255-256.)

The lithologic similarities, stratigraphic position, and the observations by both Dake and Brightman on the Tom Sauk limestone are the bases for correlation of the limestone units within the area with the Tom Sauk limestone. This also strengthens the conclusion that the Light Gray dolomite is a member of the Bonneterre formation.

<u>Channel-like structures in the Light Gray dolomite</u>: Seven channel-like structures composed of silt and porphyry and quartz sand and pebbles crop out within the Light Gray dolomite along the east side of Highway E in the NW$\frac{1}{4}$, NE$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 15, T.32N., R.4E. These trend generally perpendicular to the road in an easterly direction. Figure 2 is a sketch of the outcrops. The outcrops become progressively smaller and lower stratigraphically from north to south. The northern-most channel is eight feet wide and thirty-two inches thick in its central part. Exposures can be traced for about twenty-five feet. Forty-five feet to the south a similar lense-like body, fifty-two inches wide and thirty inches deep crops out. Some eighty-five feet farther south is the third and about twenty-five feet south of it the fourth channel. These last are both approximately two feet by one foot. The fifth channel lies seven feet farther south, the sixth another ten feet, and the seventh twelve feet more. These three are all about one foot by a half foot in cross-section. Grain sizes become smaller from the largest to the smallest channel. They range from one-half inch pebbles to fine silt and clay.

The southern-most channel is about three and a half feet lower stratigraphically than the northern-most.

The origin of these channel-like structures is uncertain. At first they were considered stream channels cut into the dolomite, but the fact that they are parallel and show a progressive change in stratigraphic position suggests that they may be near-shore sandbars formed at successively higher levels on the sea floor or beach structures representing progressive changes in sea level.

Upper Brown Dolomite

The Upper Brown dolomite is named for its brown color and its stratigraphic position above the Light Gray dolomite.

This member crops out in five general areas: about the base of the knob in the northeast portion of sec. 3, T.32N., R.4E.; on the hills in the southwest part of the same section; on the south flank of the knob in the northeast part of sec. 10, T.32N., R.4E; in the stream valleys in the northern parts of sec. 21 and 22, T.32N., R.4E.; and along the tributaries to Crane Pond Creek in sec. 2, T.31N., R.4E. The best exposures occur along the tributary to Marble Creek in the northern parts of sec. 21 and 22, T.32N., R.4E. Here, in the SE$\frac{1}{4}$, NW$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 21, it shows a thickness of about forty-five feet. It is undoubtedly thicker, but this is the thickest nearly continuous exposure known in the area.

Contacts between this unit and the Light Gray dolomite were discussed in the previous section. In addition, the Upper Brown dolomite occurs above the Light Gray dolomite on the hill in the NE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 3, T.32N., R.4E., though the direct contact is not visible. This hill is the only place in the area where all three members are known to crop out together in the normal stratigraphic sequence.

Lithologically, the Upper Brown dolomite is very similar to the Lower Brown. It is finely crystalline, usually dense, brown dolomite, locally containing felsite pebbles. Dolomite grains range from microscopic to 0.4 mm., average about 0.2 mm. Gray, orange, and brown mottling characteristics help distinguish it from the less-often mottled Lower Brown dolomite. In addition, it sometimes shows alternating half inch, orange and brown, horizontal bands, as at the outcrops in the divide near the center of the SW$\frac{1}{4}$, sec. 3, T.32N., R.4E., and on the southwest bank of Patterson Creek in the NE$\frac{1}{4}$, SE$\frac{1}{4}$, of the same section. This banding is a feature not observed in the Lower Brown dolomite. The very porous parts of the Upper Brown dolomite also serve to distinguish it from the Lower Brown unit. Bedding ranges in thickness from less than an inch to more than twelve feet. Individual beds will not serve to mark stratigraphic position since massive beds can sometimes be traced laterally into thin beds through a distance of twenty to thirty feet.

The unit weathers sharp and blocky and is very strongly jointed. It usually shows bedding striations on the weathered surface.

No fossils were found in this unit. On the basis of its lithology and stratigraphic position, it is correlated with zone 4 of the Bonneterre of the Fredericktown area after Stewart (1944, p. 2) and McQueen (1943, p. 13).

IDEALIZED EAST-WEST SECTION UP MARBLE CREEK VALLEY

Showing Interrelationships between the Members of the Bonneterre Formation

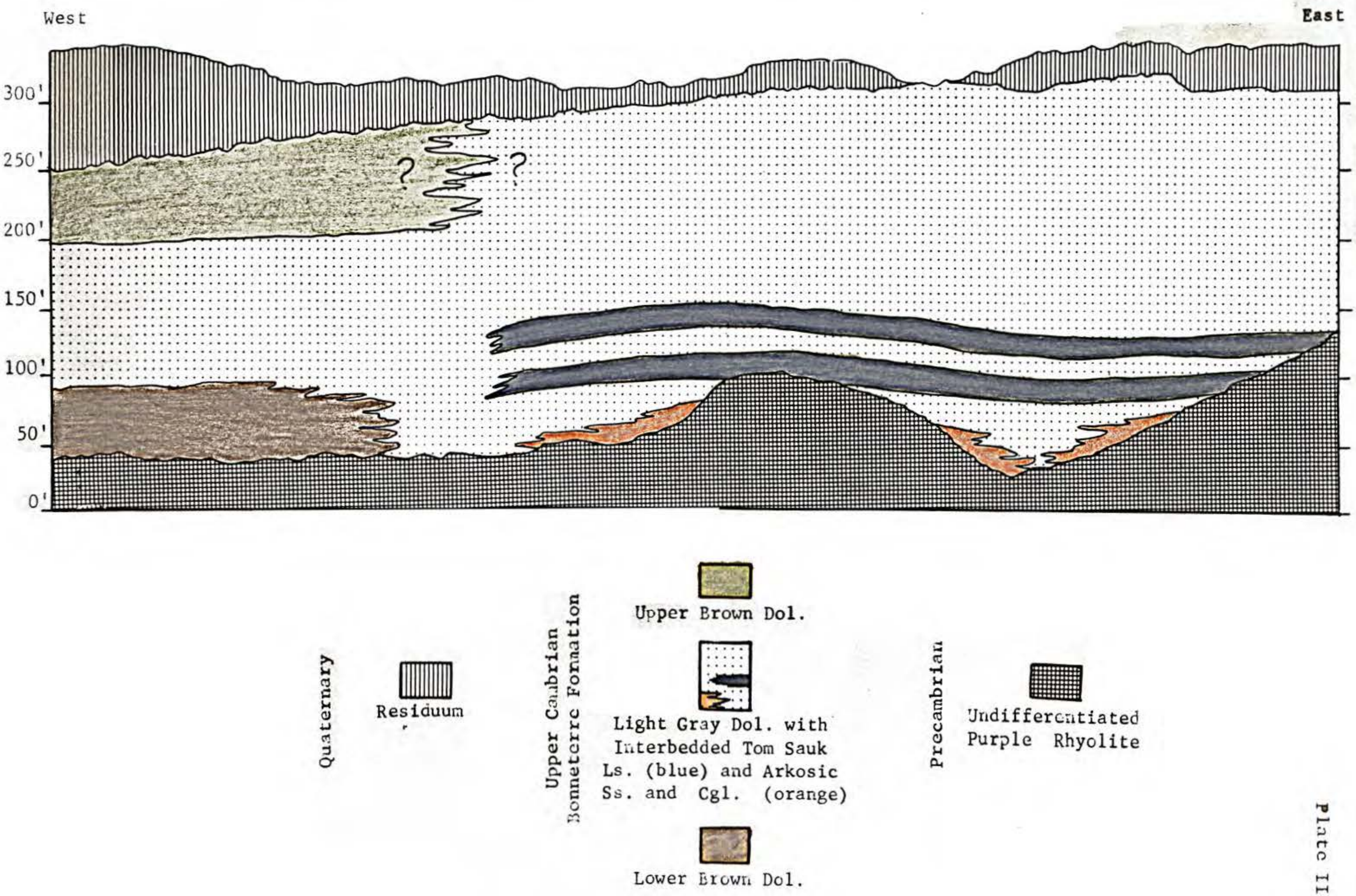


Plate II

QUATERNARY SEDIMENTS

An indurated conglomerate in a shut-in on Crane Pond Creek in the SW$\frac{1}{4}$, sec. 33, T.32N., R.4E., is probably either Quaternary or Tertiary. Quaternary and recent sediments consist of a heavy residuum on the hills and a thin alluvial cover over much of the larger stream valleys.

Quaternary (?) Conglomerate

A poorly sorted, indurated, non-bedded conglomerate occurs in a Crane Pond Creek shut-in in the NW$\frac{1}{4}$, NE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 33, T.32N., R.4E. This is the only place in the area it has been observed. Here it rests on an irregular erosional surface of the Precambrian rhyolite and occurs in discontinuous outcrops for a distance of six to seven hundred feet along Crane Pond Creek.

The conglomerate consists of material derived from the Paleozoic and Precambrian rocks and includes clay and silt, pebbles, cobbles, and boulders of banded Potosi druse, subangular Gasconade and Eminence cherts, and Precambrian rhyolite porphyry. One such porphyry boulder measured ten feet across. The cement is limonite. The material is considered Quaternary, but it may be older. Its indurated character suggests it may be older than the residuum and is definitely older than the normal alluvium.

Residuum

Residual material covers more than half the area, but liberal interpretation of the geology has restricted it to a smaller area on the geologic map (Plate III). Such interpretations are indicated by weighting of the contact lines. The residuum is especially thick in the southern portion of the area where it covers all but the igneous hills. Most of the small stream valleys are also filled with residuum.

Locally, the residuum may be in contact with each of the rock units, from the Precambrian rhyolites to the Upper Cambrian Upper Brown dolomite. Virtually every Precambrian knob and ridge is either partially or completely surrounded by residual rock materials. The Upper Cambrian units were mapped from isolated outcrops surrounded by residuum.

The residual material consists of clays, silts, cherts, quartz druse, sandstone, and porphyry boulders. The larger chert boulders, ranging to fourteen feet across, are apparently remnants of the Gasconade formation. The smaller cherts may be from the Potosi, Eminence, or Gasconade formations. Large sandstone boulders up to ten feet across are probably from the Roubidoux formation, though some may be from the Gunter sandstone, the basal member of the Gasconade. The quartz druse, which is usually banded, has come from erosion of the Derby-Doerun and Potosi formations. The clay and silt were derived from all the eroded formations.

Alluvium

Alluvial deposits fill much of the stream valleys. This is especially true of the larger stream valleys such as Marble, Little Rock, Crane Pond, and Leatherwood Creeks. Bedrock shows through this alluvial cover in many places and indicates that the alluvium is rather thin. It consists of reddish brown clay and silt, and of pebbles and boulders of chert, quartz druse, porphyry, and sandstone which have been moved and deposited by stream action. Occasionally it consists of fine gray clay. The major difference between the residuum and the alluvium is the finer texture and better sorting of the latter.

STRUCTURE

Structural features of both the Precambrian and the Paleozoic rocks appear relatively simple, but much work still remains to be done on the Precambrian. Principal Precambrian structures consist of inclined volcanic flows and tuffs with dips from about zero to forty degrees, primary flow structures in the volcanic rocks, joints, a small diabase intrusion, and at least one fault. Inclination of the volcanic flows is usually gentle, though at one place it reaches forty degrees. Structures in the Cambrian rocks consist of initial dips in the sedimentary rocks off the Precambrian knobs and ridges and joint sets which are probably related to differential compaction of the sediments about the knobs and ridges. The structural overlay to Plate III summarizes the structural data for the area. The cross sections, Plates IV and V, show the relationships between the various rock units.

Precambrian Structure

For the most part, the Precambrian extrusive volcanic rocks appear to be nearly horizontal or gently inclined, though the purple rhyolites are so similar that it is difficult to determine their exact attitude. At the roadcut in the NW¼, NW¼, NE¼, sec. 19, T.32N., R.5E., they appear to dip three or four degrees to the west beneath the basalt. The Blue School basalts also appear to be inclined four to five degrees westward.

The tile-red rhyolite in the SW¼, sec. 35, T.32N., R.4E., dips about forty degrees N.70 W. This steep dip may be explained either as a local flexure or as a fault block tilted westward. General position of the contact between the tile-red rhyolite and the overlying purple porphyry shows that the tile-red unit dips very gently southeastward through sections 28, 27, 33, and 34, T.32N., R.4E.

Judging from the little evidence available on the attitudes of the flows, there appear to have been at least two different source areas for the lavas. If the purple rhyolites at the roadcut in the NW$\frac{1}{4}$, NW$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 19, T.32N., R.5E., and the basalts and tuff at Blue School are indicative, these units may have had their source in the east. On the other hand, the gentle inclination of the tile-red rhyolite to the southeast indicates it had its origin from the northwest. Another explanation of the attitude of the extrusive rocks might be that the basement rocks have been regionally warped since emplacement of the lavas.

Flow structures. Flow layering is quite common in the rhyolites but rarely seen in the basalts. In fact, only one basalt outcrop west of Highway E near Blue School in the SW$\frac{1}{4}$, NE$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 15, T.32N., R.4E., showed this feature. There they are vertical. Planar and linear structures were not observed in the dacite-andesite.

Flow layering occurs in all the rhyolites. The most conspicuous development is in the rhyolites of the northeast portion of the area. This feature is expecially abundant along the ridge in the NE$\frac{1}{4}$, sec. 8, and the SW$\frac{1}{4}$, sec. 5, T.32N., R.5E., and in the Marble Creek shut-in in section 21, T.32N., R.5E. At these localities it has no general trend but suggests intricate involutions of the original lava. However, the layering in the shut-in does seem most often to parallel the joint set dipping thirteen degrees S.63W. The flow layering weathers into small ridges on the rock surface throughout the northeast portion of the area.

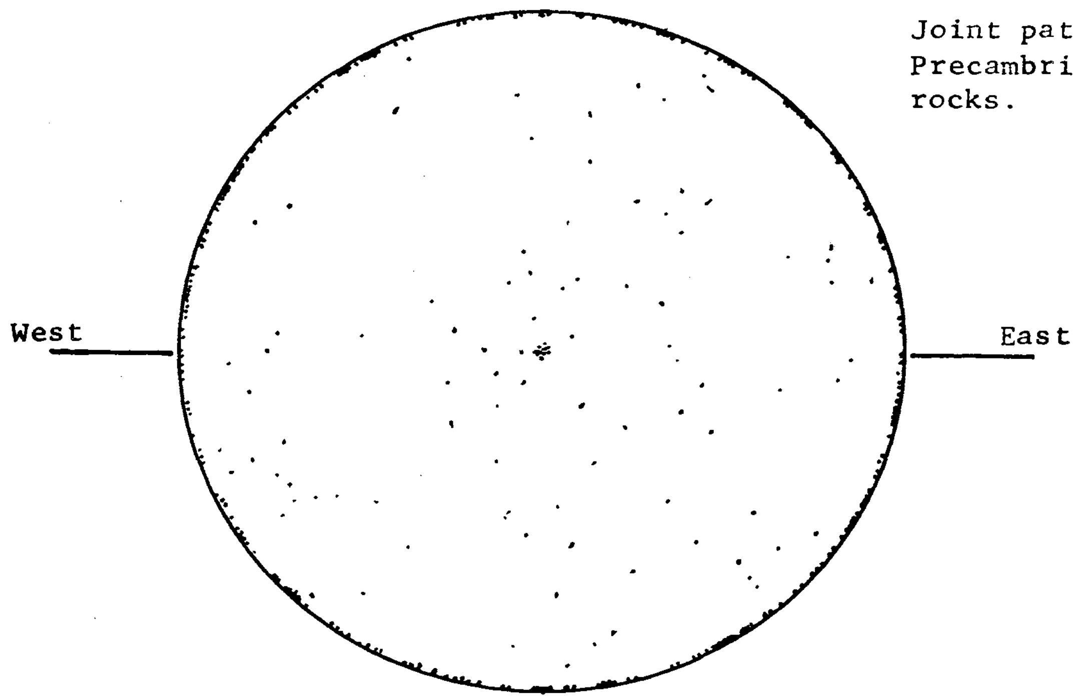
While too little work has actually been done to determine the over-all attitude of the flow structures with certainty, the flow layering most often observed is nearly horizontal or dips slightly westward. This may be supporting evidence for a source area to the east.

Joints. Joint patterns in the Precambrian rocks are shown for various locations on the structural overlay to Plate III. Since at each location two or more joint sets intersect, the various joint pattern are listed as "joint systems" on the overlay.

The numerous joints measured in the area have been plotted to show mutual relationships (see Figure 3). Each dot on the diagram represents the projection onto the upper hemisphere of a perpendicular to a joint plane passing through the center of a sphere. These joints show no distinct pattern except that most of them are vertical. This indicates that horizontal pressures were less than vertical pressures when they were formed. Such conditions would prevail in a cooling and shrinking lava flow. Lack of a preferred orientation in the over-all joint pattern indicates that the forces causing the joint fractures were local and not regional.

Inspection of the joint patterns on the overlay may give the impression that there is a general parallelism to many of the sets, but the writer feels that the apparent parallelism is only local. In some cases the change in dip and strike is rapid even within a few feet. An extreme case of such a rapid change occurs in the center, $N\frac{1}{2}$, $S\frac{1}{2}$, sec. 10, T.32N., R.4E., where the joint sets were measured at two places 150 feet apart. Four sets were measured at the first place and six at the second. Except for horizontal sets at both places, no two sets

Figure 3

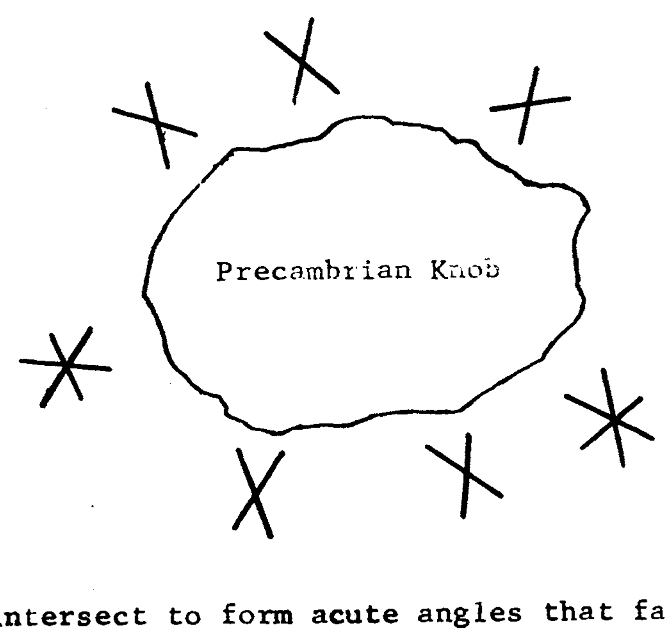


Joint pattern in the Precambrian extrusive rocks.

Each dot represents the projection on the upper hemisphere of a normal to a joint plane passing through the center of a sphere. Two hundred seven joints from all the exposed Precambrian rocks in the area are represented.

Figure 4

Idealized joint pattern in the Bonneterre formation.



Joint sets intersect to form acute angles that face updip.

were parallel. In order to avoid crowding and so as not to obscure the sedimentary dip symbols to the south, these joint patternswere left off the structural overlay. For the sake of completeness they are given here:

First system:

1. Nearly horizontal, moderate.
2. N.10E., vertical, strong.
3. N.44W., dips 58° N.46E., strong.
4. N.53E., vertical, moderate to strong.

Second system:

1. Nearly horizontal, moderate.
2. N.28E., vertical, weak.
3. N.51W., dips 55°N.39E., strong.
4. N.56W., dips 80° S.34W., moderate.
5. N.26E., vertical, moderate to strong.
6. N.40W., dips 29° N.50E.

Note that joints number three in either system are fairly parallel and probably represent the same joint set. However, even so small a variation, occurring as it does through the distance of 150 feet, would seem to deny the set regional control.

Another indication that the joints are controlled by local tension rather than by regional stresses is the tendency of many of the joints to curve into one another. This tendency was noted especially for the three northeast trending, vertical joints in the NE¼, NW¼, sec. 3, T.32N., R.4E.

At first glance, the northeast trending joints in the vicinity of King fault appear to be generally parallel, but closer inspection shows that they vary in dip by as much as fifty degrees.

The structural overlay shows that joint systems of three vertical joint sets intersecting at approximately sixty degrees are common.

These are probably crude counterparts of the joints that develop in columnar basalts to form the hexagonal columns. The majority of the joints in the igneous rocks probably originated as contraction joints due to cooling of the hot lavas.

King fault. A fault occurs in the Precambrian purple rhyolite porphyry in the SW$\frac{1}{4}$, sec. 7, T.32N., R.5E. It is here called the King fault because it is exposed on Bob King's land. The exposure is visible on the west bank of the stream in the NW$\frac{1}{4}$, SE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 7. Here the rhyolite forms a buttress that juts into the stream from the west. Horizontal flow bands in the rock are separated by quartz veins up to two inches thick that strike N.5E. and dip approximately forty-two degrees east. Fault breccia clings to the north face of the buttress. The breccia is about thirty inches thick and consists of gouge and felsite breccia fragments. The quartz veins pass from the buttress into the breccia where they have been broken and dragged upward indicating that the northern side is upthrown. North of the buttress, the felsite appears to have been shattered for about twenty feet and is covered with small, shaley, fissile chunks of rhyolite.

Heave and throw cannot be determined. If the contact between the breccia and the north face of the buttress can be considered the fault face, it strikes almost due east and dips between seventy-five and eighty degrees south. This indicates a normal fault since the north side is upthrown.

Other faults probably occur in the Precambrian rocks, but the similarity in appearance between the purple rhyolites hinders recognition of fault zones.

Upper Cambrian Structure

The Bonneterre formation appears to have no structures other than original dip, due to sedimentation, and joints and increase of original dip, due to differential compaction. Compaction faults may also be present, but none were observed.

Herbst (1952) shows a fault across sections 15, 16, and 22, T.32N., R.4E. Apparently it was used to explain the position of fine-grained brown dolomite above the Light Gray dolomite. He considered the brown dolomite as equivalent to the Lower Brown dolomite of this report. Data from the present investigation indicate it belongs to the Upper Brown dolomite member rather than the lower. On this basis, the fault of Herbst is unnecessary; and stratigraphic relationships are normal.

Buried hill structures. The Cambrian sea invaded an area of igneous knobs and ridges separated by deep valleys. In this environment, the sediments that were deposited received an original dip from the slope of the sea floor. Later, differential compaction probably increased the original dip to what it is today, with the sedimentary rocks dipping away from the Precambrian knobs and ridges.

The dip of the rocks varies continually both in direction and in degree making it difficult to project any sedimentary unit without some knowledge of the position and shape of the controlling Precambrian hills. Thus the simple processes of sedimentation and differential compaction have given rise to relatively complex structures which are difficult to follow beneath the residuum. The structure is of little aid in strata projection due to rapid variation in strike and dip of the sedimentary beds over short distances.

Buried hills give an indication of their presence by the attitude of the overlying sedimentary rocks. Based on this, it is probable that buried hills exist in the center, E$\frac{1}{2}$, NW$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 21, near the center of the line between sections 15 and 22, in the SW$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 15, and the SE$\frac{1}{4}$, SE$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 23, T.32N., R.4E. The saddle in the S$\frac{1}{2}$, SE$\frac{1}{4}$, sec. 26, T.32N., R.4E., is also probably underlain by rhyolite. The buried hill indicated in the E$\frac{1}{2}$, NW$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 21, T.32N., R.4E., is probably either deeply buried or quite small judging from the gentle dip of the sedimentary rocks above.

Joints. The Cambrian rocks are almost universally jointed. These joints do not parallel the joints in the Precambrian rocks. Evidently they have a different origin.

Generally a sedimentary outcrop has two vertical joint sets that intersect forming an acute angle facing up dip toward the Precambrian knob or ridge on which the rock is resting. A third vertical joint often trends parallel to the strike of the beds. An example of this general relationship is seen in sec. 9, T.32N., R.4E., in the sedimentary beds dipping off the Precambrian knob. In the NE$\frac{1}{4}$, SW$\frac{1}{4}$, SE$\frac{1}{4}$, of that section, vertical joints strike N.58W. and N.73W. A third set strikes N.13E. and nearly parallels the strike of the beds. In the center, S$\frac{1}{2}$, NE$\frac{1}{4}$ of the section, joints strike N.28W. and N.85E.

There are many exceptions to this general rule; and sometimes, as beside Highway E in the center, S$\frac{1}{2}$, sec. 24, T.32N., R.4E., one joint set nearly parallels the dip and two others form an obtuse angle facing updip. Insofar as the joints intersect to form an acute angle facing updip, they tend to form radial joint patterns about the Precambrian highs. (See Figure 4.)

The relationship of the joint patterns to nearby Precambrian knobs suggests that the fractures were formed through differential compaction of the sediments during and after diagenesis.

GEOLOGY OF THE NORTHEASTERN PORTION OF DES ARC QUADRANGLE, IRON AND MADISON COUNTIES, MISSOURI

By W. D. Weixelman

6°

Scale

½ 0 1 2 miles

Contour interval 20 feet

EXPLANATION

QUATERNARY

- Residuum

UPPER CAMBRIAN BONNETERRE FORMATION (?)

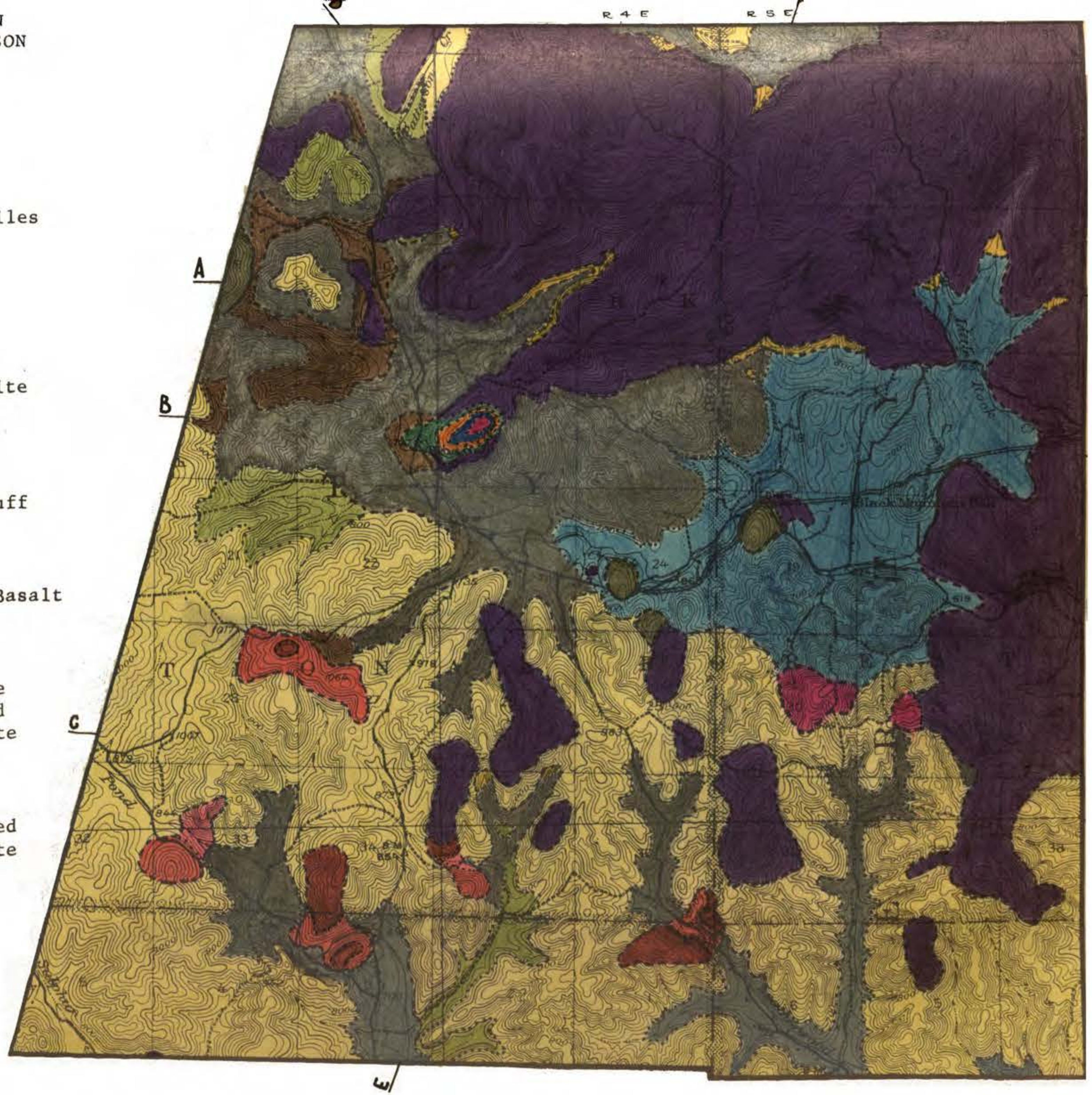
- Upper Brown Dol.
- Tom Sauk Ls. interbedded with Light Gray Dol.
- Light Gray Dol. with Arkosic Ss. & Cgl. facies
- Lower Brown Dol.

PRECAMBRIAN

- Dacite & Andesite
- Basalt and interlayered Tuff
- Undifferentiated Basalt
- Purple Rhyolite and interlayered Tile Red Rhyolite
- Undifferentiated Purple Rhyolite

Contacts:

- ——— Known
- ----- Indicated
- ..... Inferred



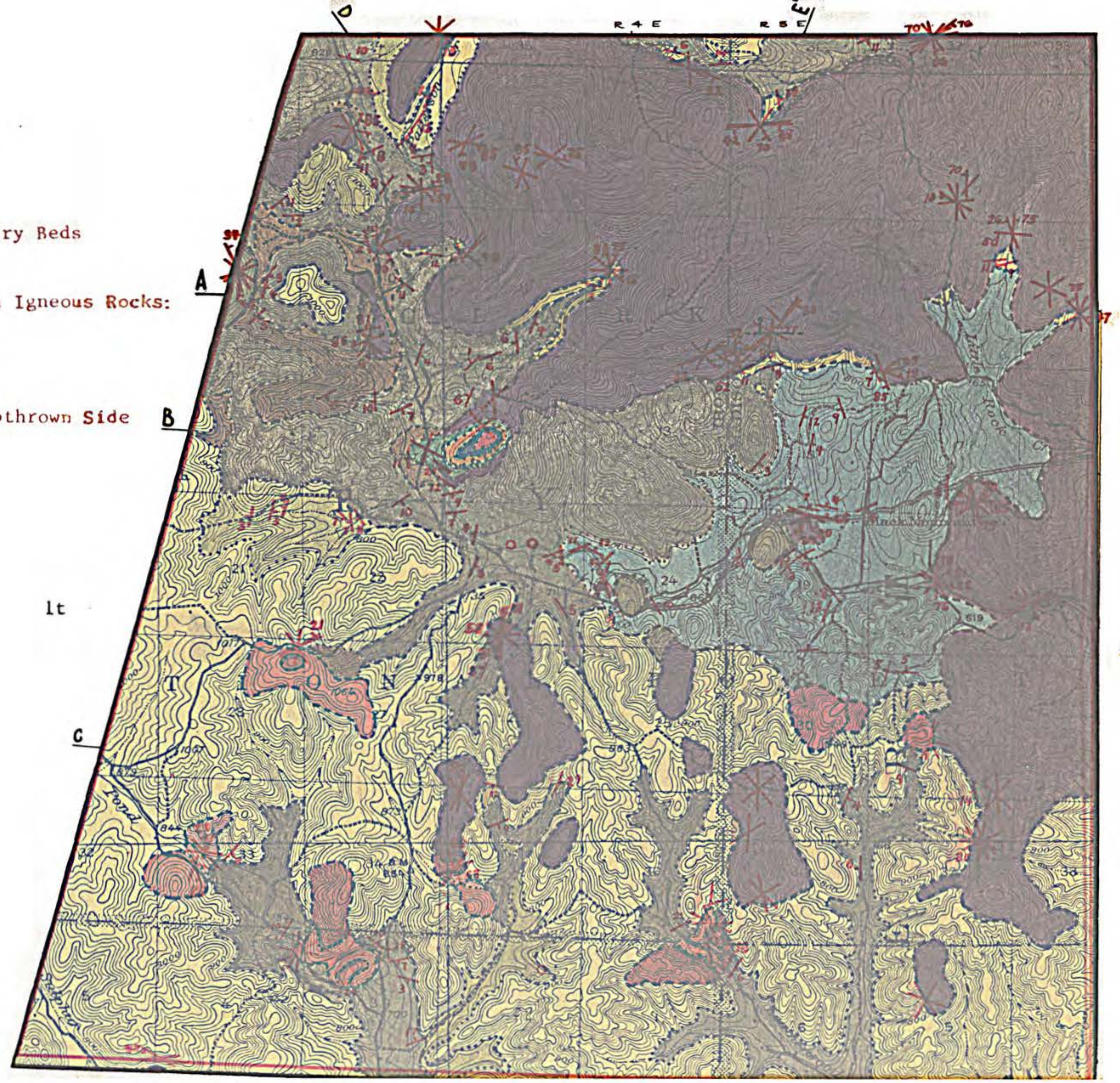
STRUCTURAL OVERLAY

Dip of Sedimentary Beds

Joint Systems in Igneous Rocks:
vertical joints
dipping joints

Fault Showing Upthrown Side

It



AEROMAGNETIC OVERLAY
SHOWING SMALL GEOLOGIC FEATURES

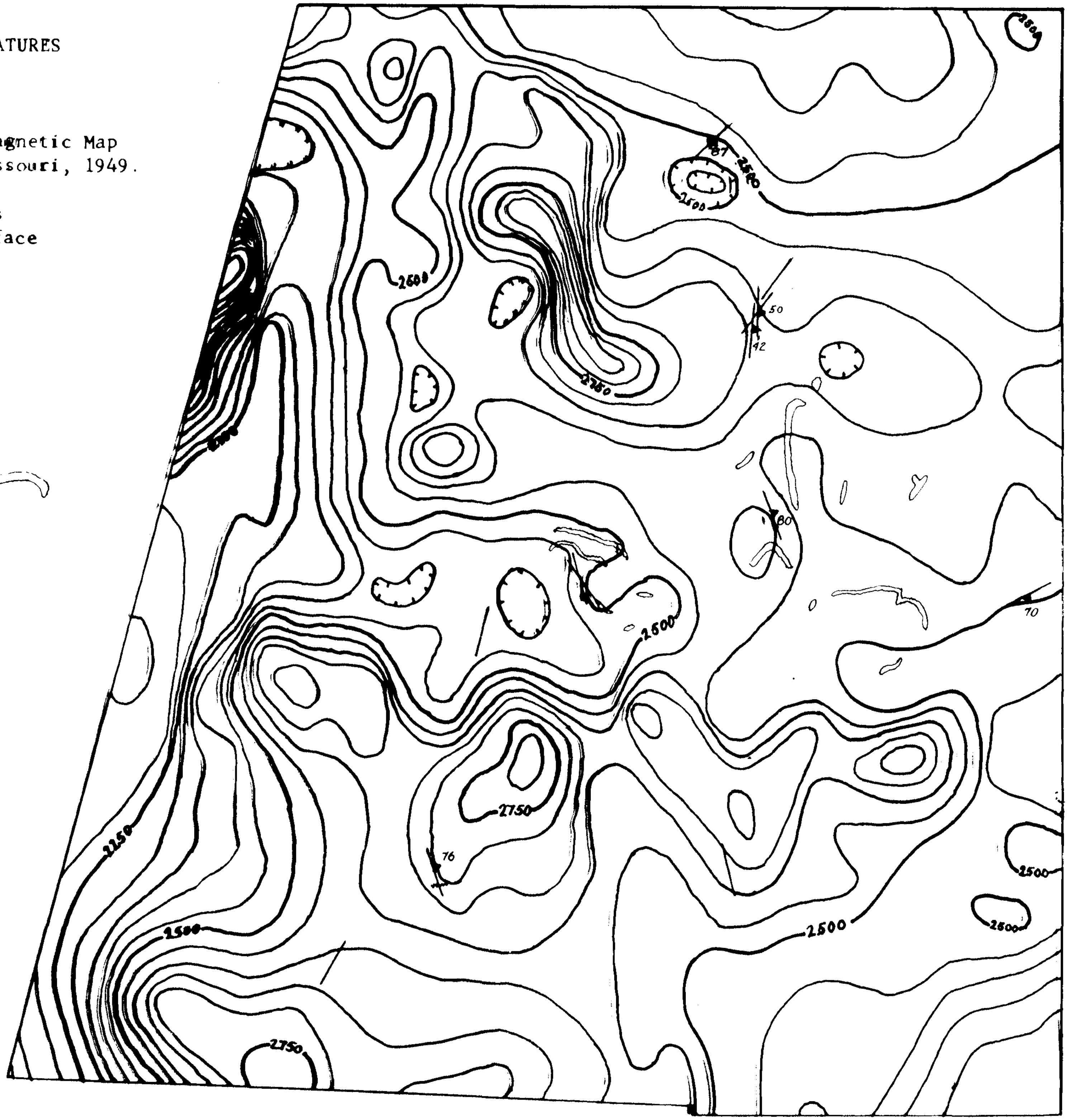
Magnetics from USGS Aeromagnetic Map
of Des Arc Quadrangle, Missouri, 1949.

Contour interval 50 gammas
Flown 1000 feet above surface

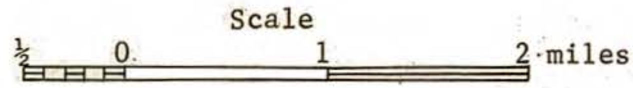
Tom Sauk Ls. outcrops:

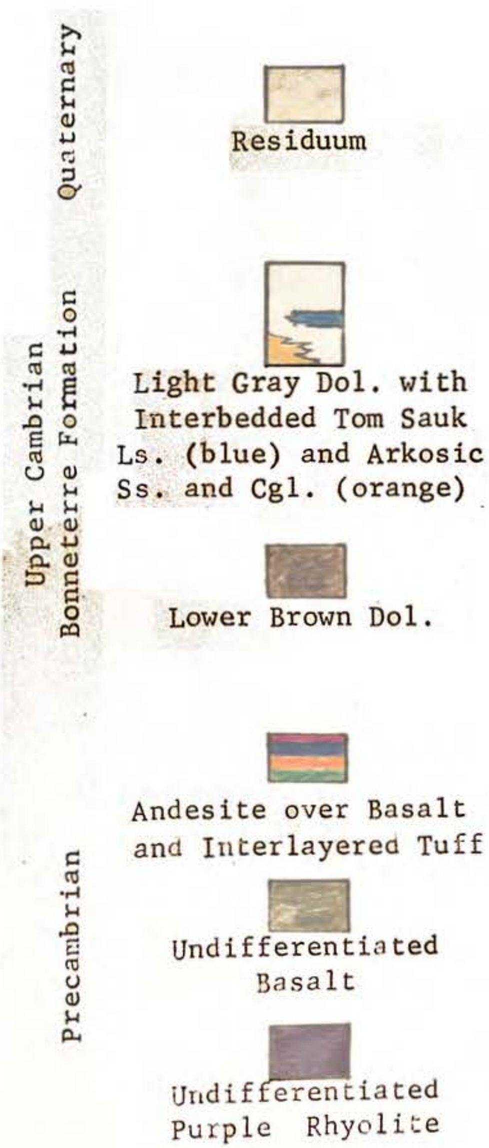
Quartz Veins:
vertical:
dipping:

Diabase Dike:

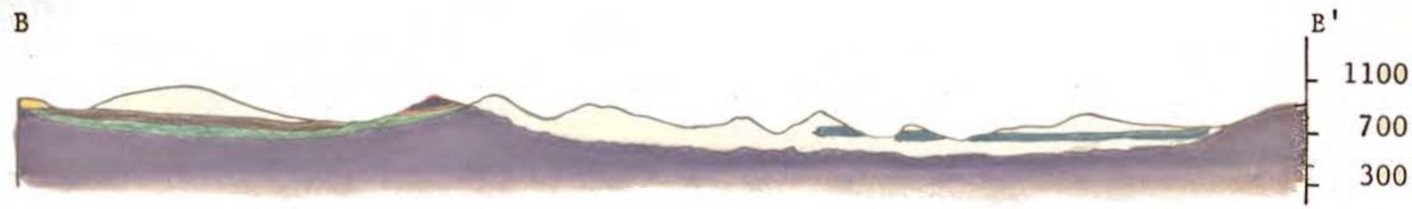


GEOLOGIC CROSS SECTIONS





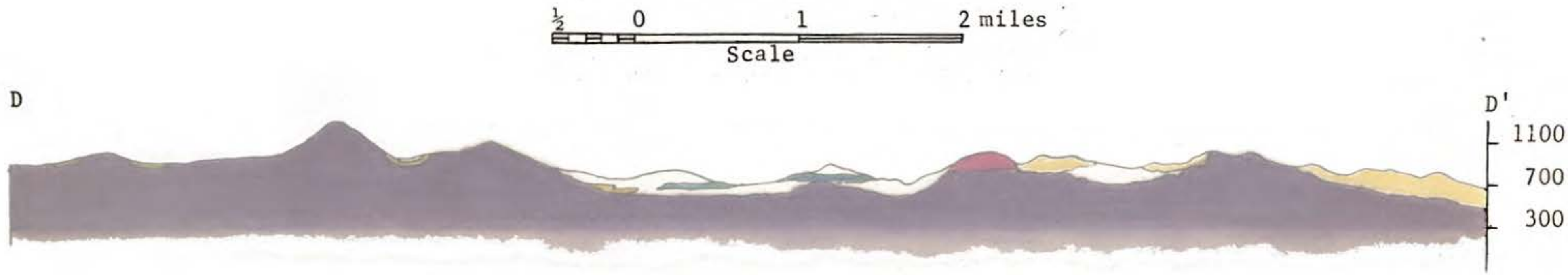
Geologic cross section AA', looking north



Geologic cross section BB', looking north

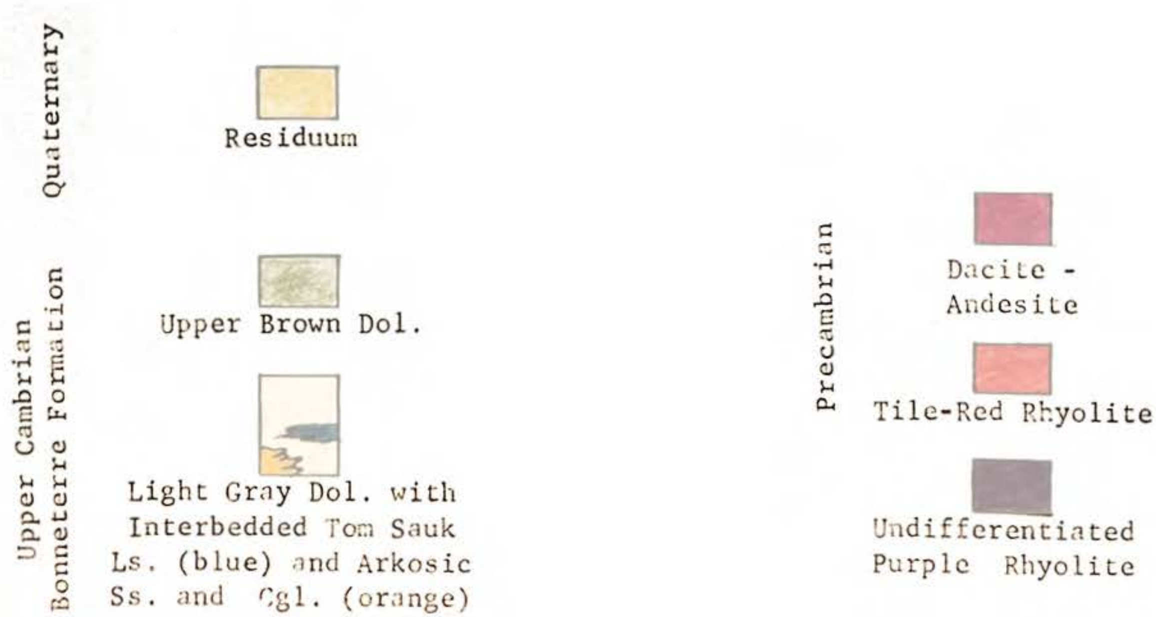
Geologic cross section CC', looking north

GEOLOGIC CROSS SECTIONS



Geologic cross section DD', looking northeast

Geologic cross section EE', looking northwest



CORRELATION OF THE PRECAMBRIAN ROCKS WITH AEROMAGNETIC DATA

An aeromagnetic survey was made of the Des Arc Quadrangle in March and April, 1948, by the United States Geological Survey in cooperation with the Missouri Geological Survey. The outcome of this work was an aeromagnetic map of the quadrangle. Survey data are given on the map:

> .... North-south traverses were flown at quarter-mile intervals over the whole area, and were tied to nine east-west base-line traverses used to correct for instrument drift and diurnal variation. A constant barometric altitude of 1,800 feet above sea level was maintained except in areas above 1,400 feet in elevation, where the altitude was increased to clear all peaks by about 500 feet.... The flight path of the aircraft was recorded by a gyrostabilized continuous-strip camera, and a gyrostabilized vertical sight was used to increase positional accuracy. ("Total Intensity Aeromagnetic Map of Des Arc Quadrangle, Missouri," 1949.)

A portion of this map has been reproduced as an overlay for the geologic map in this report in an attempt to correlate the Precambrian rocks with the aeromagnetic data. (See the aeromagnetic overlay to base Plate III.) In general one would expect that the aeromagnetic response would be related to the magnetite content of the various rock types and to their topographic expression.

Magnetic susceptibilities (k) for the various igneous rock types of the area were calculated using Slichter's method (Dobrin, 1952, p. 108). According to this method, the volume magnetic susceptibility of magnetite (0.3 cgs) is multiplied by the percent of magnetite present by volume in the rock to obtain the magnetic susceptibility of the rock. The following table lists the calculated susceptibilities:

Magnetic Susceptibility of the Various Igneous Rock Types in the Area

Rock Type	Susceptibility
Undifferentiated purple rhyolites	(0.012 cgs)
Tile-red rhyolite	(0.003 cgs)
Undifferentiated basalts	(0.030 cgs)
Lower Blue School basalt	(0.045 cgs)
Blue School tuff	(0.009 cgs)
Upper Blue School basalt	(0.045 cgs)
Andesite	(0.012 cgs)

Except for the tile-red rhyolite and the andesite, these values are all higher than the maximum values given by Dobrin (p. 109) for the respective rock types. The value for the andesite is slightly below his average value of 0.0135 cgs for andesites; that for the tile-red rhyolite is the same as his average value for rhyolites.

On the aeromagnetic map of the Des Arc Quadrangle, the entire area of this report stands out as a magnetic plateau with individual highs rising above the plateau. This indicates that the area differs essentially from the rest of the quadrangle to the south and west. It apparently shows that the mapped area is covered by a relatively thin veneer of sediments over the Precambrian basement while most of the rest of the quadrangle has a heavy blanket of sediments penetrated only occasionally by Precambrian knobs.

Within the area, the aeromagnetic data generally correlate well with the calculated magnetic susceptibilities of the various rock types.

Igneous areas where the tile-red rhyolite is exposed show much smaller closures than the undifferentiated purple rhyolites or none at all. The basalt areas give more pronounced magnetic highs than do the purple rhyolite areas of similar elevation.

The major exception to this correlation is over sections 1, 2, 11, 12, and 13, T.32N., R.4E., and sections 6 and 7, T.32N., R.5E. Here topographically low rhyolite shows relatively high magnetic relief; while topographically high rhyolite actually shows a magnetic depression. Part of the difficulty may be in contouring. Evidence from the quadrangle map shows that control is lacking for the valley area in the center of the line between sections 11 and 12. The high through the area might just as well have been contoured so as to show two separate highs. Nevertheless, the problem of a magnetic high over relatively low rhyolite and vice versa remains.

Three possible explanations for this incongruity are offered: (1) an error was made in flight location; (2) the rhyolites beneath the magnetic high contain more magnetite than is assumed, and those that form the hill on the Iron-Madison county line contain less; or (3) a body of rock with higher magnetite content is contained within the rhyolite beneath the magnetic high. In support of the first possibility, the quadrangle map states that ten percent of its area had to be corrected for locational errors, though it does not specify where. However, the errors were termed minor; and it seems doubtful that errors of as much as a mile were involved. Further sampling and thin section study are needed to confirm or eliminate the second possibility. A ground magnetic survey or profile would check on the third.

The magnetic high in sec. 9, T.32N., R.4E., can be correlated with topographically high basalt that rises to an elevation of 1,466 feet off the map to the west of the area. The magnetic readings rise from a low of 2,250 gammas to 2,850 gammas within the area and to a high of 3,245 gammas about two miles to the northeast where a surface quartz-specularite vein has been worked (Hayes, 1951, p. 126). Maximum gradient over this anomaly within the mapped area is 600 gammas in 0.37 miles. This compares to a gradient of 2,725 gammas in 0.70 miles at the Pea Ridge anomaly, 335 gammas in 0.35 miles at the Vilander anomaly, and 1,095 gammas im 0.50 miles at the Kratz Spring anomaly (Searight, Williams, and Hendrix, 1954, pp. 12-13). Realization that the Sullivan-Bourbon area anomalies are due to a source buried beneath a thousand or more feet of non-susceptible sediments while the anomaly in section 9, T.32N., R.4E., of this report occurs over exposed basalt shows the latter anomaly to be an improbable indication of important iron ore. A ground magnetic survey or profile could help verify this conclusion.

Correlation of the aeromagnetic data with rock types indicates that a buried igneous hill, probably purple rhyolite, should be found beneath the residuum in the SE¼, sec. 4, T.31N., R.4E.; in the NE¼, sec. 29, T.32N., R.4E.; and in the SW corner, sec 2, T.31N., R.4E. However, the aeromagnetic data appear less sensitive in defining small buried Precambrian knobs than are the dips in the sedimentary rocks. Note that none of the buried hills indicated by the attitude of the sedimentary rocks (see "Buried hill structures") is defined by the aeromagnetic overlay. A ground magnetic survey might prove more sensitive in this respect than the aeromagnetic survey.

ECONOMIC POSSIBILITIES OF THE AREA

The Tom Sauk limestone as a source of agricultural lime, for use in cement manufacture, or as terrazzo is the most promising economic prospect in the area. Other possibilities include Precambrian iron ores and the possibility of lead in the Bonneterre formation.

Tom Sauk Limestone

The Tom Sauk limestone represents a potential source of agricultural lime to replace the dolomite now being quarried at the little town of Vulcan, about six miles south of the area, and at Piedmont in Wayne County. Limestone, with its relatively low content of magnesia, is superior as a source of lime to dolomite, which when pure contains 21.9 percent magnesia (Pettijohn, 1957, p. 418).

The Tom Sauk limestone occurs as two separate beds in the area. Each bed is about twenty feet thick and separated by some twenty feet of dolomite from the other. Both units could be quarried together with the interbedded dolomite. The resulting calcium oxide content would still be higher than the dolomite now mined. This would permit quarrying of a sixty foot interval of rock material.

Actual outcrop areas of Tom Sauk limestone are shown on the aeromagnetic overlay to Plate III. Likely localities for lime quarries include the small nose in the center, SE$\frac{1}{4}$, NW$\frac{1}{4}$, sec. 24, T.32N., R.4E., and along the south side of the hill to the west where the upper limestone crops out, attaining a thickness of about twenty-five feet; the predominantly limestone hill that runs north-south through the E$\frac{1}{2}$, sec. 18, T.32N., R.5E.; the SW corner, sec. 17, T.32N., R.5E., where a rock quarry was once started; the southwest bank of Marble Creek in the SW$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 19, T.32N., R.5E.; and the south bank of Marble Creek in the S$\frac{1}{2}$, sec. 20, T.32N., R.5E. A modest drilling program would probably reveal other possibilities.

Of the locations mentioned, the most favorable for a quarry appears to be the hill in the E$\frac{1}{2}$, sec. 18, T.32N., R.5E. A quarry 100 feet wide and averaging thirty feet deep along the west side of this hill would yield 923,000 tons of rock, figured at thirteen cubic feet per ton. The structural overlay to Plate III suggests that the hill sits in the center of a sedimentary trough. If this is true, the quarry strip could be made wider and a higher tonnage obtained.

Besides use as an agricultural lime, the Tom Sauk limestone might be used as a source of lime for manufacture of portland cement. To check on this possibility, twelve chemical analyses were obtained from the Missouri Geological Survey for samples of Tom Sauk limestone taken from various localities in Madison, Iron, and Reynolds Counties. Although no samples were taken from the area under discussion, they can probably be considered generally representative of the Tom Sauk limestone there.

Magnesia (MgO) varies in amount from 0.74 percent to 7.51 percent. Average for the twelve samples is 2.52 percent. Magnesia for a portland cement lime must be kept low since in the final product it cannot exceed five percent.

Lime (CaO) ranges from 45.24 to 54.64 percent and averages 50.89 percent. Ranges of other constituents that might be of interest in cement manufacture are given as follows: SiO_2, 0.79-3.58 percent; Al_2O_3, 0.85-3.25 percent; Fe_2O_3, 0.16-0.68 percent; P_2O_5, 0.006-0.021 percent, with one anomalous high of 0.064 percent; TiO_2, 0.08-0.24 percent; and MnO_2, 0.034-0.106 percent.

Dake (1930, p. 70) gives a single analysis of Tom Sauk limestone. It was probably taken from the area of this report since it was said to have been "on Marble Creek, in Iron County..." (ibid., p. 69). Though he states that it is from the S½, sec. 4, T.32N., R.4E., he must have meant the S½ of section 24 since the first location is not on Marble Creek. The analysis is as follows: CaO, 53.73 percent; MgO, 2.20 percent; SiO_2, 0.31 percent; Fe_2O_3, 0.17 percent; Al_2O_3, 0.95 percent; $(Na,K)_2O$, 0.14 percent; and loss on ignition, 43.19 percent.

Another possible use for the Tom Sauk limestone is for making terrazzo. The stone has beautiful colors and texture, and it takes a fine polish. If it were not for the numerous clay and calcite veinlets running through the rock, it could be used as commercial marble.

Among the chief obstacles to use of the limestone is lack of rail and good highway facilities. Though Highway E is blacktopped in Iron County and graveled in Madison County, it would not support much heavy traffic in its present condition. The Missouri Pacific Railroad has a line between Ironton and Annapolis. It might be feasible to run a branch line down Marble Creek valley to the limestone area, a distance of about eleven miles.

Besides transportation difficulties, use of the limestone in cement manufacture faces three other problems: (1) no large cement market is nearby; (2) the interbedded dolomite could not be used with the limestone (also true if it is to be used as terrazzo); and (3) no shale is available as a source for SiO_2 and Al_2O_3. The last problem might be solved by using alluvial clays from Marble Creek valley.

Other Economic Possibilities

Other economic possibilities in the area include the Blue School tuff as a possible low-grade iron ore, and the Bonneterre dolomite as a possible host for lead ores. Any iron ore body related to the magnetic high in section 9, T.32N., R.4E., is improbable since the high occurs over exposed basalt that has a magnetic susceptibility of 0.030 cgs. In addition, the basalt forms a topographic high. A ground survey or profile over the area would demonstrate whether the anomaly is due to a deep seated source or to the surface rocks.

Thin section study shows the Blue School tuff in the SW$\frac{1}{4}$, NW$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 14, T.32N., R.4E., consists of approximately twenty-eight percent iron. This percentage is estimated on the basis that the rock is thirty-seven percent hematite and three percent magnetite by volume. Calculated on a weight percentage, the iron content would be even higher since the other constituents present (calcite, plagioclase, and quartz) are relatively light.

The tuff appears to be about thirty feet thick and apparently underlies the whole hill. If it maintains the same iron content throughout, it could constitute a low grade iron ore. Very rough calculations based on inferred distribution suggest a maximum tonnage of about 5,000,000 tons, using ten cubic feet per ton. Detailed surface mapping and thorough sampling are needed to define the potential of the body and to determine if further work is justified.

Compact and spongy hematite float, pseudomorphic after pyrite is found in the streams at the base of the igneous knob in the E$\frac{1}{2}$, sec.

9, T.32N., R.4E. Such float was probably derived from filled sink structures so common in southeast Missouri. In these, pyrite and marcasite have been oxidized to hematite and limonite (Grawe, 1945, p. 189). These deposits are of little economic importance.

Lead ores occur in the Bonneterre formation throughout the St. Francois Mountains area, so the possibility exists that such bodies could be present in the mapped area. A local resident presented the writer with a galena pebble that allegedly came from the hillside in the NW$\frac{1}{4}$, SW$\frac{1}{4}$, NW$\frac{1}{4}$, sec. 23, T.32N., R.4E. However, the fact that zone 1 of the Bonneterre, the most favorable lead-bearing zone according to McQueen (1943, p. 8), is not exposed in the area makes it improbable that lead ore will be found there. Neither can the favorable Lamotte pinch-out zones be expected since the Lamotte is not present.

GEOLOGIC HISTORY AND SUMMARY

This brief summary of the geologic history of the area is presented as a review of the foregoing sections. The objective is to focus the reader's attention on the more important concepts presented.

The oldest rocks exposed in the area are Precambrian rhyolite flows. These appear to have come from the east. Later, rhyolite of slightly different composition, with a possible source area to the northwest, flowed across areas of low relief in the original rhyolites. More basic magmas then gave rise to basalts. Later, probably through a process of fractional crystallization, andesitic flows were extruded. This basic magma was evidently of the tholeiitic type (as defined by Turner and Verhoogen, 1951, pp. 176-177) since no olivine is present in the basalts and since the andesites contain much quartz in amygdules and connecting veinlets. Even the basalts contain some amygdaloidal quartz. The quartz was probably a late differentiation product of the tholeiitic magma, much of it trapped within the already crystallized rock, some of it probably segregated and free to move through openings in the rocks.

How much time elapsed between emplacement of the rhyolites and emplacement of the basalts is unknown, but it must have been considerable since the rhyolites appear to have been deeply eroded before the basalts were erupted. The latter are restricted to a low area in the rhyolites through central Marble Creek valley.

Numerous contraction joints formed in all the flows during cooling. Faulting, _i.e._, the King fault, occurred at some time, though when is uncertain. All that can be said positively is that it was post-early rhyolite. The same is true of the introduction of the quartz veins. Those in the lower Blue School basalt, however, can be dated as post-early basalt. Evidence for intense deformation of the extrusive igneous rocks was not observed in this area. Much work remains to be done on structural relationships in the Precambrian rocks.

A long period of terrestrial erosion and apparent stability followed extrusion of the andesites, though possibly not before other rocks, later removed, were extruded. During this period the Precambrian rocks were eroded essentially to the forms they show today. A drainage pattern with a general southwest trend developed. Slow inundation of the area by Upper Cambrian seas allowed deposition of the Bonneterre, Davis, Derby-Doerun, Eminence, and Potosi formations. The seas remained into Ordovician times that resulted in deposition of the Gasconade and Roubidoux formations. Whether later sediments were deposited in the area is purely speculative since no remnants of these are found.

During Bonneterre times, conditions favoring formation of limestone over dolomite prevailed locally for short periods of time, as evidenced by the presence of the Tom Sauk limestone beds. This assumes that the dolomite was syngenetic or was formed during early diagenesis. Favorable locations in this area appear to have been areas sheltered from the open Cambrian seas. Introduction of fresh waters from the land areas into such isolated embayments kept them fresher than the open sea and more favorable to limestone accumulation (Brightman, 1938, pp. 263-265). Near the felsite knobs, deposition of clastic materials produced the arkosic sandstone and conglomerate facies in the Light Gray dolomite member. After deposition, differential compaction increased the original dip of the sediments and caused joints to form.

Using purely deductive reasoning, the long time span between Roubidoux deposition and the present, some 360 million years, would seem to necessitate deposition of later rock units than the Roubidoux. If the area were uplifted immediately following the deposition of the Roubidoux formation, surely 360 million years of erosion would have reduced the area below its present-day surface and removed all the sediments. If, on the other hand, uplift did not take place , further accumulation of sediments should be expected. From this, two possible conclusions can be drawn: Either further accumulation took place, or the sea remained so near the land surface that neither substantial erosion nor accumulation took place. Of course, further accumulation of sediments would not eliminate the possibility of there being periods of erosion other than the present. At any rate during some period after Roubidoux deposition, uplift occurred and the formations overlying the Bonneterre were eroded and removed. A heavy residuum formed over much of the land, and present-day topography expressed itself.

Tectonically, the area has been relatively stable throughout geologic times.

CONCLUSIONS

The numerous conclusions drawn during the course of this study are presented in the general order in which they occur in the foregoing sections. The chief objectives of this investigation have been realized with the exceptions that the purple rhyolites and some of the basalts have not been subdivided and the Precambrian rocks have not been correlated. A more comprehensive study that would include the Precambrian rocks of the St. Francois Mountains area altogether is needed to make such a correlation properly. Other conclusions not originally contemplated, such as correlation of the igneous rock types with aeromagnetic data, have been realized.

Earliest rocks exposed in the area are the Precambrian rhyolites. Two varieties are recognized in the field: tile-red rhyolite porphyry and purple rhyolite porphyry. Next in age are the diabase dike in section 35, T.32N., R.4E., and the basalts. At least two basalt flows are present as indicated by the Blue School basalts which enclose a tuff. The same magma that produced the basalts, probably later gave rise to an andesite through a process of fractional crystallization.

Both varieties of rhyolite form very fine, extensive outcrops while the basalts and andesite produce very poor, small outcrops. This indicates that the rhyolites are much more resistant to weathering and erosion.

The many small northeast trending quartz veins found in the Precambrian rhyolites are probably all part of the same system and are post-rhyolite. They may be related to the Silver Mine area veins, but the latter have an east-west trend and contain metalliferous values. The veins within the area do not show such mineralization.

The Bonneterre formation is the only Paleozoic rock unit exposed in the area. Younger formations have all been removed by erosion, and the older Lamotte sandstone was never deposited. Three members of the Bonneterre are recognized. These are correlated with zones 2, 3, and 4 proposed by McQueen and Stewart for the Bonneterre of the Fredericktown area. Their zone 1, the most favorable for lead ore, is not exposed in the area and probably was never deposited.

The Light Gray dolomite member, correlated with zone 3 of McQueen and Stewart, contains interbedded Tom Sauk limestone and arkosic sandstone and conglomerate facies. Two distinct units of Tom Sauk limestone separated by dolomite are recognized. These beds formed in sheltered areas of the Cambrian sea. The arkosic facies were formed from clastic materials derived from the Precambrian rocks.

Channel-like structures beside Highway E in section 15, T.32N., R.4E., need further investigation to determine their origin. It is suggested they may be sand bars formed at subsequently higher levels on the sea floor or beach structures formed beside a rising sea.

Residual materials covering most of the upland areas have been derived from the Davis, Derby-Doerun, Potosi, Eminence, Gasconade, and Roubidoux formations.

Precambrian structure consists in gently dipping flows, primary flow structures, joints, a diabase intrusion, a fault, and a local flexure or tilted fault block. More work is required to resolve the flow structures in the rhyolites. Most of the joints in the Precambrian rocks probably resulted from contraction of the rocks during cooling. Faults other than King fault possibly occur in the rhyolites but have gone undetected due to the lithologic similarities of the various rhyolite flows.

Chief structures in the Bonneterre formation are initial dip and differential compaction joints. Buried Precambrian knobs are indicated by the dips in the overlying sedimentary rocks.

For the most part aeromagnetic data correlate well with the rock types in the area. The major exception is data for sections 1, 2, 11, 12, and 13, T.32N., R.4E. This may be explained as due to locational errors, to major changes in rock susceptibilities, or to the presence of a buried body of higher magnetite content than the surrounding rock. No buried iron ores are indicated by the magnetic data.

The aeromagnetic data are not sensitive to the presence of small buried Precambrian hills despite their general correlation with the igneous rock types. A ground survey might prove more sensitive in this respect.

The aeromagnetic map for the whole Des Arc Quadrangle shows the mapped area to be a magnetic plateau and suggests that it differs essentially from the rest of the quadrangle.

The Tom Sauk limestone is the best economic mineral prospect in the area. It might be used for agricultural lime, manufacture of portland cement, or terrazzo if transportation and other problems could be solved.

There is some possibility that the Blue-School iron-bearing tuff might prove to be a small, low grade iron ore. More surface work and sampling are necessary to check this possibility. Tonnage estimates for the known exposures do not exceed 5,000,000 tons and are not encouraging.

Evidence for lead ores in the Bonneterre formation is discouraging, especially since the most favorable lead-bearing zone, zone 1 of McQueen and Stewart, is not exposed in the area and was probably not deposited.

APPENDIX:

THIN SECTION STUDY

OF

REPRESENTATIVE IGNEOUS ROCKS

SAMPLE NUMBER: 1129A-13-1 (Tile-red rhyolite porphyry).

LOCATION: Leatherwood Creek shut-in, NE$\frac{1}{4}$,NE$\frac{1}{4}$, NE$\frac{1}{4}$, sec., T.31N., R.4E., Iron County, Missouri.

AGE: Precambrian.

HAND SPECIMEN DESCRIPTION

Rock is uniformly tile-red in color and contains 5 to 6 percent feldspar phenocrysts that range from microscopic to 2 mm. across. The rock breaks with a smooth, conchoidal fracture. No grain orientation or flow structures are visible.

THIN SECTION DESCRIPTION

Textural Characteristics

Grain sizes range from submicroscopic in the matrix to 1.8 mm. by 0.9 mm. Euhedral to anhedral phenocrysts from 0.1 mm. up comprize about 7 percent of the slide. No preferred orientation is shown. Many spherulite structures are present in the matrix.

Mineralogy

Potash feldspar: Potash feldspar makes up about 63 percent of the rock. Three percent is in anhedral to euhedral perthite phenocrysts. Two percent of the slide is albite in the perthites. The perthite phenocrysts range in size from 0.1 mm. long to 1.8 by 0.9 mm.; average size is about 0.9 by 0.4 mm. The potash feldspar in the matrix was determined by staining techniques. Much of it occurs in spherulites.

Plagioclase: Plagioclase phenocrysts (Ab_{67}) comprize about 1 percent of the rock. Average size is about 0.9 mm. by 0.4 mm. More plagioclase is present in the matrix.

Quartz: A single equant, 0.1 mm. phenocryst of cryptocrystalline quartz is present in the slide. More quartz is probably present in the matrix.

Matrix: The matrix comprizes about 93 percent of the slide. Sixty percent consists in potash feldspar, and the remainder is very fine grained quartz and plagioclase. The fine texture of the matrix prevents distinction between the quartz and plagioclase.

CLASSIFICATION

On the basis of this thin section study, the rock is classified as a rhyolite porphyry according to the classification of Pirsson and Knopf.

SAMPLE NUMBER: 1129A-26-1 (Blue School tuff).

LOCATION: Hillside east of Blue School, in the SW¼, NW¼, SW¼, sec. 14, T.32N., R.4E., Iron County, Missorui.

AGE: Precambrian.

HAND SPECIMEN DESCRIPTION

Rock is dull, dark purple with elongated, reddish purple patches parallel to one another. The rock surface is speckled with small patches of white calcite which react vigorously with dilute hydrochloric acid. Alternating bands of dark purple and reddish purple are evident on the rock surface. The calcite patches are also elongated parallel to the purple bands.

THIN SECTION DESCRIPTION

Textural Characteristics

Most obvious textural characteristic is an alternating of bands about 0.5 mm. wide, of predominantly calcite, hematite, and matrix, respectively. None of the bands consist exclusively of one material, however. Hematite and matrix surround rounded calcite grains up to 0.4 mm. long in the predominantly calcite zones. Hematite forms a network of tiny veinlets through the zones that are predominantly matrix, and calcite occurs in scattered grains. Likewise, the predominantly hematite zones contain grains of both matrix and calcite.

Mineralogy

Hematite: Hematite comprizes about 37 percent of the section by volume. It occurs in bands, in a veinlet network in the matrix, and interstitial to the calcite grains.

Calcite: Another 35 percent of the section consists of calcite in rounded, egg-shaped grains ranging from less than 0.01 mm. to 0.4 mm. long. Average size is about 0.2 mm.

Matrix: The matrix, comprising some 20 percent of the rock, consists in very fine grained plagioclase laths less than 0.01 mm. long in a pyroxene groundmass. (A single plagioclase grain 0.1 mm. long was observed.) Alone, the matrix has the mineralogy of a basalt, but it is finer grained than the other basalts in the area. It contains numerous round to tear-drop shaped fragments of like texture and mineralogy. These fragments range from less than 0.01 mm. to 0.08 mm. in length.

Quartz: About 5 percent of the rock consists of equant grains of quartz in the matrix. These grains average about 0.05 mm. across.

Magnetite: About 3 percent of the section is magnetite associated in stringers and equant, anhedral grains with the hematite.

CLASSIFICATION

On the basis of the rounded and tear-drop shaped fragments found in the matrix, of the fine texture of the matrix, and of the apparent layering in the rock as a whole, this rock is classified as a tuff, though it has some characteristics of a welded tuff of unusually basic composition. The shape of the fragments suggests particles blown into the air, and the very fine texture in the fragments suggests rapid cooling that would result from such an origin. The hematite and calcite may be secondary replacements of the original basaltic tuff, which was probably more porous than the overlying and underlying basalts. Further work is needed to verify replacement as the mode of origin for these minerals.

SAMPLE NUMBER: 1129A-26-3 (Dacite-Andesite).

LOCATION: Hilltop east of Blue School, in the $NW\frac{1}{4}$, $NE\frac{1}{4}$, sec. 14, T.32N., R.4E.

AGE: Precambrian.

HAND SPECIMEN DESCRIPTION

Rock is very dark purple with white quartz-filled amygdules and plagioclase phenocrysts. Green patches of chlorite are associated with the amygdaloidal quartz. Lineation and grain orientation are absent. The quartz in the amygdules constitutes about 25 percent of the rock. Chlorite constitutes 4 to 5 percent, and plagioclase phenocrysts an additional 5 percent. The rest of the rock is too fine grained to determine the individual constituents. Largest amygdule is 11 mm. long; the smallest is just visible. Plagioclase phenocrysts range from microscopic to 1.5 mm. long. Average size is about 0.7 mm. Chlorite patches range up to 2.5 mm., average about 1.5 mm.

THIN SECTION DESCRIPTION

Textural Characteristics

Grain sizes range from submicroscopic in the matrix to euhedral plagioclase phenocrysts 1.5 mm. by 0.8 mm. No preferred orientation is evident. Contains network of quartz veinlets connecting quartz-filled amygdules.

Mineralogy

Plagioclase: Thirty-seven percent (17 percent in phenocrysts, 20 percent in the matrix) of the rock consists of plagioclase (Ab_{66}). If the amygdaloidal and veinlet quartz is discounted, the rock is fifty percent plagioclase. Phenocrysts are euhedral to subhedral and show albite, carlsbad, and pericline twinning. Largest phenocrysts are 0.8 mm. by 1.5 mm. Average size is about 0.6 mm. by 0.3 mm. Andesine in the matrix consists of numerous thin laths ranging from submicroscopic to 0.2 mm. long separated by interstitial potash feldspar.

Potash feldspar: Potash feldspar comprises 18 percent of the slide or, discounting the quartz, 24 percent. It all occurs in the matrix, interstitial between the plagioclase laths.

Quartz: Cryptocrystalline quartz in a network of veinlets and rounded amygdules constitutes about 35 percent of the section. Largest amygdule present is 2.9 mm. by 5.2 mm. Veinlets range from less than 0.1 mm. to 2.2 mm. wide. In places sharp-angled microscopic breccia is interlaced by quartz veinlets. Veinlets sometimes cut andesine phenocrysts.

Magnetite: Two percent of the rock consists of equant magnetite phenocrysts with an additional 2 percent in the matrix.

Chlorite: Chlorite comprises about 5 percent of the slide. It is associated in the amygdules with the quartz.

Calcite: Calcite is also associated with the quartz, but not with the chlorite. It comprises about 2 percent of the slide.

CLASSIFICATION

On the basis of this thin section study, the rock is classified as an andesite according to the classification of Pirsson and Knopf. This assumes that the quartz is not an integral part of the rock. If the quartz is considered a part of the rock, it is a dacite.

SAMPLE NUMBER: 1129A-27 (Lower Blue School basalt).

LOCATION: West of Highway E, in the SW$\frac{1}{4}$, NE$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 15, T.32N., R.4E., Iron County, Missouri.

AGE: Precambrian.

HAND SPECIMEN DESCRIPTION

Rock is grayish black and vesicular and so fine grained as to obscure all the minerals present. Vesicles range from less than 1 mm. to 4 mm. and average about 1.5 mm. across. Density of the vesicles is about one per square inch. The rock breaks with a slaty appearance with many parallel surfaces 2 to 5 mm. apart. Occasional vesicles are filled with quartz.

THIN SECTION DESCRIPTION

Textural Characteristics

Section is exceptionally uniform in texture. Rare plagioclase phenocrysts 0.2 mm. in length are present. Most of the rock consists of plagioclase laths less than 0.1 mm. long with interstitial augite. Texture is ophitic.

Mineralogy

Plagioclase: Sixty percent of the section consists of plagioclase laths with an average length of 0.08 mm. The albite-anorthite content was not determined due to the difficulty of finding properly oriented crystals sufficinetly large to measure extinction angles. Laths are subhedral to euhedral.

Augite: Interstitial augite comprises about 25 percent of the section. It is mostly anhedral, rarely subhedral. Individual grains average about 0.01 mm. across.

Magnetite: The section contains about 15 percent magnetite in equant, anhedral grains that average about 0.01 mm. across.

Hornblende: Rare grains of hornblende were observed. These were all less than 0.005 mm. long.

CLASSIFICATION

This rock is classified as a basalt according to Pirsson and Knopf's classification.

SAMPLE NUMBER: 1129A-35 (Purple rhyolite porphyry).

LOCATION: Streambed north of road in the center, NW¼, SW¼, sec. 35, T.32N., R.4E., Iron County, Missouri.

AGE: Precambrian.

HAND SPECIMEN DESCRIPTION

Rock is purple, porphyritic, non-porous. Phenocrysts are potash and plagioclase feldspars, quartz, and magnetite. The feldspars are both pink and gray and constitute some 30 percent of the rock. They range in size from microscopic to 3 mm. long. Quartz phenocrysts form 7 to 8 percent of the rock and range in size up to 2 mm. Magnetite phenocrysts constitute between 4 and 5 percent of the rock and range from microscopic to 2 mm. No grain orientation or flow structures are visible.

THIN SECTION DESCRIPTION

Textural Characteristics

Grain sizes range from submicroscopic in the groundmass to phenocrysts 4.1 mm. by 2.9 mm. The phenocrysts show no preferred orientation or association. They range from euhedral feldspar laths to anhedral quartz and magnetite, all embedded in the very fine matrix.

Mineralogy

Plagioclase: Plagioclase phenocrysts (Ab_{62}) form about 20 percent of the rock. They are in the shape of euhedral to subhedral laths ranging in size from 0.1 mm. long to 2.9 mm. by 4.1 mm. Average size is approximately 2.3 mm. by 0.9 mm. An additional 15 percent of the rock consists of plagioclase laths in the matrix.

Potash feldspars: Potash feldspar occurs mainly in perthite phenocrysts with albite and in the matrix. It constitutes some 43 percent of the section. Minor orthoclase phenocrysts are present. The matrix is about 30 percent potash feldspar. The perthite phenocrysts make up 13 percent of the section and are about 38 percent albite. They range in size from 0.1 mm. by 0.05 mm. to 1.2 mm. by 2.6 mm.

Quartz: Quartz occurs in anhedral phenocrysts that range from less than 0.1 mm. to 1.2 mm. by 0.6 mm. across and constitute some 12 percent of the rock. Another 4 percent quartz occurs in the matrix.

Magnetite: Anhedral magnetite makes up about 5 percent of the section. Four percent is in anhedral, equant phenocrysts that range from less than 0.1 mm. to 1.8 mm. across.

Calcite: About 1 percent of the section consists of calcite which partially replaces both plagioclase and perthite phenocrysts.

CLASSIFICATION

On the basis of this thin section study, the rock is classified as a rhyolite porphyry after the classification of Pirsson and Knopf.

BIBLIOGRAPHY

BIBLIOGRAPHY

Brightman, George F., 1938. The Tom Sauk Limestone Member of the Bonneterre Formation in Missouri: Journal of Geology, Vol. 46, pp. 248-267.

Dake, C. L., 1930. The Geology of the Potosi and Edgehill Quadrangles: Missouri Bureau of Geology and Mines, 2d ser., Vol. 23.

Dobrin, Milton B., 1952. Introduction to Geophysical Prospecting: New York, McGraw-Hill.

Grawe, Oliver R., 1945. Pyrites Deposits of Missouri: Missouri Geologic Survey and Water Resources, Vol. 30.

Hayes, William C., Jr., 1951. Precambrian Iron Deposits of Missouri: Unpublished Doctor's dissertation, The State University of Iowa, Iowa City.

Herbst, E. L., 1952. The Geology of the Northwest Portion of the Des Arc Quadrangle: Unpublished Master's thesis, The University of Missouri, Columbia.

James, J. A., 1951. The Relationship of Regional Structural Geology of Ore Deposits in the Southeast Missouri Mining District: Unpublished Doctor's dissertation, The University of Missouri School of Mines and Metallurgy, Rolla.

McQueen, H. S., 1943. Occurrence of Dolomite in the Fredericktown Area, Madison County, Missouri: Appendix II, 62d Biennial Report, Missouri Geological Survey and Water Resources.

National Research Council, 1948. Rock Color Chart: Prepared by the Rock-Color Chart Committee representing the United States Geological Survey, the Geological Society of America, The American Association of Petroleum Geologists, the Society of Economic Geologists, and the Association of American State Geologists and distributed by the National Research Council, Washington, D. C.

Pettijohn, F. J., 1957. Sedimentary Rocks: Second edition, New York, Harper & Brothers.

Pirsson, Louis V., and Knopf, Adolph, 1955. Rocks and Rock Minerals: Third edition, New York, Wiley.

Robertson, Forbes., 1949. Areal Geology of the Precambrian Rocks of Missouri: Unpublished manuscript and map, The Missouri Geological Survey and Water Resources, Rolla.

Searight, Thomas K., Williams, James H., and Hendrix, James S., 1954. The Structure and Magnetic Surveys of the Sullivan-Bourbon Area, Missouri: Report of Investigations No. 16, Missouri Geological Survey and Water Resources, Rolla.

Stevens, Robert P., 1958. Paragenesis of the Minerals in the Einstein Vein, Madison County, Missouri: Unpublished Master's thesis, The University of Missouri School of Mines and Metallurgy, Rolla.

Stewart, D. R., 1944. Criteria for Identifying Formations Exposed in Southeastern Missouri: Unpublished paper, the Missouri Geological Survey and Water Resources, Rolla.

Turner, Francis J., and Verhoogen, Jean, 1951. Igneous and Metamorphic Petrology: New York, McGraw-Hill.

United States Geological Survey, 1949. Total Intensity Aeromagnetic Map of Des Arc Quadrangle, Missouri: Map prepared by the United States Geological Survey in cooperation with the Missouri Geological Survey and Water Resources.

Zimmerman, Richard, 1959. Geology of the Annapolis Area, Iron County, Missouri: Unpublished Master's thesis, The Missouri University School of Mines and Metallurgy, Rolla.

VITA

Wesley Dean Weixelman was born to Mr. and Mrs. Clarence Peter Weixelman on the 29th of April, 1933, in Manhattan, Kansas. There he attended public and parochial schools and graduated from Sacred Heart Academy in 1951. He attended Kansas State College until spring of 1953, when he was drafted into the army. Most of his service time was spent with the Korean Military Advisory Group in Taegu, Korea, where he served with the G-1 Advisory Office to the Korean Army first as a clerk typist and later, after promotion to sergeant (E-5), as office administrator. He was honorably released from the army in April, 1955, and was readmitted to Kansas State College in the fall of that year. The College granted him a Bachelor of Science degree (geology major) in the spring of 1957. He entered the Missouri School of Mines and Metallurgy in September of that year to begin work towards a Master of Science degree. He is now Company Geologist for the Missouri Portland Cement Company of St. Louis, Missouri.