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Detection of buried basement highs by airphoto drainage pattern analysis, Reynolds and Wayne counties, Missouri

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DETECTION OF BURIED BASEMENT HIGHS BY AIRPHOTO DRAINAGE PATTERN ANALYSIS, REYNOLDS AND WAYNE COUNTIES, MISSOURI

BY

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A

THESIS

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INTRODUCTION

Purpose and Scope

The purpose of this study is to determine if it is possible to detect buried Precambrian igneous hills in Wayne County and the larger part of Reynolds County in southeast Missouri by the use of aerial photo drainage pattern analysis.

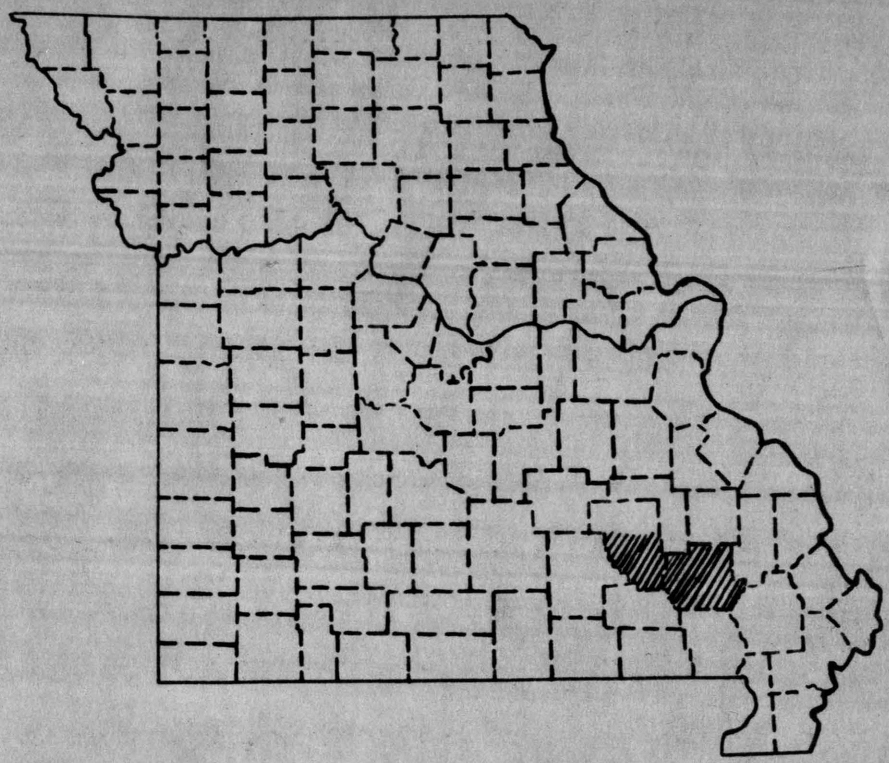
The St. Francis Mountains are located in southeast Missouri. They form a part of the Precambrian basement complex, and have been exposed at the surface by the erosion of the lower Paleozoic sediments which covered them. Some of the hills which make up the St. Francis Mountains are exposed to a great degree, while others still have their greater bulk concealed by the sediments. It would be expected that there are hills still completely buried under the sediments. To detect those buried hills in the above stated manner, Wayne and Reynolds counties (Plate IA) are chosen because they lie just south and southwest of the St. Francis Mountains and are expected to include buried basement topographic highs.

Detection of basement structural highs is generally of economic value since ore deposits (Ohle and Brown, editors, 1954) and petroleum are often associated with such features.

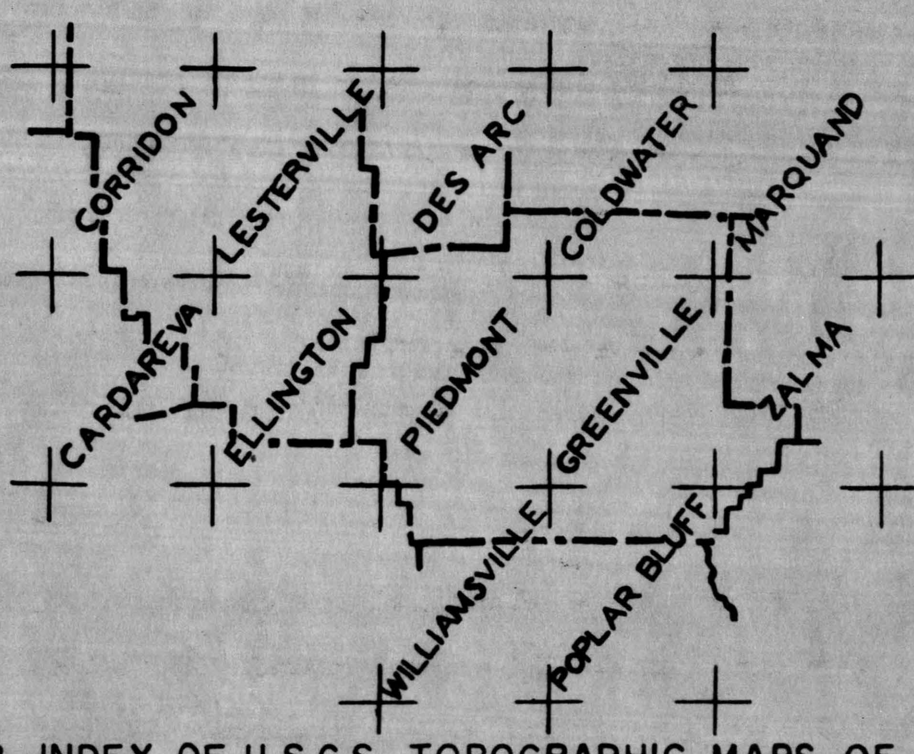
Acknowledgments

The author wishes to express his appreciation to the faculty of the geology department of Missouri School of Mines and Metallurgy, and to the personnel of the Missouri Geological Survey whose help and

PLATE I



A. MAP OF MISSOURI SHOWING LOCATION OF STUDY AREA



B. INDEX OF U.S.G.S. TOPOGRAPHIC MAPS OF STUDY AREA

advice made the completion of this thesis possible. Professor J. C. Maxwell directed the research for this thesis. Professor R. A. Black assisted in the magnetic investigation of the thesis areas. Professor A. C. Spreng aided on various parts of the study and visited the thesis areas. The Missouri Geological Survey aided financially with the field expenses, and Dr. T. R. Beveridge, State Geologist, made available well log data, and unpublished manuscripts. Mr. E. H. Woolrych of the Missouri Geological Survey assisted with the illustrations.

Review of Literature

Review of literature failed to reveal any published information concerning detection of buried basement highs by surface drainage analysis from aerial photos. This lack of published information cannot be attributed to the newness of this idea in the field of geology. It is almost certain that oil and mining companies are using drainage pattern analysis to detect topographic highs of the basement complex.

A number of articles on photogeology (Rea, 1941; De Blieux, 1949; 1951; Tator, 1954) discuss detection of salt domes by drainage anomalies in the Gulf Coast region. The main themes of these articles do not concern buried igneous hills, but their discussions involve the same principles followed in this report.

Other articles (Dake and Brown, 1925, pp. 130, 131, 133; Bernitz, 1932) discuss drainage patterns from the geomorphological point of view. The ideas expressed in these articles make up part of the discussion under "Drainage Pattern Analysis" in pages 16 to 41 of this report.

Present Work

The major part of the work on this problem was carried on during the summer and fall of 1957. The aerial photos used and their index mosaics were prepared by Aero Exploration Company, of Tulsa, Oklahoma. The index mosaics were grouped according to individual counties. A pocket lens-stereoscope and a mirror stereoscope with magnifying binocular attachment were employed for the aerial photo examination. An Askania Schmidt type, temperature-compensented, vertical component magnetometer, was used for the field work.

GEOGRAPHY

Location and Size

The thesis area is located in southeast Missouri south of the St. Francis Mountains (Plate IA). Its southernmost limit is about 30 miles north of the Arkansas-Missouri State line, and extreme eastern limit about 41 miles west of the Mississippi River.

Wayne County includes an area of 740 square miles approximately. Its maximum dimensions are bounded by parallels 36° 56' and 37° 19' north latitude, and meridians 90° 07' and 91° 47' west longitude.

Reynolds County bounds the westernmost edge of Wayne County. The northern portion of Reynolds County is not included in the thesis area. The southern part, which is included in this report, is about 523 square miles in area and is bounded at its maximum dimensions by parallels 37° 03' and 37° 27' north latitude, and by meridians 90° 44' and 91° 13' west longitude. It should be understood that when Reynolds County is mentioned in the rest of the thesis only its southern part is referred to and not the whole county.

Plate 1B illustrates the 15-minute series of U.S. Geological Survey topographic maps that cover the thesis area.

Culture (Plate II)

The major towns in Wayne County are, Piedmont (1548)[1], Williamsville

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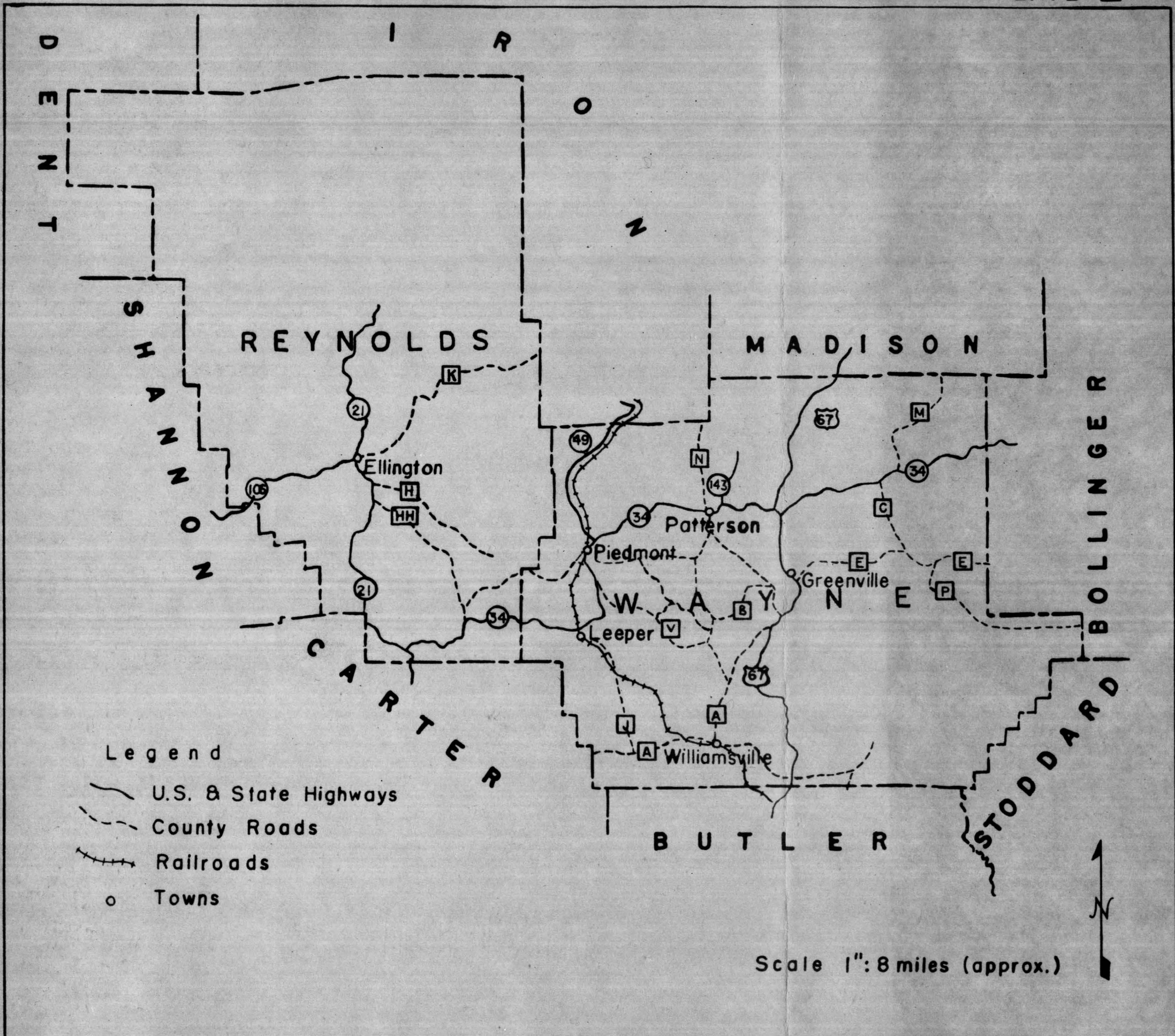
[1] Number after the town's name refers to its population according to Missouri State Highway map, 1957.

PLATE II



MAIN TOWNS AND ROADS OF WAYNE AND REYNOLDS COUNTIES

(492), Greenville, county seat, (270), Leeper (250), and Patterson (123). Greenville has been moved since the Wappapello Reservoir was built in 1941. It previously occupied the floodplain of the St. Francis River along section line 12 and 13, T. 28 N., R. 5 E., as shown in the Greenville quadrangle topographic map. Now it is located along U.S. Highway 67, 1.8 miles north of its previous location.

The major towns of Reynolds County are: Ellington (777), Centerville, county seat, (250), Bunker (250), Black (130), and Lesterville, (116). Of these, only Ellington is located within the thesis area.

The rest of the towns in the two counties have populations less than 100, and are regarded mainly as farming communities.

The major occupation of the natives is farming, followed by the lumber industry and mining. Farms are almost universally located on the broad floodplains of large streams. The tree-covered ridges and uplands are the sources of the timber. Iron ore mining is not as economically important an industry as the lumbering, but is being carried out in some parts of the two counties.

Several major highways cross the two counties, and are supplemented by "black-top" and graded gravel-surfaced county roads. The road conditions as shown by the topographic maps have changed considerably. New county and gravel roads have been constructed and roads shown as poor and unimproved on the topographic maps, have been improved to the level of county roads. However, some roads that are represented on the map as good gravel roads have been abandoned and are now inaccessible except with a jeep or on foot.

Of tremendous value in establishing magnetic traverses were the timber trails which had been used to haul cut timber over ridge tops and were abandoned after they were no longer needed. Some of those trails are still in good condition, but there are also some which could scarcely be followed because of vegetation growth since their abandonment. The best way to locate these timber trails is to detect them on aerial photos and plot their courses on the corresponding topographic maps.

Two reservoirs (Wappapello and Clearwater) have been constructed within the boundaries of the two counties by the U.S. Army Corps of Engineers for purposes of flood control, Wappapello Reservoir was built in 1941, and is located in southeast Wayne County. A dam across St. Francis River in the extreme southeast part of the county and just north of the Butler-Wayne County line controls floodwater from the St. Francis River system north of the dam. Clearwater Reservoir was built in 1948, and is located in the western part of Reynolds County. A dam across Black River along the Reynolds-Wayne County line controls the floodwater of the Black River drainage system north of it. The two reservoirs also provide camping and fishing facilities, and thus serve as recreational areas for tourists.

PHYSIOGRAPHY

Regional Setting and Topography

Wayne County is on the southern flank of the Ozark Dome, immediately south of the St. Francis Mountains. In the northwest part of the county granite and prophyry hills of the St. Francis Mountains province rise above the inter-montane valleys. The southeast border of Wayne County lies within the lowlands which form a marginal strip one to two miles wide within the county boundaries. The upland between the granite hills on the north and the lowlands on the south is maturely dissected, and rugged. The average relief of the upland is estimated at 200 feet. Some small areas of the upland consist of flatwoods[1] while other parts consist of the wide floodplains of the master streams of the St. Francis River system.

Reynolds County (including the part of the county north of the thesis area) lies near the crest of the Ozark Dome. Its northeast and eastern margins are included in the St. Francis Mountain province, and possess a rugged topography. The northwestern part extends into the Salem Plateau. The rest of the county (thesis area included) is maturely dissected, of rugged topography, and is characterized by wide floodplains of the Black River and its large tributaries. The general slope of the surface is southeastward.

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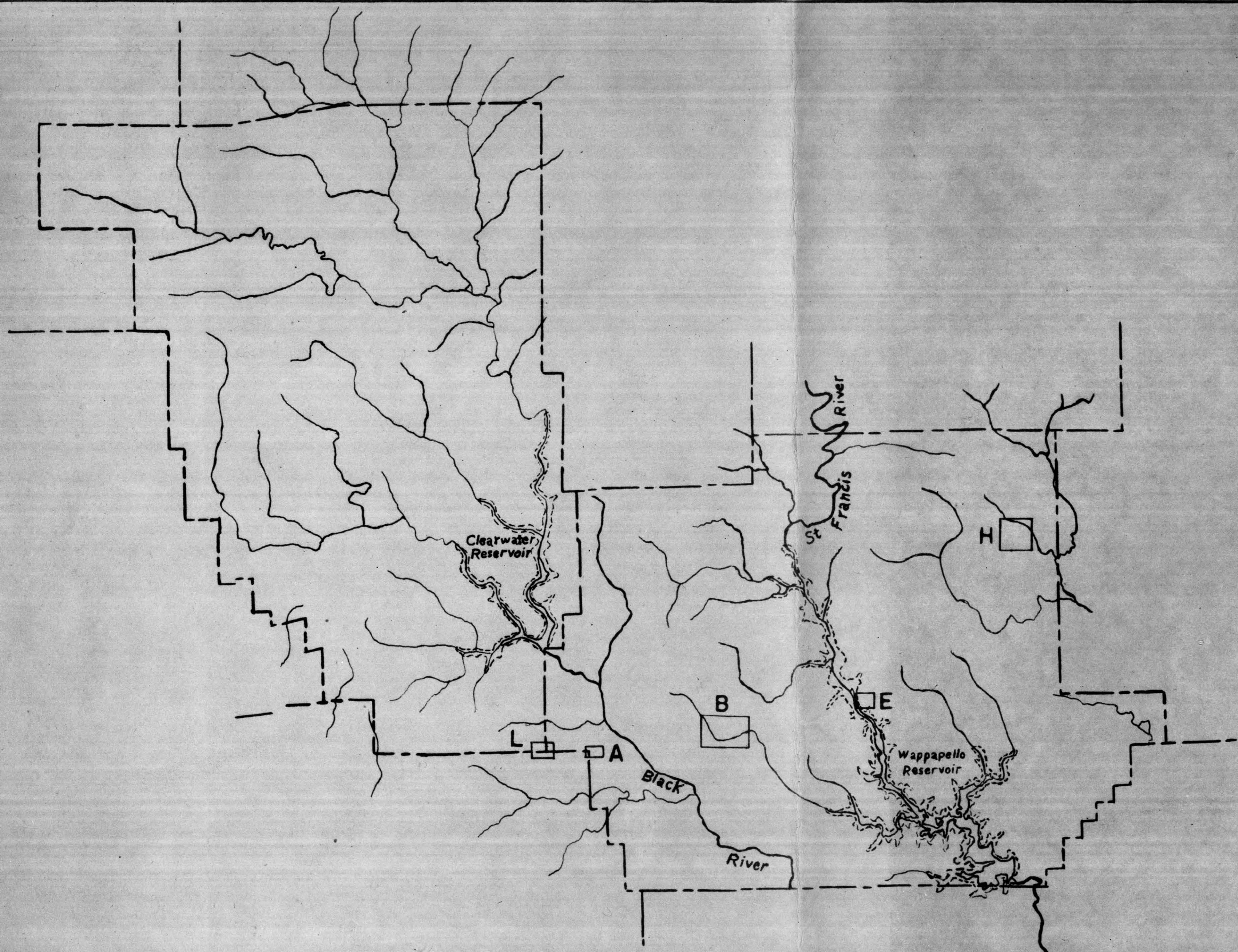
[1] Large areas of uncut, tree covered upland whose essential characteristic is a lack of definite channels, (Fenneman, N. M., 1938, p. 639).

Drainage (Plate III)

All of Wayne County is located in the St. Francis River drainage basin except the southeastern part which is drained by Black River, and a small area in the northeast drained by Bear Creek, a tributary of Caster River. Both the St. Francis and Black Rivers including their tributaries have southeasterly courses.

The Black River drainage system drains all of Reynolds County. The Black River follows a southerly course along the eastern margin of the county. The tributary streams follow easterly to southeasterly courses from the western edge of the county to the master streams.

PLATE III



GENERAL DRAINAGE OF WAYNE AND REYNOLDS COUNTIES, AND LOCATION OF ANOMALOUS AREAS INVESTIGATED IN THE FIELD

GEOLOGIC HISTORY

The geologic history of the region parallels that of the St. Francis Mountains and neighboring areas. It is discussed in detail by Dake (1930) and Bridge (1930) in their reports on the Potosi-Edgehill quadrangles and Eminence-Cardareva quadrangles respectively. Wayne and Reynolds Counties are in such proximity to the above mentioned quadrangles that most of the events in the geologic history of those areas are coincident or at least very intimately interrelated. A resume of the past events as discussed by the above authors is presented here.

In Upper Cambrian time the sea advanced over the Precambrian rhyolite porphyry which had been intruded by granites and cut by basic dikes. The Precambrian rocks at that time had been subjected to a long period of erosion and had a relief of approximately 1500-2000 feet in the St. Francis Mountains and Eminence areas. The advance of the sea caused deposition of the Lamotte formation. The bulk of the Lamotte formation seems to have been transported from remote sources, although locally it is composed of partly reworked arkosic detritus derived from the local Precambrian landmass. Following the Lamotte, dolomites of the Bonneterre formation were deposited. Next came the Davis formation which is made up of interbedded limestone and shale. Deposition of the Davis formation was followed by the dolomites of the Derby-Doerun formations.

During the deposition of the above beds the whole area was completely submerged except perhaps for a few high igneous peaks projecting above the water. The deposited beds occupied the submerged valleys and depressions between the igneous hills and overlapped against the hills.

The deposition of the Derby-Doerun formations was interrupted by a period of uplift which brought the higher portions of the Ozarks above the water and subjected the newly formed strata to erosion.

The area was submerged again to allow the thick-bedded dolomites of the Potosi formation to be deposited on the surface of the older eroded beds. The Potosi formation was followed by the dolomites of the Eminence formation without any significant interruptions. Deposition of the Eminence formation came to an end during a gradual uplift of the area which marked the dividing line between Cambrian and Ordovician periods.

After an emergence of considerable duration the Ordovician seas encroached over the eroded region depositing the dolomites of the Gasconade formation with the Gunter sandstone member at its base. By the end of the Gasconade deposition the high relief of the St. Francis Mountain area and surrounding region was reduced to a gently undulating surface. The deposited sediments filled the depressions between the Precambrian hills and smoothed out the irregularities caused by previous erosion. Only a few of the highest Precambrian peaks were still uncovered when deposition of the Gasconade came to an end as the result of an uplift. After an emergence of short duration the area was submerged again to be covered by alternating beds of sandstone and limestone of the Roubidoux formation. Next, there were two slight emergences and submergences causing deposition of the dolomites of the Jefferson City formation and the sandstones and limestones of the Cotter formation respectively.

The depositional record after the Cotter is very meager. The remainder of the Ordovician, Silurian, and Devonian periods is not represented; but this does not necessarily mean the region was a landmass during those times since adjacent areas record several marine invasions.

At the beginning of the Mississippian period the area of this report was a low landmass which was gradually submerged reaching its maximum submergence during the Osage epoch. Erosion following uplift at the end of Osage time completely stripped off the newly deposited Mississippian beds except for a few scattered patches of silicified residual boulders.

During early Pennsylvanian time the area became a peneplained surface which suffered repeated submergences and emergences. A final uplift in early Pennsylvanian time brought the area above the sea, and to the best of knowledge it has never been re-submerged.

The region has undergone continuous erosion since Pennsylvanian times. It has been peneplained during Tertiary times, possibly as late as the Pliocene, and has undergone several uplifts since then.

The Pleistocene glaciation which affected northern Missouri did not reach as far south as the area of this study.

At present the formations outcropping over most of the area of study are the Roubidoux, Gasconade, and Eminence formations. The

Roubidoux formation underlies the uplands, the flatwoods[1], and caps most of the ridge tops. Gasconade and Eminence formations occupy the hill slopes under the Roubidoux formation and make up the valley floors.

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1 See footnote page 9.

DRAINAGE PATTERN ANALYSIS

Method of Study

To study the drainage pattern of the thesis area as a whole, and to get an idea of what seemed to be its normal appearance and what could be regarded as anomalous, the complete drainage network of the two counties was traced from aerial photo index mosaics. The tracing was done on transparent matt plastic film.

The main streams and their large tributaries were fairly easy to trace. However, the lower magnitude streams were difficult to trace in some parts of the index mosaic for the following reasons: First, their small size made them difficult to detect. Second, where the tone of some photographs in the index mosaics was too dark the courses of the lower magnitude streams became obscure and difficult to trace. Wherever such was the case, topographic maps were used as an aid. Although these maps are not suited for working out the network of the lower magnitude streams, they helped in confirming the direction of the drainage in a particular area. Third, where the photographs in the mosaic were not well aligned it was difficult to trace the courses of the streams from one photograph to the adjacent one. Despite the great care and length of time taken to trace the lower magnitude streams properly, some areas proved to be extremely difficult for such detail work and consequently a complete picture of the drainage pattern could not be obtained from the index mosaics in those places.

For the reasons listed above repeated revision of the traced drainage seemed necessary. Therefore, lead pencil was used first to work out the true relationship of the streams. India ink was used afterwards for retracing. Dotted lines and dashed lines were used to delineate the boundaries of river floodplains and undissected uplands respectively from the undissected· topography.

After certain areas were picked as probable for the occurrence of basement topographic highs, their drainage was traced in detail using individual aerial stero-photos as the base. The purpose of the second tracing was to detect very small streams not discernable on the index-mosaics. A close study of the second tracing and the bedrock geology as interpreted from aerial photos determined whether the selected areas still looked favorable. The study of bedrock geology as seen from aerial photos included tracing of beds, noting differences in soil tone and in vegetation.

Drainage Anomalies as Criteria for Detecting Buried Hills

In southeast Missouri the major drainage systems flow in a southeasterly direction. These directions are followed by the Black River and St. Francis River systems. The flow in this direction is a consequence of the surface slopes due to Ozark Uplift in post-Pennsylvanian times. However, the surface slopes are of comparatively small magnitude, and, therefore, the general drainage pattern in southeast Missouri is of the dendritic type.

In a small area, the courses of an assemblage of streams might be influenced by a subsurface basement high. Also this particular small area is part of a much larger area whose general drainage pattern is dendritic. When viewed as part of the drainage pattern of the larger area, the assemblage of streams of the small area would show dendritic pattern. When looked upon in such a manner, the influence of the subsurface basement high would be very difficult to detect and is not readily apparent.

However, if the assemblage of the streams in the small area was isolated from the rest of the drainage system, and the courses of the individual streams within the assemblage were analyzed in relation to each other, certain patterns could be found which would be hard to detect otherwise. These certain patterns have been referred to in this report as drainage anomalies.

Drainage anomalies which suggest buried structural highs are expected to show patterns of the radial and annular type. In the radial pattern, streams flow away from a common center to all directions, and in the annular type the streams form a ringlike pattern. Ideally, the radial pattern would occur over the area where the buried hill is located, having the common center of the radiating streams over the summit of the hill, whereas the annular pattern would be corcentric about the buried hill.

Figure 1, shows a hypothetical example of radial and annular drainage patterns over a structural high.

In nature an ideal case as shown below is infrequent. The drainage anomalies may not be sufficiently developed to attract immediate attention. The vague tendencies of some streams to reveal radial and annular patterns may raise much doubt and ambiguity as to whether a subsurface structural

Figure 1 - Hypothetical radial and annular drainage patterns.

high is the cause. In other words the drainage anomalies range from well developed patterns to those about which it is very difficult to make any judgement. There are no certain laws to follow or quantitative measurements to make in detecting favorable areas. The basis of the judgement here is solely qualitative and subjective.

Bernitz (1932, pp. 508-509) makes a point of significance regarding the subject discussed here. She states that annular pattern is an

> "...illustration of the increasing influence of structure over slope as drainage approaches maturity. Slope alone controls the initial courses of streams; structure and slope, the adjusted courses of maturity."

It seems likely then, that areas most favorable for detection of anomalous drainage are those whose drainage has reached the stage of maturity. In its youngful age, drainage would show the effect of the underlying igneous hill by a radial pattern which is the consequence of the slope. As the area progresses toward maturity, the increasing influence of the buried hill on the surface drainage will bring the annular pattern into the picture.

It can be concluded that in a region of mature drainage, areas exhibiting both radial and annular patterns are more probable sites for buried igneous hills than those which show only radial or annular pattern. However, the above restriction should not eliminate completely the consideration of areas showing only one type of drainage anomaly.

Causes of Drainage Anomalies

Under the discussion of the geologic history of the area of this report it was mentioned that this region underwent several oscillations of level from Cambrian to Pennsylvanian times which caused the sea to cover it repeatedly. These repeated submergences caused the Precambrian igneous hilly areas to be covered by a series of formations which were eroded slightly during the short emergences. The deposited beds overlapped the igneous hill slopes and incorporated at their bases the disintegrated detritus of the hills. Beds of the same time horizons were deposited at higher elevation along the flanks of the igneous hills than at some distance away from the hills. As a result of this difference in elevation the deposited sediments possessed initial dips around the periphery of the igneous hills.

The successive younger formations overlapped the hill flanks covering higher and higher parts of the hill slopes until the hills were completely buried. The impression of the underlying igneous structures, however, persisted in the form of domes in the overlying sediments. Differential compaction also aided in making the domes more pronounced. The higher hills still indicated the domed structure at the end of the sedimentary history whereas the lower hills were unable to do so. With sedimentation coming finally to an end, streams began dissecting the land. They were helped in their efforts by at least two uplifts. The dips of the Paleozoic formations around the igneous hills as observed at present are therefore largely the result of initial dips.

Other causes have been advanced by different workers to explain the observed dips around the igneous hills. These causes, including initial dips, are listed below.

1 - Igneous intrustion after lithification of sediments.

2 - Crustal deformation.

3 - Isostatic adjustment.

4 - Differential compaction of sediments.

5 - Increase of dip resulting from removal of soluble beds.

6 - Initial dips.

Dake and Bridge in a special article (1929) and Bridge in his report on the geology of Eminence-Cardareva quadrangles (1930, pp. 151-168) discuss the above listed causes and prove the first three as completely out of question; while the next two are responsible on a very minor scale, the last cause, that is initial dips, was concluded to be the outstanding factor for the local dipping of strata around the Precambrian igneous hills.

Bernitz (1932, pp. 507-508) states, "During the initial stage of dissection of a dome mountain, the streams are consequent in origin and radial in pattern. As erosion advances nonresistant layers are exposed along which subsequent tributaries develop. As these grow in length they reach successive original consequent streams that extend radially down the slopes. By capturing the upper portions of these they increase their own volume and reduce that of the consequent streams. The more fortunate subsequent streams will, furthermore, increase their length at the expense of the less fortunate subsequents as they extend their valleys headward in the weak rock which encircles the dome. Holding their own, in this struggle for survival, will be a few consequent master streams that have dug channels deeper than those of the piratical subsequents. Thus, there results a series of subsequent streams which tend to assume a circular or annular pattern and a few trunk streams which are consequent in origin and radial in pattern."

If these statements of Bernitz, and those on page 19 are applied to the thesis area, the initial radial drainage pattern would be the result of erosion of the domed sediments above the buried igneous hills. With advanced erosion a subsequent annular pattern would begin to show as the courses of the streams are deflected downdip on resistant sedimentary formations.

Drainage Pattern of the Igneous Area in Eminence-Cardareva Quadrangles

The writer thought it would be appropriate to study the drainage pattern of an area where basement highs are known to exist before any attempt was made to select anomalous drainage patterns within the thesis area. Such a study would supplement what has already been discussed about the behavior of drainage patterns over and around buried basement highs. Also, this study would aid in the evaluation of the selected anomalous drainage patterns in the thesis area.

Plate IV shows the drainage pattern tracing of the greater part

PLATE IV

GENERAL DRAINAGE PATTERN OF THE IGNEOUS AREA, EMINENCE-CARDAREVA QUADRANGLES, SHANNON COUNTY

Legend

Drainage channels

Porphyry outcrops

Scale 1": 1 mile
numbers refer to patterns described on page 22.

N

of the igneous area of Eminence-Cardareva quadrangles. Also shown are most of the exposed igneous hills within the traced area. Examination of this tracing reveals the absence of any radial drainage pattern over the Precambrian hills. Annular drainage patterns around the igneous hills are frequently developed. But these annular patterns are not symmetrical and are not so neatly and well developed as to make them stand out among the drainage pattern of the area as a whole.

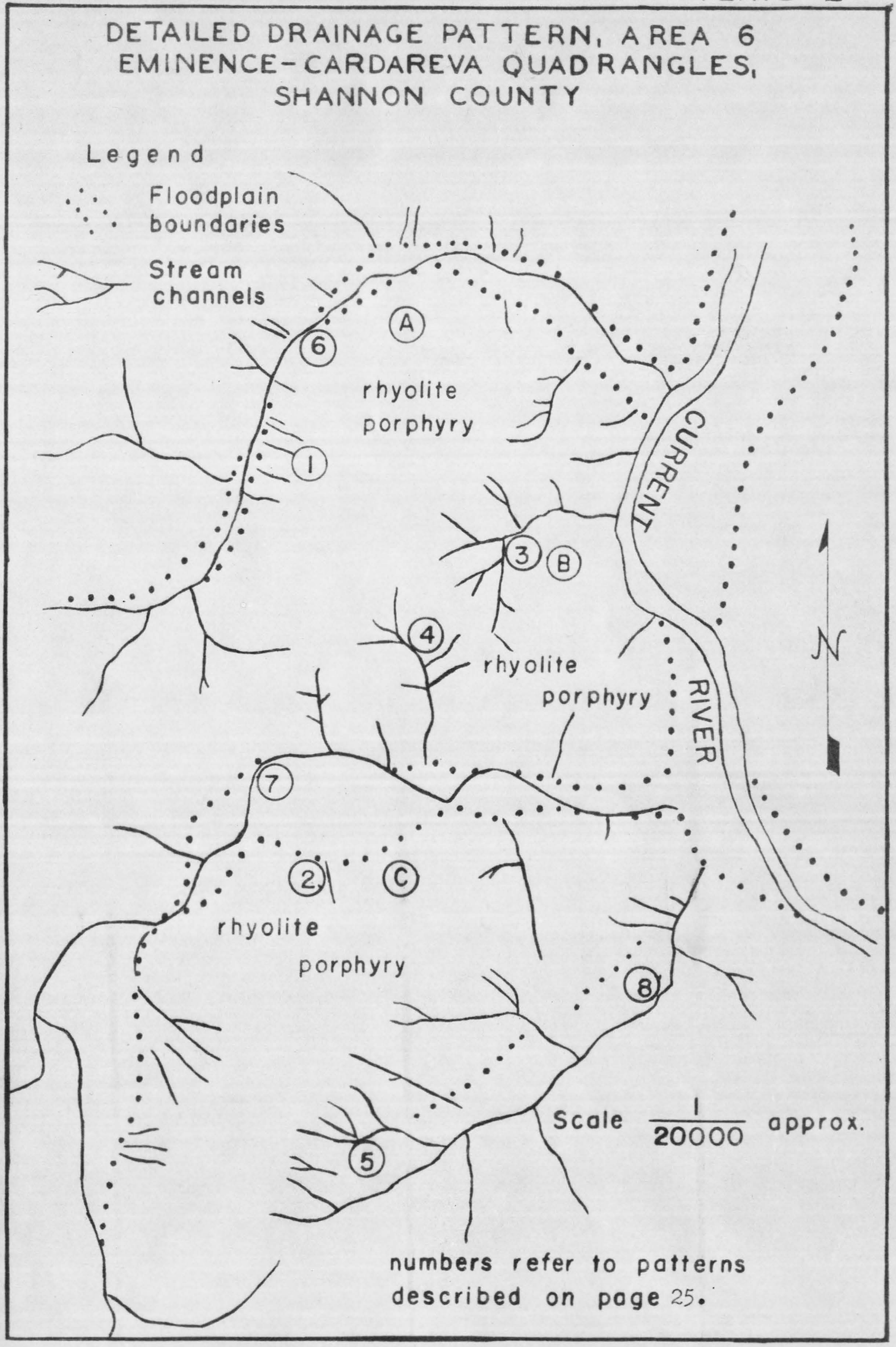
However it seems obvious that some of the stream courses in the immediate neighborhood of the igneous hills are directly influenced by their presence. For example in plate IV the streams numbered 1, 2, 3, 4, and 5, run in courses perfectly parallel to the adjacent igneous knobs. Also, streams 6 and 7 give the impression that they would have continued in their original directions if it was not for the resistant crystalline knobs which seem to have deflected their courses by almost ninety degrees. The large arc, indicated by number 8, of Current River, gives the impression that the river is running parallel to the boundary of an igneous mass east of the river. The several small porphyry exposures to the east of Current River at this locality probably betray the presence of a large crystalline mass concealed by the sediments.

It seems clear then that well developed radial and annular patterns are absent from the area. The discrepency between the expected and actual behavior of the drainage pattern in the neighborhood of the igneous knobs can probably be explained as follows. The radial and annular drainage patterns are not developed as expected in the neighborhood of the crystalline knobs which are exposed to a large degree because the weaker sedimentary rocks overlapping those knobs have been eroded away. The anomalous drainage patterns are developed within the weaker sedimentary rocks that conceal the igneous knobs. Once these sediments that cover the igneous knobs are eroded away the anomalous drainage pattern over the knobs and to a large extent around them is destroyed. There still might be streams along the slopes of an igneous hill leading away from it in a radial fashion. But because of the high resistance to erosion of the igneous hills, these streams are not developed well enough to be noticed on the index mosaic.

To complete the investigation, the writer made a second tracing from individual aerial photos of the drainage pattern around some of the igneous knobs. The second tracing might bring out detail in the drainage pattern that could not be resolved in the first tracing from the index mosaic.

Plate V, shows a second tracing from individual aerial photos of three porphyry knobs. Knobs A and B are located in S½ sec. 29, sec. 32, T. 29 N., R. 2 W. and W½ sec. 33, E½ sec. 32, T. 29 N., R. 2 W. respectively. Knob C occupies most of sec. 5, T. 28 N., R. 2 W. The striking absence of any drainage channels in the areas of the hills is notable. The first order streams that are developed on the steep slopes of the hills such as those indicated by 1 and 2 are difficult to detect and cast a doubt as to their presence. The assemblages of the streams marked by 3, 4, and 5 are developed primarily in the softer sediments overlapping the igneous hills. As these

PLATE V


DETAILED DRAINAGE PATTERN, AREA 6
EMINENCE-CARDAREVA QUADRANGLES,
SHANNON COUNTY
Legend
Floodplain boundaries
Stream channels
A
B
C
1
2
3
4
5
6
7
8
rhyolite porphyry
rhyolite porphyry
rhyolite porphyry
CURRENT
RIVER
N
Scale 1/20000 approx.
numbers refer to patterns described on page 25.

sediments erode away, the igneous mass underneath will appear and the drainage pattern of the stream assemblages shown by 3, 4, and 5 will be destroyed. The hills A, B, and C will become one area cut by stream 7, with a few streams hardly detectable on aerial photos leading away from it. Such an area is indicated by 1 on plate V.

Another thing to notice in plate V is the well developed annular pattern exhibited by streams 7 and 8. This annularity could not be detected in the general tracing from the index mosaic, but the second tracing from individual photos brings out this detail. Also to be noticed is the well developed half circular course of stream 6. It seems clear that the course of the streams 6, 7, and 8 are influenced by the prophyry hills near them.

Now if we think of hills A, B, and C as still buried under the sediments, we would expect radial and annular drainage patterns to develop in those sediments just like the drainage patterns of the streams 3, 4, and 5. If such were the case then the areas occupied by these three hills would exhibit the expected drainage pattern in areas of buried basement highs.

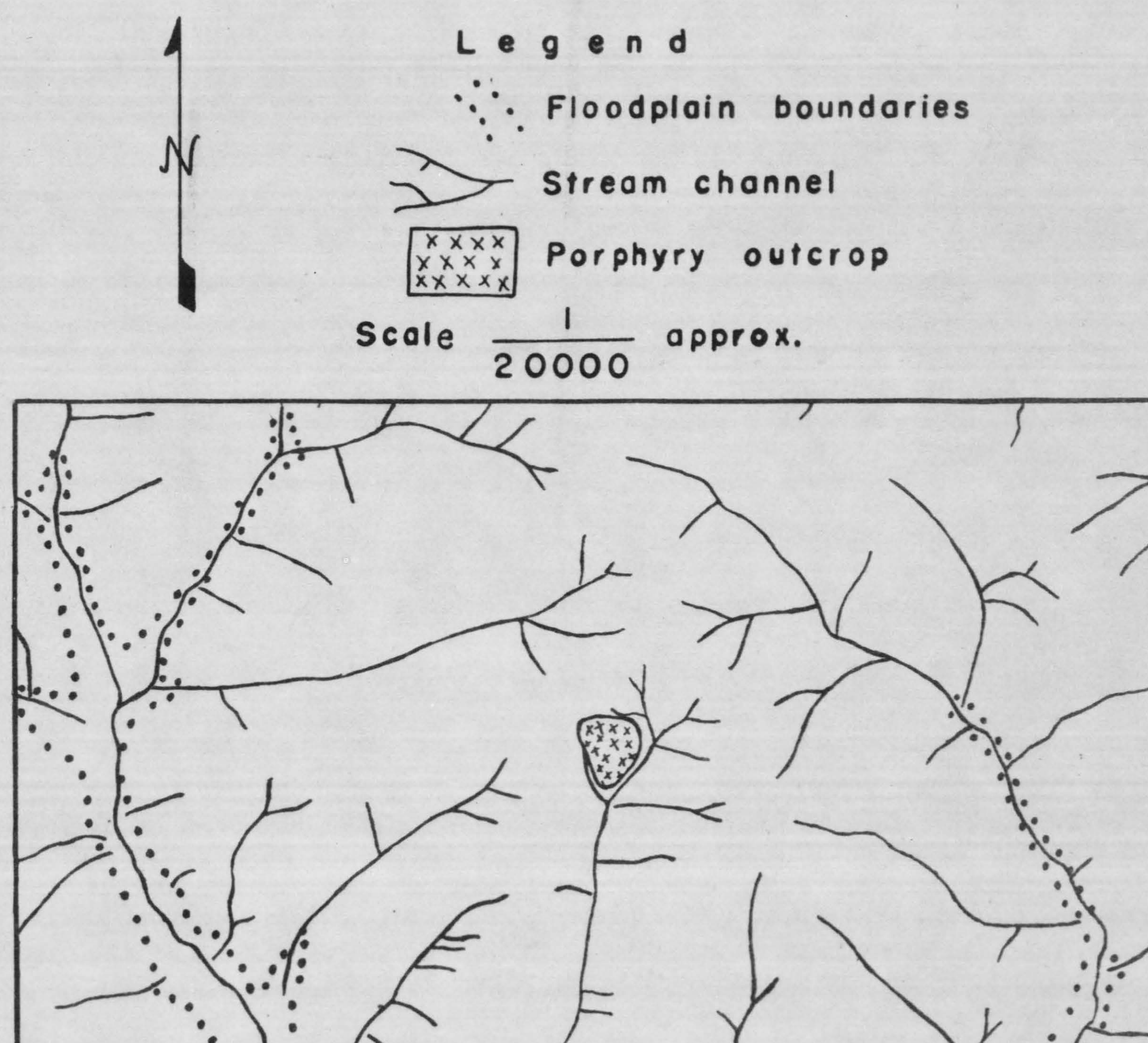
As actual examples of almost buried basement highs consider the drainage patterns developed around the porphyry masses 9 and 10 (Plate IV). These drainage patterns are good examples of anomalous drainage patterns which are to be expected over buried basement highs. The fact that a small porphyritic exposure is present in both areas makes it completely sure the anomalous drainage is due to the buried basement high. But even if the porphyry exposures still had been concealed by the sediments, the writer would certainly have marked the drainage patterns of area 9 and 10 as possible indications for buried basement highs. Plate VI is a detailed tracing from individual photos of the developed drainage pattern around the prophyry exposure 9. Note the well developed radial and annular patterns shown in the detailed tracing.

Examination of the geologic map of the Eminence-Cardareva quadrangles reveals dipping sediments in a radial pattern in the area of the igneous exposures 9 and 10. Exposure 9 is located at NW$\frac{1}{4}$ sec. 15, T. 29 N., R. 4 W., and exposure 10 at NW$\frac{1}{4}$ sec. 3, T. 28 N., R. 3 W. It is also seen that the dips are confined to the areas of the anomalous drainage patterns.

The question may be raised why other areas such as those shown by 11 and 12 in plate IV, which have basement highs almost concealed by the sediments, do not show typical anomalous drainage patterns as in areas 9 and 10? Part of the answer lies in the fact that the mosaic tracing of the drainage pattern of the igneous area of Eminence-Cardareva quadrangles is subject to the same limitations and difficulties encountered in tracing the drainage patterns of Wayne County and Reynolds County. Those limitations and difficulties were discussed on page 16. But the main reason why well developed anomalous drainage patterns are not the case over most of the igneous hills which are almost completely buried under the sediments is because the crystalline knobs have irregular shapes and outlines which do not permit the ideal anomalous drainage patterns to develop. This fact can be brought to attention by examination of the shapes of the ex-

PLATE VI

DETAILED DRAINAGE PATTERN, AREA 9
EMINENCE-CARDAREVA QUADRANGLES
SHANNON COUNTY



posed crystalline hills in both the Eminence-Cardareva and Potosi-Edgehill quadrangles. Most of the hills seem to possess elongate and irregular outlines and only a few exhibit conical forms.

For purposes of comparison, the porphyritic irregular masses of which Thorny Mountain and Stegall Mountain are parts can be contrasted with that of the conically shaped hill in the corner of sections 13, 14, 23, and 28, T. 29 N., R. 4 W., in the Eminence-Cardareva quadrangles. It is expected that the drainage patterns which developed within the sediments concealing the above mentioned irregularly shaped mountains would not have shown well developed anomalous patterns. The drainage patterns had to conform to the influence of the irregular shape of the resistant basement rocks buried beneath them. Consequently anomalous drainage patterns may not have developed in a manner such as to suggest immediately to the observer the possibility of buried basement highs.

<u>Anomalous Patterns in Thesis Area</u>

After completing the study of the drainage pattern of the Eminence-Cardareva igneous area the writer proceeded to select anomalous drainage patterns within the thesis area. Twenty four anomalous patterns were selected on the first mosaic tracings of Reynolds and Wayne Counties. Any area which showed the slightest tendencies for radial and/or annular patterns was indicated for consideration. These areas are discussed in Appendix I, and are shown by letters on Reynolds County and Wayne County mosaic tracings, Plates XIII and XIV respectively. After all the areas that appeared anomalous were indicated, a close study of them was made to select from among them those which exhibited a more anomalous drainage pattern. Nine such areas were thought to be worth further investigation. Of these 9 areas, 5 were selected for field check. These 5 areas are discussed below. Topographic maps were used along with the drainage tracings to help visualize the stage of dissection of the indicated areas. Discussion of the detailed tracings made for further study of selected areas are included in Appendix II.

Area L (Reynolds County) Plate VII.

Aerial photos: BMB 1-21 to 24, 2-32 to 34.

Topographic map: Ellington quadrangle; sec. 25, SE$\frac{1}{4}$ sec. 26, secs. 35, 36, T. 28 N., R. 2 E.
S$\frac{1}{2}$ sec. 30, sec. 31, T. 28 N., R. 3 E.
N$\frac{1}{2}$ secs. 1 and 2, T. 27 N., R. 2 E.
N$\frac{1}{2}$ sec. 6, T. 27 N., R. 3 E.

Study of the detailed tracing reveals that further investigation might be fruitful. The lower magnitude streams combine with the larger ones to produce well developed radial and annular patterns. It is true that not all of the lower magnitude streams seem to be a part of the anomalous pattern. Examples of such streams are those labeled 1 and 2. However, those that are near the center of the area (number 3) seem to radiate out in all directions from a single common center.

Area L is the only one in the whole group of areas where rock outcrops supplemented the study of drainage pattern. The stereoscopic examination of the individual photos revealed two hills within the area whose shapes resembled closely the porphyry knobs in Eminence-Cardareva quadrangles. Those hills are located where numbers 3 and 4 appear on Plate VII. The hills have the form of tapered cones, rise higher than the surrounding terrain, and have steep slopes and domed peaks. It is worthwhile to compare this description with that of the igneous hills in Eminence-Cardareva quadrangles discussed on page 52 . The great resemblance of the two hills in area L to the igneous knobs in the Eminence-Cardareva quadrangles suggests that they are of igneous nature. Field examination later proved they were felsite porphyry.

A third knob much less conspicuous than the two knobs discussed above was observed on the photos. It is indicated by number 5 on the detailed drainage map. The most significant thing about it is not its shape, but the dark tone it possesses compared to that of the surrounding hills. The tone contrast, vegetation density, and somewhat notable outline of the hill led the author to suspect that it might also be of igneous nature. Later field examination confirmed the interpretation.

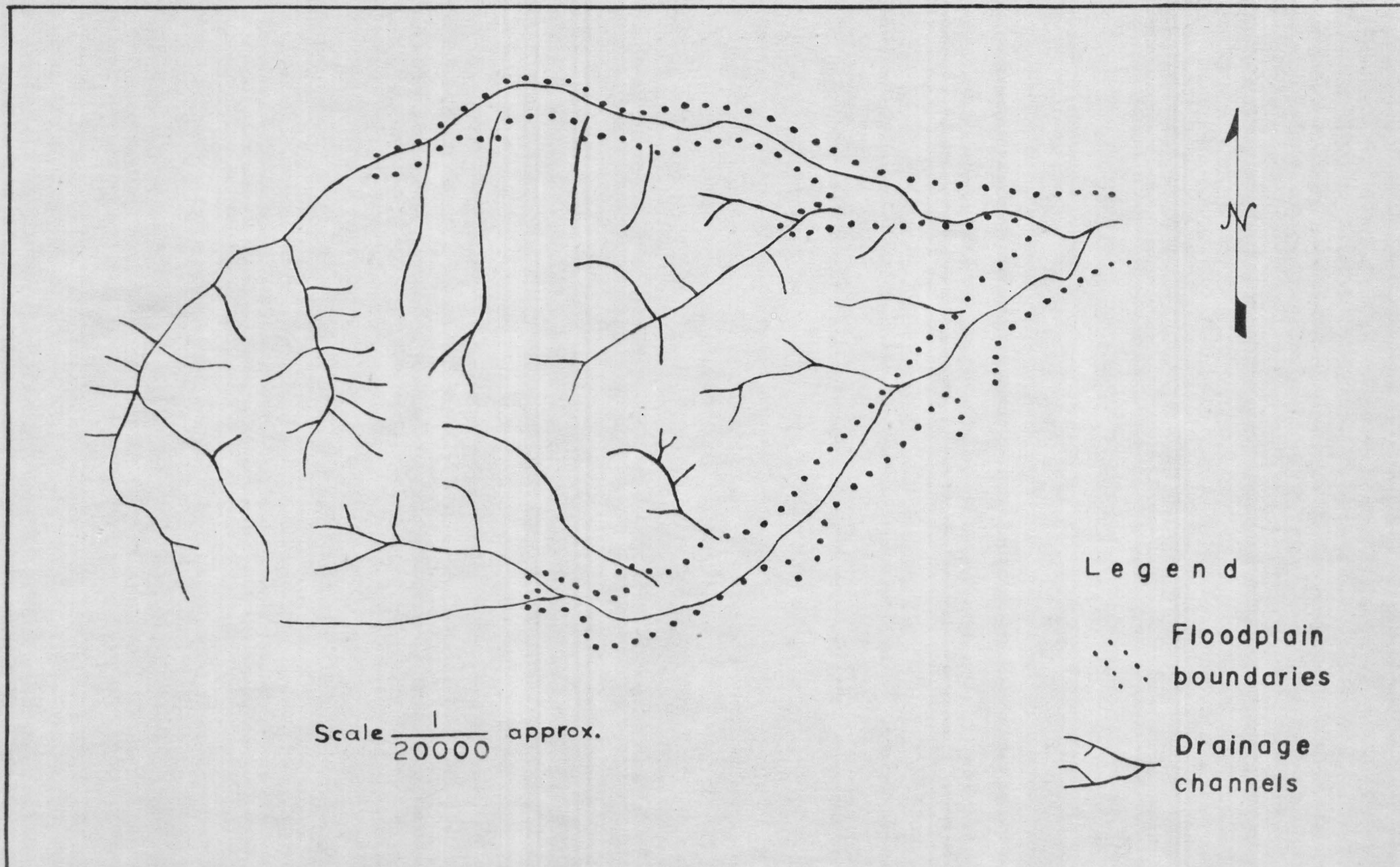
Area A (Wayne County) Plate VIII

Aerial photos: BMI 9-33 to 36, 10-19 to 21.

Topographic map: Piedmont quadrangle; SE$\frac{1}{4}$ sec. 33, S$\frac{1}{2}$ sec. 34, T. 28 N., R. 3 E.
NE$\frac{1}{4}$ sec. 4, N$\frac{1}{2}$ sec. 3, T. 27 N., R. 3 E.

The detailed tracing of area A displays a well defined radial pattern. The streams within the area seem to radiate in all directions away from a common center. The annular pattern is much less well defined among the lower magnitude streams than the radial pattern. However, the amount that the two large boundary streams seem to contribute to the

PLATE VIII



DETAILED DRAINAGE PATTERN, AREA 'A', WAYNE COUNTY symmetry of the area is notable. The resemblance of the drainage pattern of this area to that in Plate VI is striking.

Area E (Wayne County) Plate IX

Aerial photos: BMI 6-11 to 13, 6-49 & 50, 6-71 & 72.

Topographic map: Greenville quadrangle; sec. 18, N½ sec. 19, T. 28 N., R. 6 E.

The detailed tracing of area E strengthens the impression of its anomalous drainage character. The radial pattern is quite well developed and so is the annular pattern. The notable thing about this area is its circular outline.

Area B (Wayne County) Plate X

Aerial photos: BMI 4-28 to 32, 6-67 to 71.

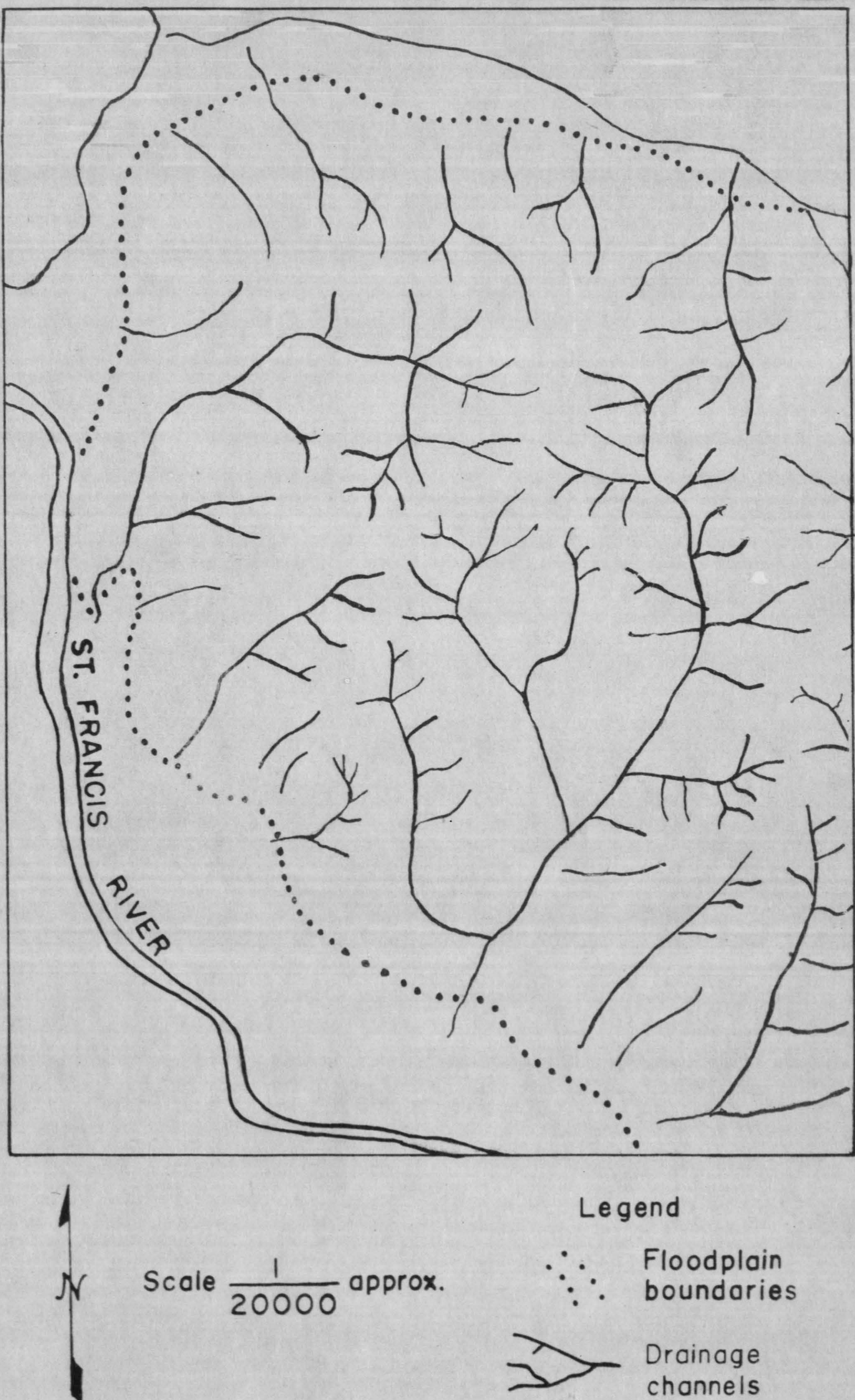
Topographic map: Piedmont quadrangle; S½ sec. 14, secs. 22, 23, 24, 25, 26, E½ sec. 27, T. 28 N., R. 4 E.

Area B exhibits about the same degree of anomalous character on the detailed tracing as it does on the mosaic tracing. There seems to be an anomalous pattern among the stream assemblages of this area. The larger magnitude streams reveal poor anomalous radial and annular patterns, and so do the lower magnitude streams that are near the middle of the area. The anomalous character of this area seems to the author to be more convincing if the area is looked upon as a whole. It still possesses a poor oval outline as it does on the mosaic tracing.

Area H (Wayne County) Plate XI

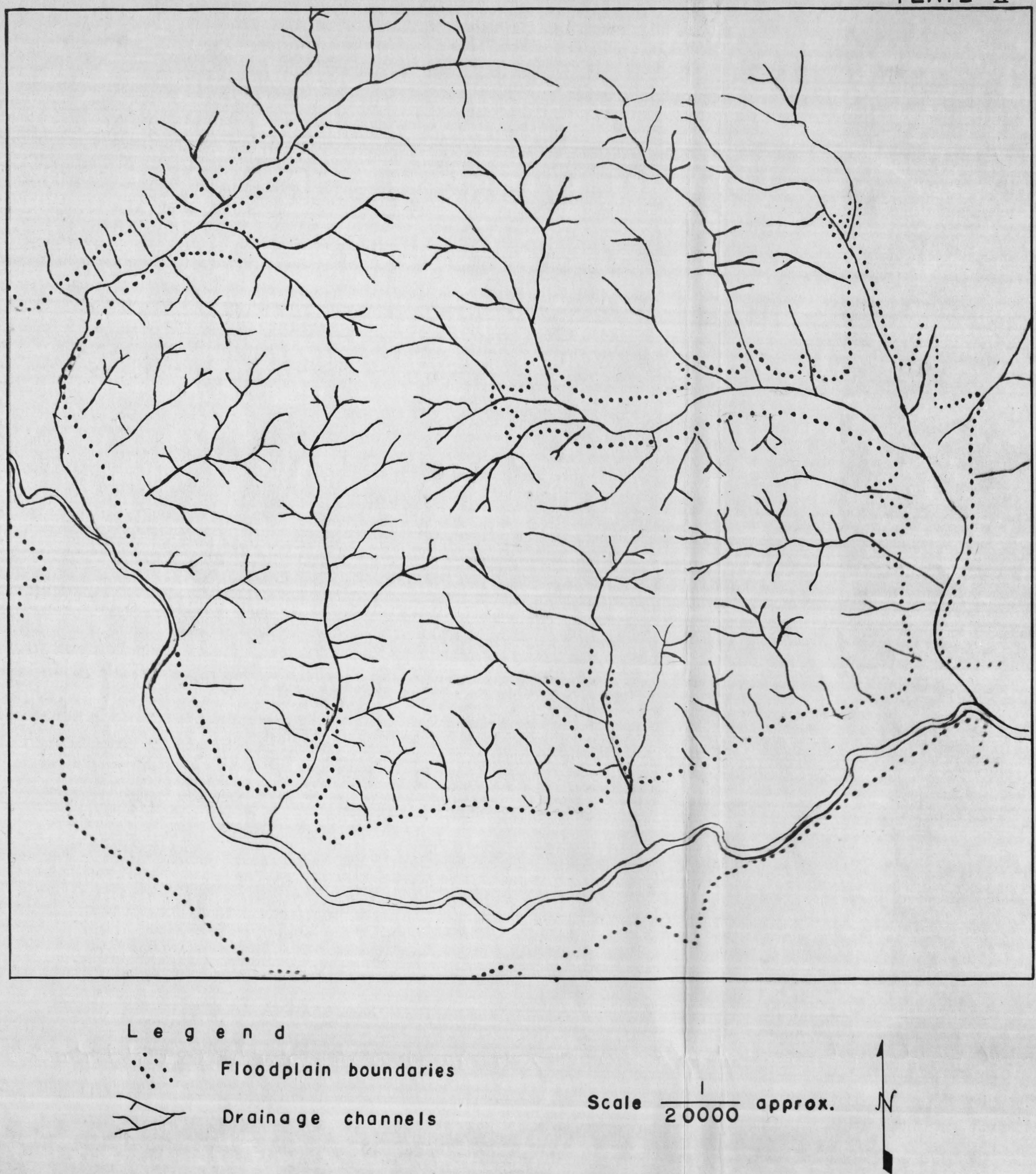
Aerial photos: BMI 8-71 to 75, 13 to 16, 93 to 97.

PLATE IX



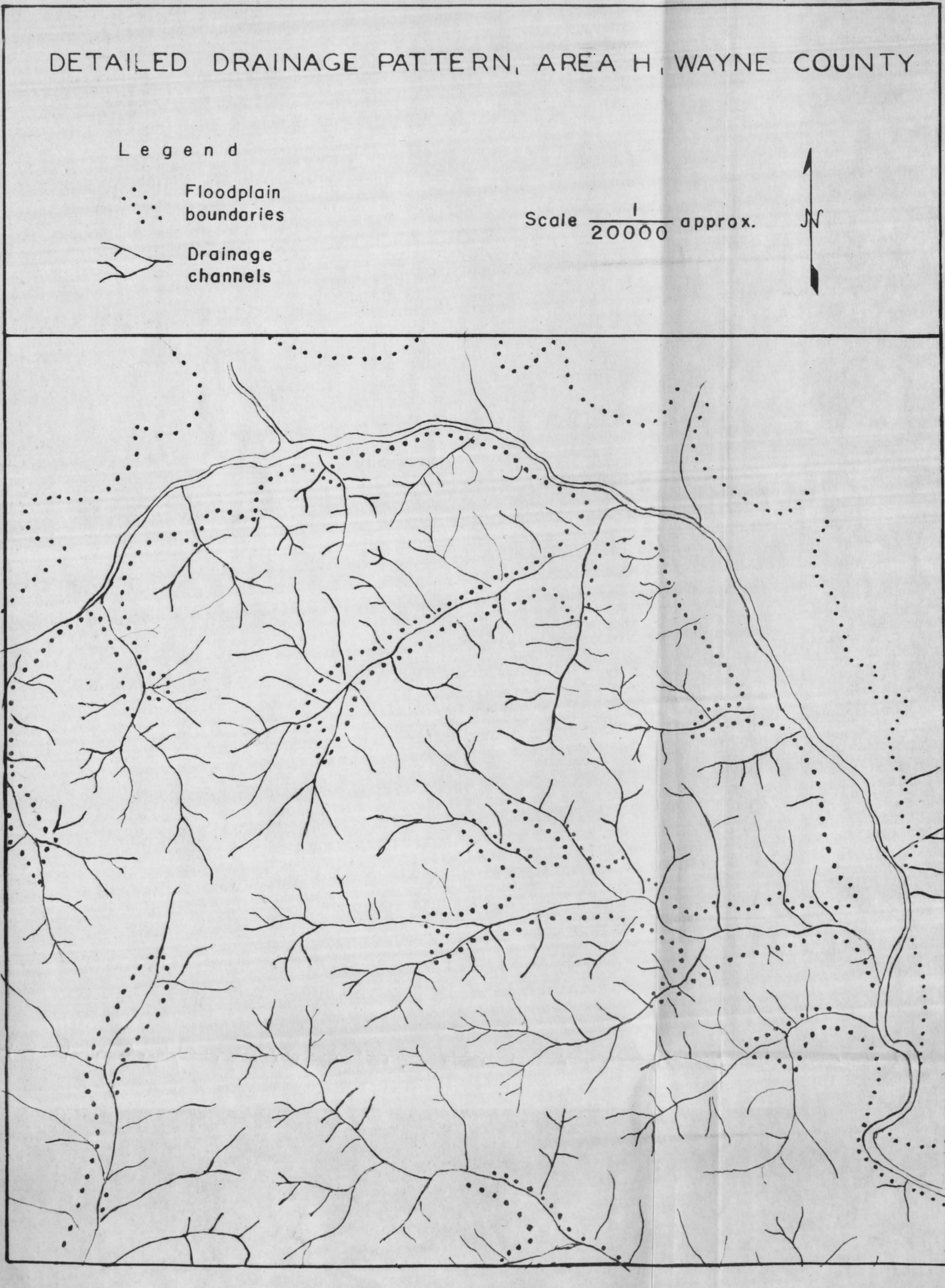
DETAILED DRAINAGE PATTERN, AREA 'E' WAYNE COUNTY

PLATE X



DETAILED DRAINAGE PATTERN, AREA 'B' WAYNE COUNTY

PLATE XI


DETAILED DRAINAGE PATTERN, AREA H, WAYNE COUNTY
Legend
Floodplain boundaries
Drainage channels
Scale 1/20000 approx.
N

Topographic maps: Greenville & Zalma quadrangles; secs. 33, 34, 35, T. 30 N., R. 7 E.
secs. 2, 3, $E\frac{1}{2}$ sec. 4, $E\frac{1}{2}$ sec. 9, secs. 10, 11, T. 29 N., R. 7 E.

The anomaly on the detail tracing of area H was not as apparent as that found in area D[1]. A radial pattern is still evident among its medium size streams, and even among the lower magnitude ones. The annular pattern seems to be as well or better developed than the radial one.

The final selection of the above discussed areas as worth investigating in the field does not mean at all that none of the other areas listed in Appendices I and II offer promising results. Because of the limited time available for field investigation, the number of considered areas had to be limited to four or five. In some cases a choice had to be made between equally promising areas taking into consideration size and accessibility. A choice of this nature had to be made between area K in Reynolds County and area H in Wayne County. Although both areas are comparable in size, the accessibility in the latter area is less problematical than that in the former. Furthermore, the northwestern part of the former area is surrounded by the waters of Clearwater Reservoir.

When area L of Reynolds County was selected from the index tracing the writer was completely unaware of the existence of the igneous outcrops. Their presence was suspected only when the individual aerial photos of the area were examined stereoscopically. The author did not

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[1] See Appendix II, page 96.

consider this sufficient reason for omitting this area from further investigation.

The area occupied by the igneous exposures is only a small fraction of area L. It is clear from the detailed tracing that the overwhelming majority of the streams in the area supplement each other to form a large outstanding drainage anomaly. The small local drainage anomalies around the exposed hills are only parts of this outstanding drainage anomaly.

An analogous area to area L is that containing the drainage anomaly shown in Plate VI. The writer would certainly have considered this area for further investigation if it were within his thesis boundaries. He would not have known that an igneous exposure exists in this area (the small porphyry outcrop could not be identified as such from the aerial photos) until he had checked it in the field.

An argument may be raised that if the igneous hills were still concealed by the sediments, the anomalous drainage pattern may not have developed as well as it is at present. The author is quite aware of this argument, but is unable to imagine just how anomalous the drainage pattern would have been if the igneous hills were still buried. There is no way to tell whether the area would have been identified as anomalous or not.

In closing this discussion it would be wise to stress again that in the detection of anomalous areas there are no certain rules or formulas to follow, the judgment is solely qualitative and subjective. Along with the responsibility of personal judgment the investigator must also continually keep in mind the conclusions arrived at in the examination of the drainage of the igneous areas of Eminence-Cardareva quadrangles. Namely, that the drainage patterns developed within the sediments concealing irregularly shaped mountains are not expected to show well developed anomalies. Frequently it becomes difficult, due to the distortion resulting from the influence of the irregular shape of the basement high to decide whether a drainage pattern is anomalous.

Methods for Verifying Analysis

Field Mapping.-- Since the sedimentary beds over the buried hills are assumed to be domed, their dissection would expose outcrops whose attitude if plotted on a map would reveal an annular pattern, dipping away from the buried hill. Dake (1930, pp. 185-191) and Bridge (1930, p. 152) mention several localities where they observed such radial dips, suspected buried hills as the cause, and in some areas observed porphyry float.

An obvious and direct method then, for checking the areas picked by drainage anomalies as favorable for location of buried igneous hills would be to study the attitude of the outcrops in the selected areas. However, fieldwork undertaken for this purpose yielded unsatisfactory results. Residuum cover in this region is widespread and thick enough to make outcrops very rare. The available outcrops are adequate to indicate the stratigraphic horizons, but they are inadequate for local structural mapping.

Fieldwork, with the aid of published geologic reports about adjacent areas, well logs, and unpublished reconnaissance maps (Missouri Geological Survey) indicated the presence of the Gasconade and Roubidoux formations in the thesis areas. Sandstone, quartzite, and chert float were observed on most ridge tops in the field. Three specimens of Lecanospira, a gastropod characteristic of the Roubidoux formation were also collected, one from area B and two from area H. Surface evidence of the Gasconade was rare.

Photogeologic Mapping.-- Mapping from aerial photos of the different formations in the thesis areas may lead to the discovery of dips that would not be otherwise noticed in the field. Photogeologic mapping proved to be a partial success. It is discussed on pages 42 to 65.

Geophysical Surveying.-- Another alternative, as suggested by Dr. A. C. Spreng, to arrive at conclusions for the project at hand, was to employ magnetic and gravimetric methods. The magnetic method proved to be most successful of the methods tried. Application of the geophysical methods are discussed on pages 66 to 81.

PHOTOGEOLOGY OF GASCONADE AND ROUBIDOUX FORMATIONS

Introduction

It was discovered in the field that the thesis areas were covered by residuum and it was realized that no bedrock outcrops could be observed in the aerial photos. On the other hand if the formations present or their contacts could be determined photogeologically, then any dips that might exist in the anomalous areas would be revealed by the different elevations at which the formations or their contacts will appear. In order that the dips be detected in this way, the changes in elevations of the formations must be of large magnitude, since many small changes would be hard to detect in the available aerial photos.

To proceed with this investigation an effort was made to discover if Roubidoux and Gasconade exhibited any consistent characteristics which could be identified in aerial photos. It was necessary to study aerial photos of an area which had been mapped geologically and which contained these formations.

The Eminence-Cardareva quadrangles (Bridge, 1930) were selected for photo geologic study because they met these requirements. Other reasons for selecting these quadrangles were their proximity to the thesis area, and their great extent. The proximity reduces the possibility of great lithologic variations between mapped areas and the thesis area. The great extent would make the conclusions reached in the study more valid than if the mapped area was small.

Potosi-Edgehill quadrangles (Dake, 1930) were also considered for this study, but Eminence-Cardareva quadrangles were selected because considerably more of this area is covered by the Roubidoux and Gasconade formations, and also because the Cryptoaoon reef (*C. ozarkensis*), which occurs in the Gasconade formation about 70 feet below the Gasconade-Roubidoux contact, is shown on the geologic map. The southern portion of Cardareva quadrangle which lies within Carter County was omitted from the study because the aerial photos for this area were not available.

Criteria Used and Their Limitations in Photogeologic Mapping

H. T. U. Smith (1943, pp. 222-224) discusses the criteria which can be used for lithologic interpretation of rock types from aerial photos, and the factors that limit the use of these criteria. These criteria and limitations are summarized here:

Criteria

1 - Topographic expression

2 - Rock and soil coloration

3 - Vegetal zoning

4 - Solutional effects

Limitations

1 - Topographic relief-individuality of topographic expression is most distinctive during the mature state of erosion of a region.

2 - Thickness of soil cover-surface expression loses much of its distinctiveness if the soil cover is too thick.

3 - Presence of glacial drift-obscures surface expression of bedrock geology.

4 - Seasonal conditions at the time the photo is taken will influence its usefulness in geologic mapping.

Application of Criteria and Limitations to Eminence-Cardareva Quadrangles

Of the criteria listed above, topographic expression held the prime position in the study of Eminence-Cardareva quadrangles. Next came soil coloration and after it vegetal zoning. Soil coloration was used on a major scale throughout the study and in many cases proved to be extremely useful in making a definite decision regarding the presence of one formation or the other. In some cases where topographic expression failed to apply, soil coloration was found to be the sole betrayer of the presence of a certain formation. Vegetal zoning was useable only on a local scale.

No primary and secondary structures whatsoever could be distinguished in the aerial photos. Therefore, application of such criteria could not be exercised. Few solution structures such as sink holes were detected throughout the region, but their presence on a local scale excluded the possibility of their use for the problem at hand. It should be remembered at this point the objective of the photogeologic study was not to determine the lithology of the rock present. Its purpose was to study the characteristics of two specific formations and find if they exhibit consistent noticeable differences which could be used in adjacent areas to detect their presence. The lithology of the formations and their distribution in the study area was already known and this knowledge permitted the photogeologic study to be undertaken.

The factors which tended to obscure the distinctive characteristics of the formations were the advanced erosional stage, as in the central area of the igneous hills, and the widespread great thickness of residuum present. These two factors correspond to the first two reasons listed under limitations of photogeologic criteria on page 43. Because of the presence of residuum, definite contacts could not be detected between the formations. Therefore, the contact lines had to be approximated. Another factor which rendered the study more difficult was the presence of formations in insufficient thickness to be noticed in the aerial photos. Frequently the presence of approximately 40-60 feet of Gasconade under the Roubidoux was not detected.

Although the Eminence-Cardareva area is covered with unbroken expanses of trees except where widely separated farm lands exist, forest cover did not limit in any way the photogeologic study of the region. The reason for this is because the aerial photos were taken during the months of March and April when the trees were still barren of leaves.

Photogeologic Characteristics of Gasconade and Roubidoux Formations in Eminence-Cardareva Quadrangles

Gasconade and Roubidoux Formations.-- In the Eminence-Cardareva area, Roubidoux is the youngest formation present on a large scale. Jefferson City formation and the few small patches of Mississippian and Pennsylvanian rocks are not considered here because they are too minor to have any photogeologic significance. Roubidoux, the youngest formation present, underlies the slightly dissected uplands, and caps the ridges above the Gasconade in maturely dissected localities, or is present as small isolated patches on top of ridges made up of Gasconade and older rocks.

Roubidoux generally manifests itself in broadly curved hilltops, the crests shaped almost like a half circle. In sharp contrast, ridges capped by Gasconade have narrow pointed crests. In cross section the ridges would appear triangular shaped (Plate XIIa and b, Examples 2, 3, and 4[1]). Optical illusion due to parallax in stereoscopic viewing of the photos exaggerates these topographic differences.

Another difference between Roubidoux and Gasconade formations is the dark tones shown by the former compared to the later. Hilltops capped by Roubidoux especially by small isolated patches, show very well this contrast of dark tone against the lighter background of Gasconade. In the slightly dissected upland regions where Roubidoux alone is present, its dark tone is not very significant because of lack of contrast.

The cryptozoan reef in the Gasconade formation, mentioned on page 43, is about 2-3 feet thick. Although the actual reef outcrop cannot be seen on the aerial photos, its presence can be detected in some localities. Where the sediments above the reef have been eroded away to a large extent, the reef appears to form almost level, or slightly convex-up ridgetops in cross section. In longitudinal section a sharp topographic break separates its gently sloping surface from the steep slopes of the rock unit which overlies and underlies it (Plate XIIc and d). This characteristic of the reef was noticed to occur on ridges

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[1] Reference is given in Appendix III to photographs which illustrate the features mentioned in the discussion of the Photogeology of Roubidoux, Gasconade, and Eminence formations.

PLATE XII

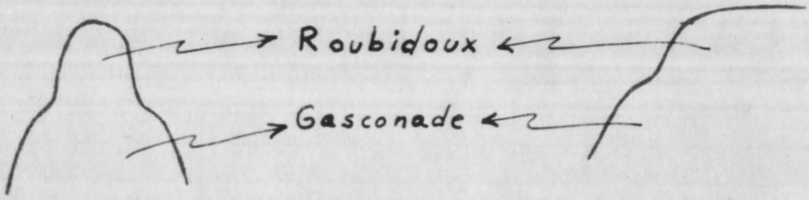
CROSS-SECTIONS ILLUSTRATING THE TOPOGRAPHIC EXPRESSIONS OF ROUBIDOUX AND GASCONADE FORMATIONS IN EMINENCE-CARDAREVA QUADRANGLES, SHANNON COUNTY

(a) (b)

Ridges made up or capped by (a) Roubidoux, (b) Gasconade

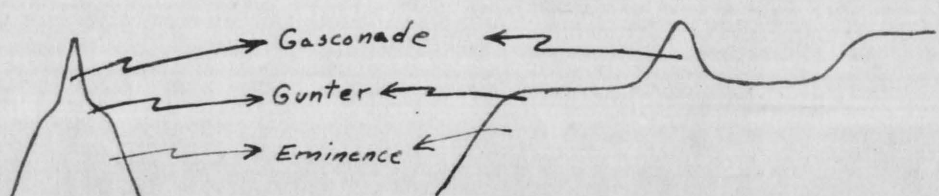
(c) cross section (d) longitudinal section

The cryptozoon reef of Gasconade



(e) cross section (f) longitudinal section

Formational break between Gasconade and Roubidoux



(g) cross section (h) longitudinal section

Ridges made up of Gasconde, Gunter, and Eminence bordering the large streams.

Where an isolated patch of the Gasconade formation occurs above the reef it will show the typical pointed Gasconade shape at its top and grade to the flat reef at its bottom (Plate XIIg and h).

In the majority of cases, where the geologic map indicated the presence of isolated patches of the Gasconade cryptozoan reef on top of the ridges, these isolated patches show in the photos the typical Roubidoux characteristics. This relation of the Roubidoux characteristics to the Gasconade reef areas seemed in general to be faithfully kept. For example, suppose the geologic map shows a long ridge made up of Gasconade and the cryptozoan reef is present only in the areas of highest elevation on top of the ridges. The aerial photos would show the same ridge in the typical Gasconade form except for the reef areas which would exhibit Roubidoux characteristics. To determine whether the characteristics shown in the reef areas were actually due to Roubidoux not represented on the geologic map or to Gasconade formation, a field check was deemed necessary. Field work revealed the presence of Roubidoux float on top of ridges which had been marked by Gasconade reef only.

Gasconade-Roubidoux Contact.— With the exception of a few localities, the Roubidoux-Gasconade contact in the studied areas could not be accurately determined[1]. Although sharp definite contacts could not be

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[1] Bridge in his fieldwork could not detect Gasconade-Roubidoux contact over most of the area. He mentions (1930, p. 164), "....the lack of the Gasconade-Roubidoux contact over much of this area....".

detected, approximate contacts could be inferred from topographic breaks or tone differences. While this approximation could clearly be made in many cases, quite a few other areas did not reveal the presence of Gasconade under the Roubidoux at all, although the geologic map showed its presence.

Causes of Gasconade-Roubidoux Characteristics.-- The writer thinks that solution of the dolomite beds (Bridge, 1930, p. 110) can account for the differences in shape, tone, and the poorly defined contacts between Roubidoux and Gasconade. The Gasconade formation, except for chert, is made up completely of dolomite. The Roubidoux formation overlying the Gasconade is made up of alternating layers of dolomite and sandstone of variable thickness. The great solubility of the Gasconade dolomite and Roubidoux dolomite and the non-solubility of the Roubidoux sandstone is the factor responsible for the poorly observed contacts between Roubidoux and Gasconade. The effect of solution on the dolomites in the Roubidoux sandstone was observed frequently in the field and along road cuts. Where Gasconade dolomite has been carried away by solution, the Roubidoux sandstone above it has settled upon the lower horizons of Gasconade, crumbled and broken up so as to make definite Gasconade-Roubidoux contacts hard to find. The presence of residuum adds to the complexity of locating the contacts.

Solution might also explain why the reef areas of Gasconade exhibited Roubidoux characteristics in the aerial photos. The 70 feet of dolomite between the reef and the top of the Roubidoux has been carried away by solution and the Roubidoux has settled down to the level of the reef. In some cases it has settled to even lower horizons. The Roubidoux considered in this manner is not in place. It consists of large boulders of sandstone settled over the reef; but there is enough of it present to impart to the reef area the typical Roubidoux tone and characteristics. Although Bridge does not mention it anywhere in his report, the presence of large amounts of Roubidoux float over the reef leads the writer to believe that Bridge did see the Roubidoux float but did not indicate it on the geologic map because it is not in place. Also the geologic map shows the contact between the small isolated patches of Roubidoux on top of the Gasconade by dots instead of solid black line as is the case between other formations.

The reason that Roubidoux characteristics are confined mostly to those parts of the Gasconade where the cryptozoan reef is present might be explained by the fact that the reef is silicified (Bridge, 1930, p. 113) and its resistance to erosion is much greater than that of the soluble dolomite. Thus, the dolomite between the reef and the Roubidoux was carried away by solution and the Roubidoux has slumped on top of the reef. An argument can be raised that confinement of Roubidoux characteristics mostly to the reef areas of Gasconade may be due to moisture. The silicified cryptozoan reef may prevent ground water from passing into the subsurface, and as a result the moisture present in the rocks above the reef will cause the reef areas to appear dark toned in the aerial photos. This possibility can be excluded for the following reasons: First, Roubidoux still possesses the dark tone in places where the 70 feet of Gasconade dolomite separate it from the reef; second, no differences in tone can be observed in photos taken during widely separated periods; and third, no springs or water flows can be observed in the field above the cryptozoan reef.

In those areas where Roubidoux is in place and is not covered by a great thickness of residuum (Plate XIIe and f), there is a topographic break along the Roubidoux-Gasconade contact. This definite break is attributed to the difference of lithology between the Roubidoux and the Gasconade.

The darker tone of the Roubidoux formation probably is due to residual iron oxide cement which has been concentrated during weathering and partial erosion of the sandstone (Bridge, 1930, p. 122).

<u>Gunter Sandstone, Basal Member of Gasconade</u>.-- The G ter sandstone, the basal member of the Gasconade formation, is variable in composition (Bridge, 1930, p. 100), but is known in general to be made of sandstone. While its presence is revealed in the aerial photos in some areas (Plate XII g and h), it is completely unidentifiable in other areas. It was also noted that the Gunter sandstone can be more readily discerned in the eastern-portion of the Eminence-Cardareva area.

Wherever it is identified, it forms a good topographic break along the otherwise uniform slopes of Gasconade and Eminence formations. In those places where its full thickness is apparent, it appears as a ledge that can be traced easily from one hill to another.

Compared with the topographic expression, vegetation plays a minor role in revealing the presence of Gunter sandstone. In some areas a long narrow line of evergreens outlines the Gunter sandstone.

In some localities all the younger rocks above the Gunter have been eroded away and only Gunter is left to cap the ridges. Gunter in this position shows the same topographic expression as the Gasconade reef under similar conditions. Although the Gunter sandstone capped ridges seem to be slightly flatter than those that are capped by the Gasconade reef, differentiation between the two on a topographic basis is difficult. The best method to tell the two units apart would be to determine the position of the unit in question with respect to the other formations present. It would be of great help to plot, on a topographic map of the area the approximate elevations and thicknesses of the formations as seen in the aerial photos. The nearly 200 foot interval between the Gasconade reef and the Gunter sandstone is bound to show if the plotting on the topographic map is not too much in error. Confusion still remains in places where a great deal of solution has taken place.

Eminence Formation.-- If it were not for the partial detection of the Gunter sandstone, differentiation of Gasconade from the underlying Eminence formation would have been extremely difficult if not impossible. Except for a few cases too local to be considered, not the slightest contrast could be detected between the Gasconade and Eminence formations. The great photogeologic similarity between the two formations is most probably due to identical lithologies.

Exposed Precambrian Igneous Hills

A large number of Precambrian igneous hills are exposed beneath the eroded Paleozoic sediments in the Eminence-Cardareva quadrangles. The degree of exposure varies from hills largely stripped of the sediments above them, to those where only small parts of their upper portions are exposed.

Those hills which are largely stripped of their sediments offer a striking contrast (in the aerial photos) to the sedimentary ridges that surround them. The most significant thing about those hills is their topographic expression. They show a somewhat higher relief than the rest of the terrain surrounding them. In their general outline some look like tapered cones, but the majority show bold, elongated and irregular shapes. They have large bases, steep slopes, and broadly rounded curved tops. Where vegetation and soil are not present, rock outcrops can be observed on the slopes and the summits of the hills. The overlapping sediments form flatirons against their slopes, and a large number of first order streams lead away from them radially. Although conspicuous tone and vegetation differences could not be detected between the igneous hills and the surrounding sediments, some of the former showed denser vegetation than the later. Igneous rocks that outcrop on a much smaller scale could not be detected as such.

Potosi-Edgehill Quadrangles

The conclusions arrived at in the Eminence-Cardareva quadrangles about the photogeology of Gasconade and Roubidoux formations were applied to the Potosi-Edgehill quadrangles. The study of Roubidoux and Gasconade in the later quadrangles confirmed in general the conclusions reached in the Eminence-Cardareva area except for the Gunter sandstone which is not present in the Potosi-Edgehill quadrangles and the Gasconade reef which is not shown on the geologic map.

Discussion of Results

To emphasize what has been stated before, it should be noted that the above study must not lead the reader to the conclusion that distinction between the Gasconade and Roubidoux formations photogeologically was completely successful. At many localities where the geologic map indicated the presence of Gasconade or Roubidoux formations, the aerial photos failed to indicate it. However, such cases were few compared to those where the two formations could be identified.

The application of the results of this study to other areas is limited because of the complete lack of previously published information about the photogeology of the Roubidoux and Gasconade formations. These formations have more or less the same lithologies throughout their areas of exposure, and the conclusions about them reached in the Eminence-Cardareva quadrangles might be expected to pertain in other areas. However, their applicability can not be assumed without further study except for those areas in close proximity to the Eminence-Cardareva quadrangles.

The application of the photogeologic characteristics found helpful in the study for identifying Gasconade and Roubidoux formations can be easily confused by the presence of other formations exhibiting very similar photogeologic characteristics. This has been already noted in the case of the Eminence formation in Eminence-Cardareva quadrangles.

This observation leads to the conclusion that if Gasconade and Roubidoux are to be mapped photogeologically in a certain area, it must be ascertained that the two formations are the only ones present in the area.

The writer concluded that the results arrived at in the above study of the photogeology of Roubidoux-Gasconade formations could be applied without much doubt to the thesis areas for the following reasons: First, the study of areas concerned in this thesis are relatively close to Eminence-Cardareva quadrangles. Second, only Roubidoux and Gasconade formations are present in thesis areas. Third, the thesis areas are covered by thick residuum and show the same stage of dissection as that found in the Eminence-Cardareva quadrangles.

The discussion of the photogeology of the Roubidoux and Gasconade formations as presented in this thesis is generalized. Many of the minor details and observations have not been included because they are not essential to the objective of this report.

PHOTOGEOLOGIC MAPPING OF THESIS AREAS

The basis of the photogeologic mapping of the thesis areas is the photogeologic study made on the Eminence-Cardareva quadrangles as described in the previous sections. The photogeologic maps of the thesis areas are presented on Plates XV to XIX.

Several of the difficulties encountered in the study of Eminence-Cardareva quadrangles were also encountered in the photogeologic mapping of the thesis areas. They can be easily summed up as follows:

1. Difficulty of determining whether a formation is present in place or as slump and float.

2. Difficulty of determining the exact contacts of formations and their elevations.

3. Difficulty of detecting the presence of small thicknesses of a formation.

To determine whether a formation such as Roubidoux is in place or not, the presence of a definite topographic break was searched for[1]. If the formation were in place, then a definite topographic break would be expected to exist. But if it were present as slump and float, no definite break would be present although the geometric shape (Plate XIIa) and tone of the ridge would still indicate the presence of Roubidoux formation.

The determination of the exact contact between different formations could not be accomplished by photogeologic mapping because of the thick

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[1] See page 48.

residuum present in all of the thesis areas. Therefore, all the formational contacts shown on the photogeologic maps are approximate. Another factor which rendered the approximate contacts as shown on the map subject to further error was the impossibility of determining the exact elevation from aerial photos due to lack of control points.

The difficulty of detecting the presence of small thicknesses of a formation could not be overcome in any way. This source of error was present constantly in the study of both the Eminence-Cardareva quadrangles[1] and in the thesis areas. Photogeologic maps of areas B (Plate XVII) and H (Plate XIX) illustrate this point well. The presence of about 20 to 40 feet of Gasconade formation below the Roubidoux formation in the southern part of area B and northern part of area H is in doubt.

The study of alluvium was not considered in the study of Eminence-Cardareva quadrangles. It has been included in the photogeologic maps of the thesis areas to make the mapping more complete. Wherever a stream exhibited sufficient meandering to cause any floodplains along its banks, these areas were shown on the photogeologic maps as alluvium.

After the thesis areas were mapped from aerial photos, field checks were undertaken to determine if any evidence could be found which would contradict the photogeologic mapping. Lack of evidence found in the field left the maps virtually unchanged except in area L where important changes had to be made.

<u>Area L</u> (Reynolds County) Plate XV

From reconnaissance maps and earlier field work it was thought that

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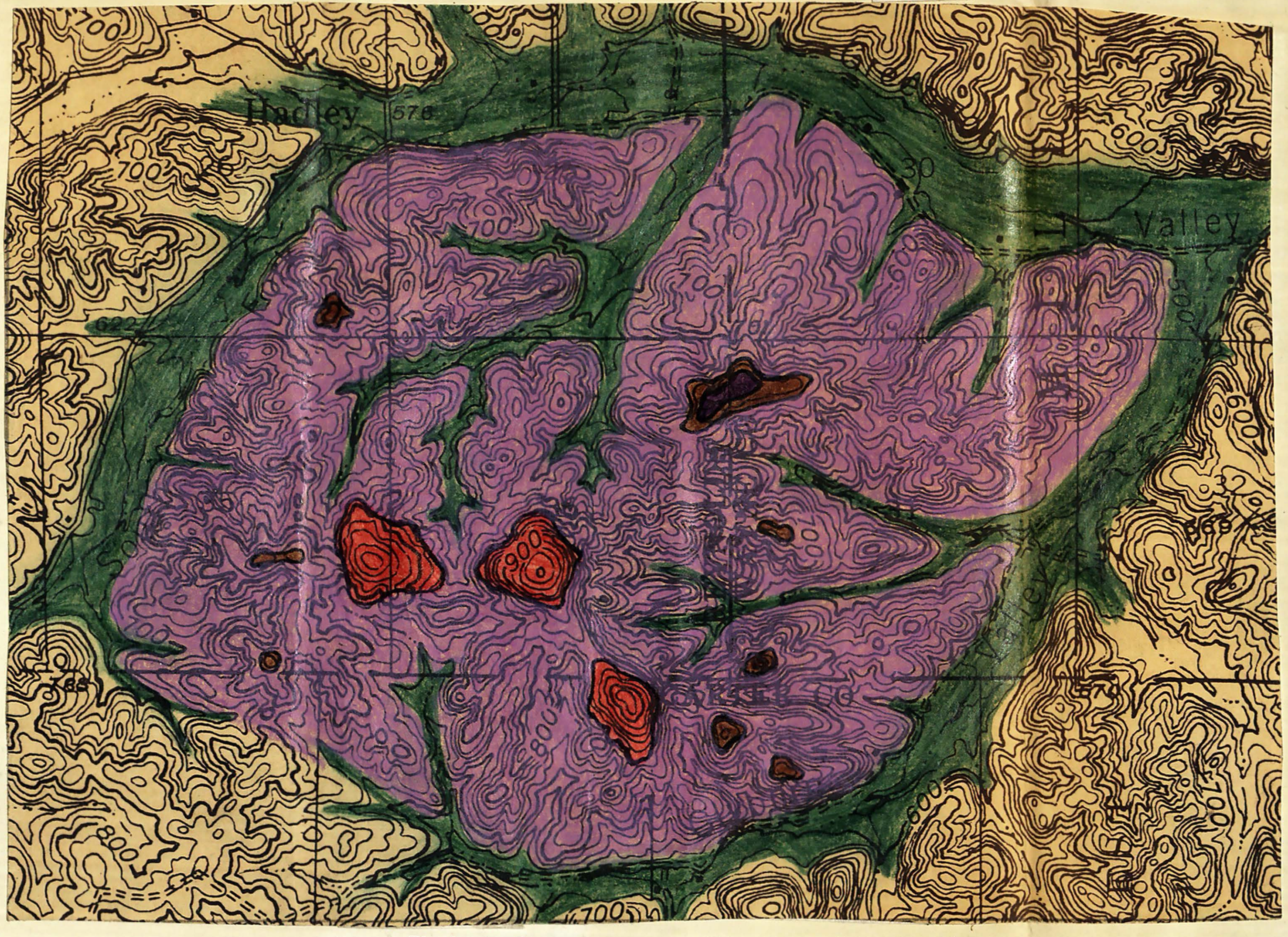
[1] See page 45.

PLATE XV

R 2 E R 3 E

T 28 N

T 27 N



Photogeology of Area "L", Reynolds County

LEGEND

(green)	Alluvium	Recent
(orange)	Roubidoux Formation	Ordovician
(purple)	Gasconade Formation	Ordovician
(brown)	Gunter Sandstone	Ordovician
(lilac)	Eminence Formation	Cambrian
(red)	Igneous Rocks	Precambrian

Contour Interval 20 feet

Scale $\frac{1}{31250}$ Approx

0 ½ 1 2

Miles

NOTE:- The legend, scale, and contour interval shown above apply also to Plates XVI, XVII, XVIII, XIX.

area L might contain Roubidoux float which had slumped on the lower horizons of the Gasconade formation. Therefore, this area was mapped as containing Gasconade and Roubidoux formations. Mapping of area L was particularly difficult because of the presence of initial dips commonly associated with the igneous knobs, and the almost complete absence of definite topographic breaks which would separate one formation from another.

Fieldwork after the photogeologic mapping resulted in discovery of small isolated dolomite outcrops which were identified as the Eminence formation. This discovery changed what was mapped on the photogeologic map as Gasconade and Roubidoux formations to Eminence formation and Gunter sandstone. Unfortunately these dolomite outcrops were grouped close together on a single ridge slope. They were not scattered widely throughout the area, therefore, a better check could not be obtained. Further close photogeologic study revealed the only possible locality for Gasconade formation to be on the boundary of sections 30 and 36.

Area A (Wayne County) Plate XVI

No outcrops could be found in the close vicinity of area A. However, 1.5 miles due east from it and just south of the town of Mill Springs a high cliff exposes Eminence, Gasconade, and Roubidoux formations. Approximate elevation of the Roubidoux formation in this cliff checks fairly well with that mapped for area A.

Area B (Wayne County) Plate XVII

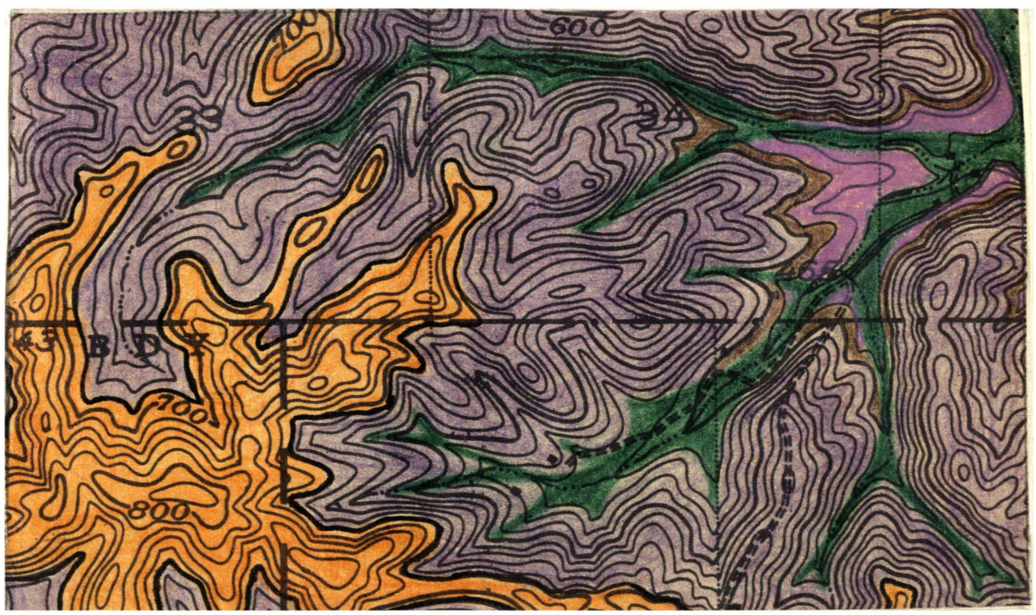
The 600 foot elevation was picked from aerial photos as the contact

PLATE XVI

R 3 E

T 28 N

T 27 N



Photogeology of Area A, Wayne County.

See page 58 for legend

LEGEND

	Alluvium	Recent
	Roubidoux Formation	Ordovician
	Gasconade Formation	
	Gunter Sandstone	
	Eminence Formation	Cambrian
	Igneous Rocks	Precambrian

Contour Interval 20 feet

Scale $\frac{1}{31250}$ Approx

0 ½ 1 2

Miles

PLATE XVII

Photogeology of Area "B", Wayne County.

See page 58 for legend

LEGEND

Alluvium		Recent
Roubidoux Formation	}	Ordovician
Gasconade Formation	}	
Gunter Sandstone	}	
Eminence Formation		Cambrian
Igneous Rocks		Precambrian

Contour Interval 20 feet

Scale $\frac{1}{31250}$ Approx

0 ½ 1 2

Miles

between the Gasconade and Roubidoux formations. Only on one ridge just south of the area did the aerial photos reveal what might be considered as a good Gasconade-Roubidoux contact. The contact on this ridge was placed at 570 feet.

The closest outcrop to area B was discovered at about 1.5 miles due east from the area near the Green Hill School at NE¼ sec. 19, T. 28 N., R. 5 E., (not shown on the map of Plate XVII). At this locality a cliff of Gasconade formation is exposed. The highest elevation of the exposure of the dolomite was about 540 feet. The contact of the Gasconade and Roubidoux formations could nowhere be detected and consequently the Gasconade formation in this vicinity was of little value in confirming the photogeologic mapping.

Assuming the elevation of the Gasconade-Roubidoux contact to be correct, the maximum present thickness of Roubidoux is about 200 feet. This figure is somewhat larger than the 145 feet measured subsurface section near Wappapello (Heller, 1954, pp. 78-80, Plate I). However, Heller notes that the Wappapello section does not represent the complete thickness of Roubidoux formation.

Area E (Wayne County) Plate XVIII

Several exposures of the Gasconade-Roubidoux contact were observed within and in the vicinity of area E. These exposures permitted an accurate check of the formational contacts of the photogeologic map. As a result of the field check, the Gasconade-Roubidoux contact had to be lowered about 15 feet in the southern and southeastern part of the area. In the northern part where Roubidoux formation is shown to be dipping, no

PLATE XVIII

R 5 E R 6 E

T 2 8 N

Photogcology of Arca "E", Wayne County.

See page 58 for legend

LEGEND

Alluvium	Recent
Roubidoux Formation	Ordovician
Gasconade Formation / Gunter Sandstone	
Eminence Formation	Cambrian
Igneous Rocks	Precambrian

Contour Interval 20 feet

Scale $\frac{1}{31250}$ Approx

0 ½ 1 2

Miles

outcrops could be found to confirm that such was the case. One field evidence that might suggest the presence of dipping beds, is the difference in elevation of some exposures of the Gasconade-Roubidoux contact. In the extreme **southern** part of the area the Gasconade-Roubidoux contact occurs at about 410 feet of elevation. In the **western** part, along the ridge (Cedar Bluff) just **west** of the numeral 13, the contact is exposed at approximately 500 feet elevation. Another field evidence that may confirm the presence of dipping beds is the very gentle due **south** dips of the dolomite beds of Cedar Bluff. These gentle dips can be seen best if viewed from the floodplain across the river. The photogeologic evidence for the dips was rather weak because no good formational contacts could be observed.

Area H (Wayne County) Plate XIX

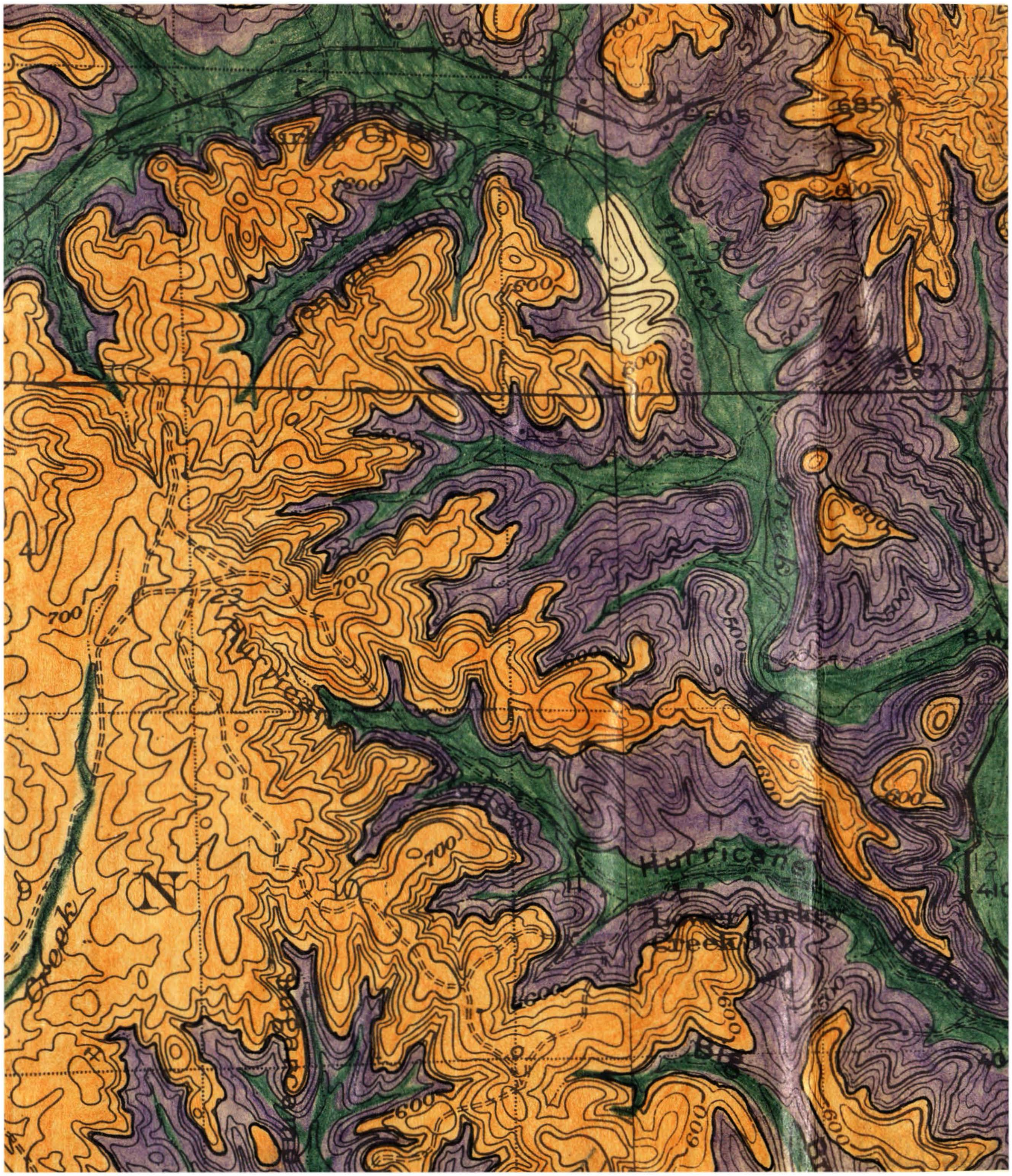
The Gasconade-Roubidoux contact could not be located in the field in this area. Gasconade formation is exposed in the lower parts of Hurricane Hollow, and along some parts of the banks of Caster River floodplain (not shown on the map). Roubidoux formation could not be detected in place throughout the area. Its float could be seen on the ridges and in the valley bottoms. In the field a large mass of sandstone was observed in the northern part of the mapped area. It is located approximately where the numeral 36 appears on the map, about a quarter of an inch east of the word "Turkey". Little significance could be attached to the presence of this sandstone mass because it did not seem to be in place. Its appearance gave the impression of slumpage.

PLATE XIX

R 7 E

T 30 N

T 29 N



Photogeology of Area "H", Wayne County.

See page 58 for legend

LEGEND

Alluvium		Recent
Roubidoux Formation	}	Ordovician
Gasconade Formation, Gunter Sandstone	}	
Eminence Formation		Cambrian
Igneous Rocks		Precambrian

Contour Interval 20 feet

Scale $\frac{1}{31250}$ Approx

0 ½ 1 2

Miles

GEOPHYSICAL INVESTIGATION OF THESIS AREAS

Methods Used

Seismic, gravimetric, and magnetic methods are the geophysical methods for detecting buried basement highs. Seismic investigation is costly and requires much specialized equipment operated by a trained crew. Therefore, seismic investigation was not considered for the problem at hand. Gravimetric and magnetic methods seemed suitable because they are easy and fast to employ.

The magnetic method was chosen for this study because no gravimeter was available and because magnetic data could be more quickly accumulated. In gravimetric surveys, elevations of stations must be known within limits determined by accuracy required. In magnetic surveys only the location of a station is necessary.

Magnetometer Scale Constant

An Askania Schmidt type, temperature compensated, vertical component magnetometer was used for the magnetic survey. The scale constant of the magnetometer was not known at the start of the survey. Since no Helmoltz coil was available at that time, the ground coil method was used to calibrate the magnetometer, which works on the same principle as the Helmoltz coil. The calculated scale constant of the magnetometer was 20.5 gammas per scale division.

Station Spacings in the Field

No definite distance was established for use between successive stations in the field. Although an effort was made to keep the station spacings constant along survey lines, the spacings varied because they depended on the size of the area, variation in the successive station readings, and the accuracy required by the survey. An important factor affecting the uniformity of station spacing was that the station location must be free of external magnetic disturbances such as electric power lines, fences, buildings, and cars. The spacings in general ranged from 0.1 mile to 0.35 mile throughout the survey with the greater number of the spacings falling in the range of 0.1-0.2 miles. The location of the stations are shown by black dots on the magnetic maps of the thesis areas.

On roads where a car could be driven distances between successive stations were measured by the car odometer. Along timber trails which could be traversed only on foot, distances were measured by pacing. For more accurate determination of the location of stations, use was made of topography and other markers shown on the topographic maps which were identified in the field. Locationsof stations along main roads and in places where identifiable markers are available are fairly accurate. Locations of stations along abandoned timber trails and in wooded areas are much less certain. Although no definite figures can be given for the inaccuracies involved, 100 feet can be taken as an approximate average. Considering the scale of the maps used in plotting the traverses, inaccuracies of this magnitude do not affect the general outline of the magnetic maps prepared from these surveys. The maps are inaccurate only in the fine details.

Corrections Applied to Station Readings

Diurnal and base corrections were applied to station readings. Because the sizes of the surveyed areas were small, and the normal correction was of such low magnitude[1], it was not employed.

The values obtained for certain stations changed considerably in a matter of a few hours. A 26 gammas change was noted at one elevation. Another station on a different date had a 146 gammas change.

Part of this variation is due to diurnal variation. The change in station values due to this cause is commonly in the neighborhood of 20 to 30 gammas. Therefore, the 146 gamma change can not be attributed to diurnal variation. Magnetic storms would be a plausiable explanation for this large change in reading, but the frequent occurrence of these large changes excluded this possibility. The large variation in the station readings were associated with and apparently due to large changes in temperature.

This object was not discovered at the start of the survey in late August, but became apparent in late fall when the daily temperature range increased. Associated with the above 26 gammas change was a range of 2.7° centigrade. The 146 gammas change was associated with 17.0° centigrade changes. This defect in the instrument seemed to account for the part of the variation which can not be attributed to diurnal change or magnetic storms.

Since no other magnetometer was available, the writer resurveyed some of the traverse lines on cloudy days when the range of temperature

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[1] Normal correction is +11.9 gammas in a direction of N9E in the region around Greenville, Missouri.

was very small. This method helped to obtain more accurate values for those stations.

Errors Involved in the Station Readings

Even on days with little temperature change to affect the station readings, the values obtained were not accurate. The inaccuracies in the station readings were due to the condition of the magnetometer and its tripod. They resulted from errors in the orientation of the tripod turn-table, leveling of the magnetometer, and reading of the scale. The compass used in orientation of the turn-table did not fit in firmly with the turn-table guidehole. As a result at least one half degree of play was present in the compass, which is the maximum allowable error in the orientation of the turn-table. The error involved in leveling of the magnetometer was due to the different sensitivities of the two level bubbles on the instrument. Whereas a very small turn in the leveling screw shifted one bubble from its level position, the second bubble did not respond in the same manner to similar move of the level screw. Another source of error was the frequent shift in the level bubble when the magnet was being released. A series of scale readings did not repeat themselves within tolerable limits for a given station. Therefore, the writer frequently had to take three sets of readings and choose the value for which two sets came the closest.

The amount of error from each of the above sources is not known, nor is it known whether the errors accumulate or compensate each other.

In spite of the contribution of each source of error to the station readings, the writer thinks the inaccuracies involved were within the tolerance of the survey. The magnitude of the total error is not large enough to distort the general framework of the resultant magnetic map or to leave one in doubt as to whether an anomaly is present. The magnetic survey was undertaken not as a geophysical investigation of buried basement highs but to determine if magnetic anomalies existed in areas thought, on the basis of drainage patterns, to contain buried basement highs.

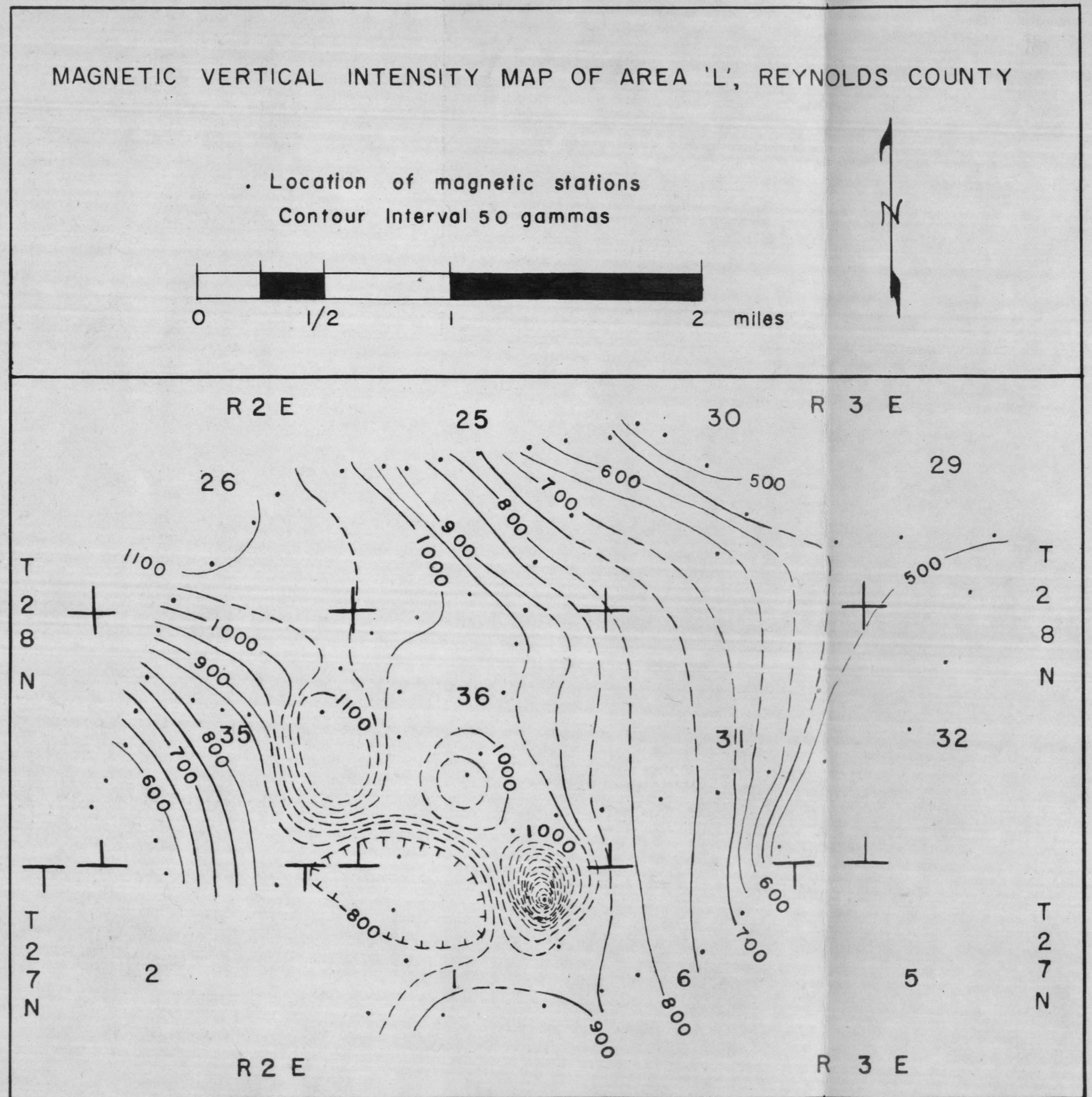
Magnetic Maps of the Thesis Areas

Magnetic vertical intensity maps for the thesis areas except Area A (Wayne County) are shown on Plate XX and Plates XXIII to XXV. Area A is represented by a magnetic vertical intensity profile (Plate XXI). The profile and the maps are drawn to a scale of approximately two inches to one mile. Magnetic contour interval differs from map to map to achieve clarity of presentation in places where the intensity values change greatly in short distances.

Area L (Reynolds County).— It was not necessary to determine the presence of an anomaly in area L since exposed igneous peaks had been observed. However, it seemed desirable to determine the pattern of the magnetic intensity of an area known to contain basement highs. A magnetic map of such features would help in judging the cause of anomalies that exist in the other thesis areas.

Plate XX shows three positive anomalies and one negative anomaly located approximately in the middle of the area. The southernmost

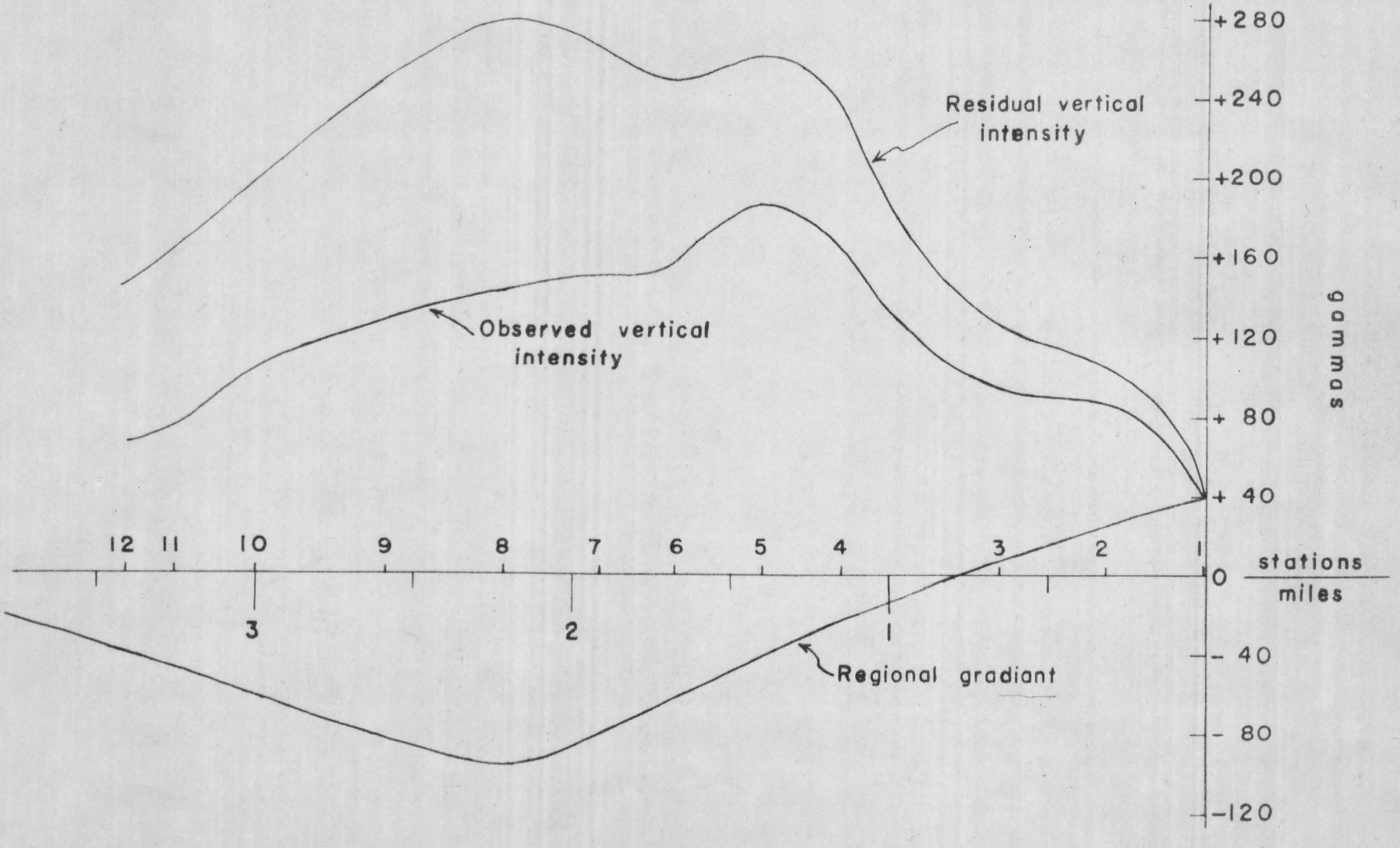
PLATE XX


MAGNETIC VERTICAL INTENSITY MAP OF AREA 'L', REYNOLDS COUNTY
. Location of magnetic stations
Contour Interval 50 gammas
0
1/2
1
2 miles
N
R 2 E
R 3 E
T 28 N
T 27 N
25
30
26
29
36
35
31
32
2
6
5
1100
1000
900
800
700
600
500

positive anomaly has an approximate magnitude of 615 gammas. The one just to the northw st of it shows a magnitude of approximately 63 gammas. The positive anomaly to the west has a probable magnitude of 137 gammas. The negative anomaly of about 50 gammas is located west and south of the three positive anomalies. The magnetic intensity in the area is highest where the igneous peaks are exposed in the area. It diminishes rather uniformly as the western and eastern limits of the area approached.

Area A (Wayne County).-- A magnetic intensity profile was made for this area (Plate XXI) because of the lack of enough stations to draw a magnetic contour map. The profile represents a traverse from station 1 to 12 shown on Plate XXII. The influence of the regional gradient was removed from the field readings to show more clearly the anomalous profile. The regional gradient at this locality was obtained from the Magnetic Vertical Intensity Map of Missouri (1939).

The writer feels that the Magnetic Map of Missouri should not be closely relied upon when used for magnetic investigation of areas as small as area A which is a little over a mile in length. The station spacings of this map in the region of the thesis areas are 2 miles along highways. Therefore, the shape of the regional gradient curve (shown in Plate XXI) should be considered to represent the qualitative rather than the quantitative character of the regional gradient along the traverse. That an anomaly is present in area A is certain but its magnitude as represented by the amplitude of the residual profile is questionable.



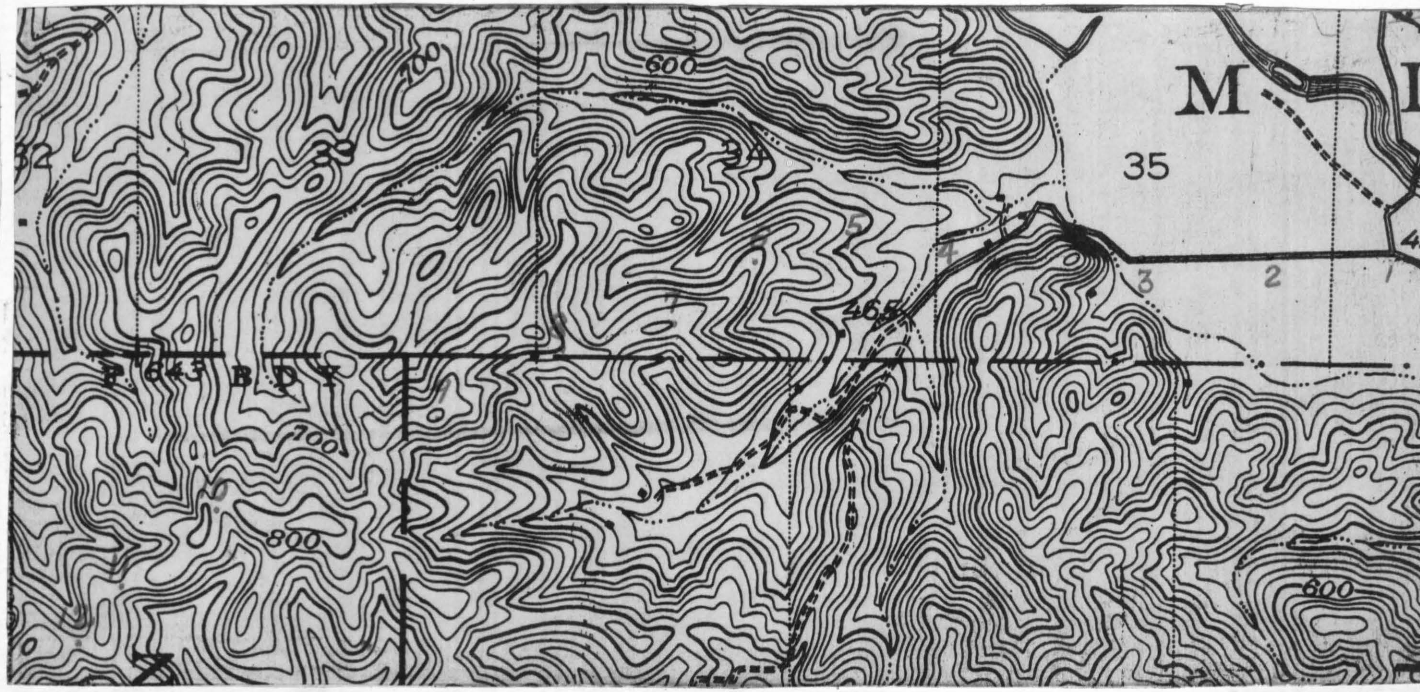
MAGNETIC VERTICAL INTENSITY PROFILE OF AREA 'A', WAYNE COUNTY

PLATE XXI

R 3 E

T 28 N

T 27 N



Topographic map and locations of magnetic stations Area "A", Wayne County.

<u>Area B (Wayne County)</u>.-- The magnetic map (Plate XXIII) of this area does not show a closed anomaly. It represents a nose trending slightly west of north with a maximum magnitude of at least 200 gammas. Its cross sectional profile possesses an asymmetrical outline, the gradient to the east being steeper than that to the west.

The position of the nose does not conform to the area outlined by the drainage pattern. It is displaced slightly east of the area of anomalous drainage. The magnetic map of Missouri shows a closed 200 gamma contour line in exactly the same location as area B.

<u>Area E (Wayne County)</u>.-- The map (Plate XXIV) of this area shows a closed, somewhat circular, asymmetrical anomaly with an approximate maximum magnitude of 312 gammas. This anomaly is not indicated on the magnetic map of Missouri because it is too small to have been detected by the widely spaced magnetic stations used to construct that map. However, the sharp curve of the 100 gamma contour line on the Missouri map possibly can be due to the anomaly of area E.

<u>Area H (Wayne County)</u>.-- The magnetic map (Plate XXV) of this area shows 50 gamma contour lines trending generally northwest. In the upper right corner of the map the contour lines begin to close indicating a maximum positive anomaly. The location of this anomaly is just beyond the northeast limits of area H. The range of the values of magnetic intensity involved in the magnetic map of area H is over 700 gammas.

The magnetic character of area H is represented on the magnetic map of Missouri as part of a positive anomaly of about 900 gammas

PLATE XXIII

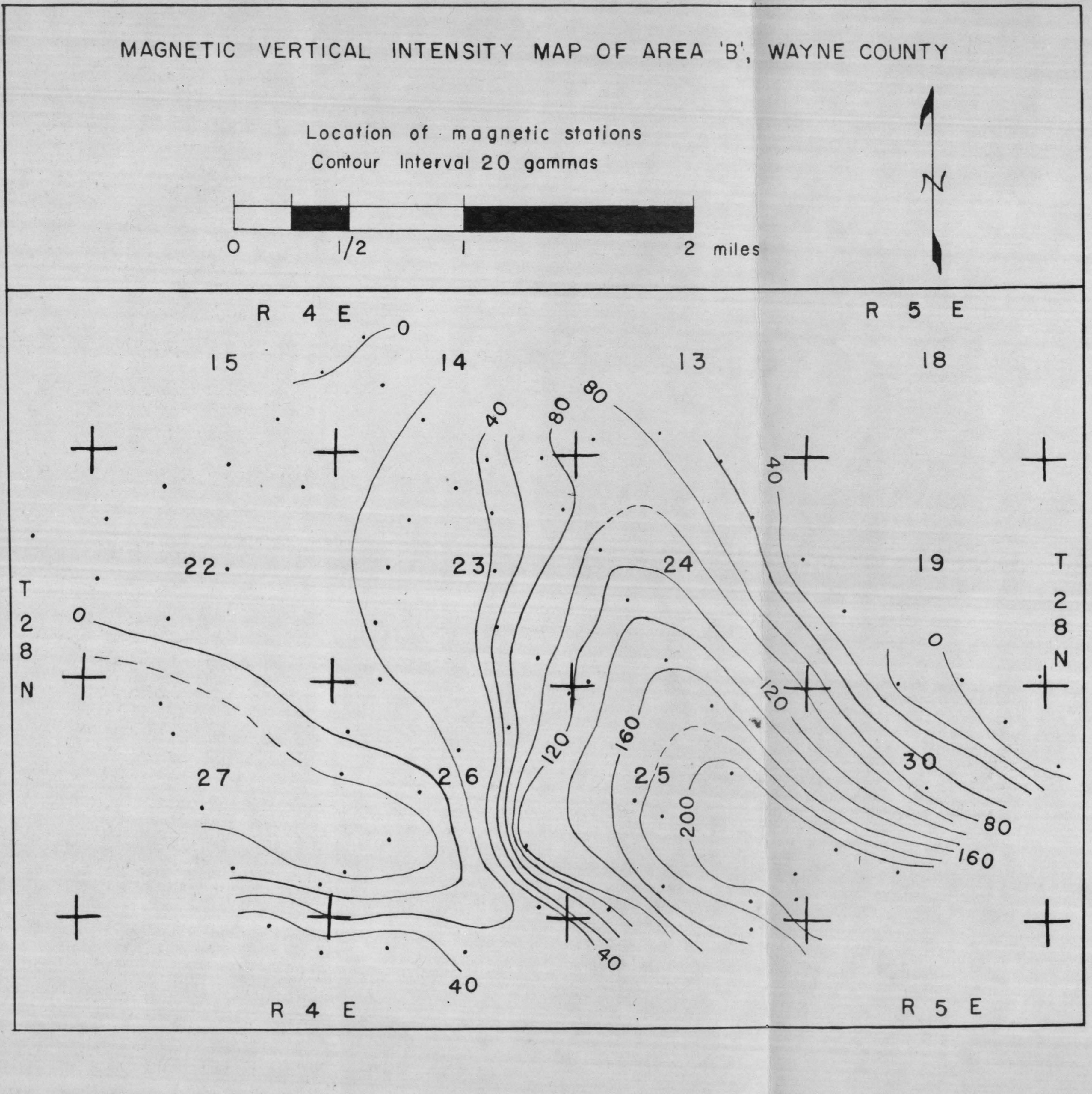
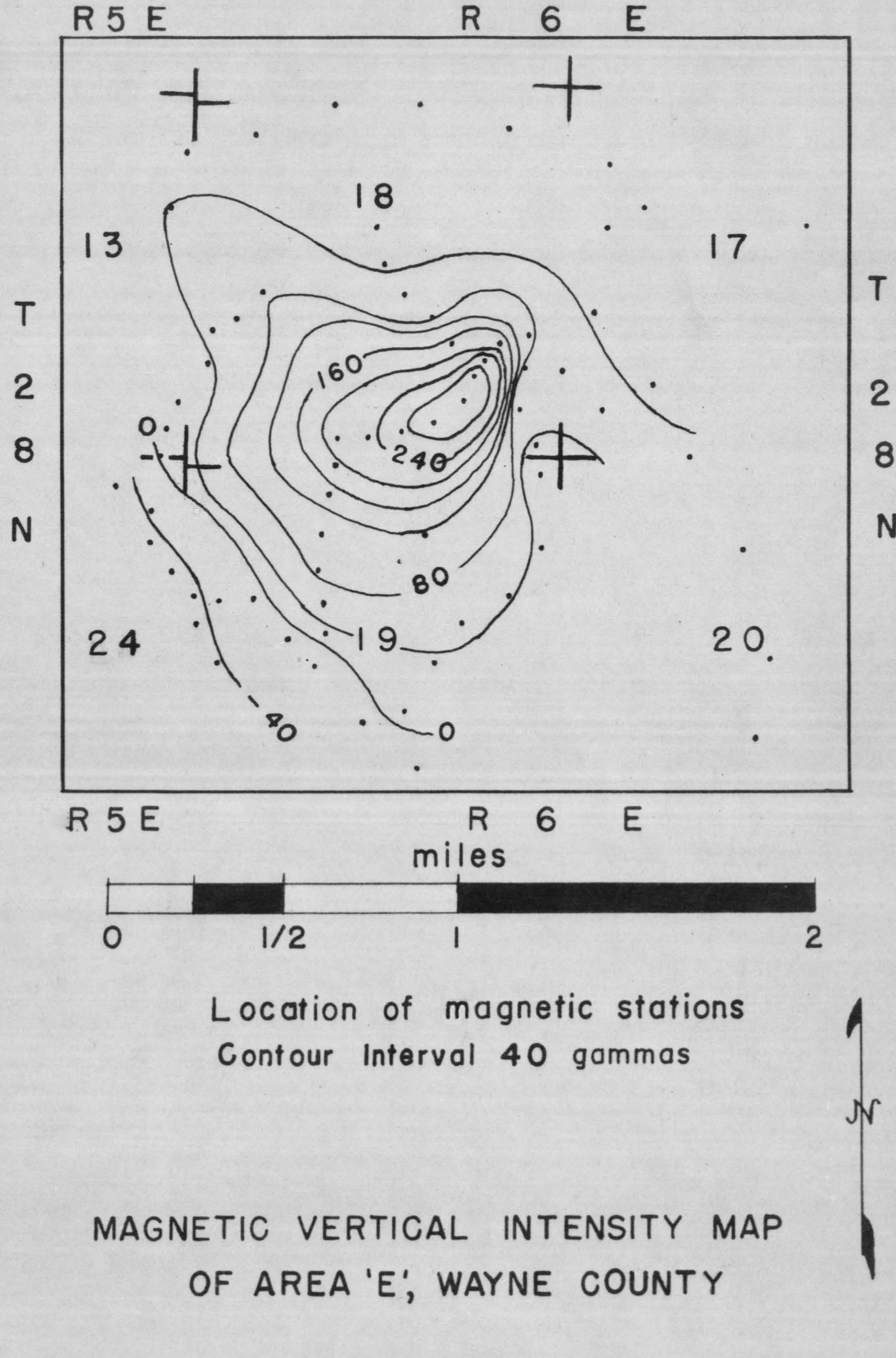

MAGNETIC VERTICAL INTENSITY MAP OF AREA 'B', WAYNE COUNTY
Location of magnetic stations
Contour Interval 20 gammas
0
1/2
1
2 miles
N
R 4 E
R 5 E
15
14
13
18
22
23
24
19
27
26
25
30
T 28 N
T 28 N
0
40
80
120
160
200
R 4 E
R 5 E

PLATE XXIV



MAGNETIC VERTICAL INTENSITY MAP
OF AREA 'E', WAYNE COUNTY

and of large areal extent. Area H occupies the southwestern flank of this anomaly.

Interpretation of Magnetic Data

In the magnetic investigation of any area, after a magnetic map has been prepared it is necessary to interpret the data obtained in order to determine the causes of any anomaly present. If complete data (magnetic map of the area, regional gradient, susceptibility of the rocks present in the area) have been obtained during the survey, quantitative interpretation on an assumed geologic configuration can be done; but if the data obtained are incomplete only qualitative interpretation is possible.

The data obtained for the magnetic investigation of the thesis areas were incomplete. Complete magnetic data were not obtained for the following reasons: 1 - The nature of the thesis problem did not demand the determination of the various physical properties of buried basement highs. It required only the determination of the presence of such features. 2 - To establish the regional gradient necessary for qualitative interpretation it would have been necessary to carry the survey a considerable distance beyond the limits of the study areas. 3 - The inaccuracies involved in the magnetic station values due to the condition of the magnetometer would produce excessive errors in any quantitative interpretation. 4 - Only area L (Reynolds County) within which the basement high is already exposed, and area E (Wayne County) presented an anomaly for which any qualitative interpretation could be carried on. For such an interpretation the susceptibilities of the rocks of the basement high in area E would be required. These rocks are not exposed within or in the immediate neighborhood of area E. The nearest exposed rocks could not be assumed to be the same as those in area E, since different types of basement rocks are exposed approximately 8 miles to 10 miles from area E. To the north are 2 granite exposures west of Bear Creek in secs. 10 and 14, T. 29 N., R. 6 E., (Geologic reconnaissance maps, Missouri Geological Survey). To the northwest latite and rhyolite porphyry are exposed at Logan Mountain, Mudick Mountain, Frenchman's Hill ---etc.(Robertson, unpublished manuscript, Part I, 1952). The magnetic susceptibility value[1] for the granite is 0.7 to 1.8 x 10^{-3} cgs, and for the rhyolite is 0.5 to 2.0 x 10^{-3} cgs. No such values are available for the latite. Moreover, the range of susceptibility values for each rock type is large. To interpret the anomaly of area E in terms of these susceptibility values would involve too much uncertainty to make the interpretation useful.

Four causes can be advanced to account for anomalies like those obtained within the thesis areas. These causes are:

1 - Folded sediments.

2 - Concentration of magnetic minerals in sediments.

3 - Changes in the magnetic susceptibilities of the basement rocks.

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[1] Above values are quoted from a letter dated April 14, 1958 by Mr. J. Allingham, geophysicist, United States Geological Survey, to the writer. Mr. Allingham states that the susceptibility values given above were measured from the basement rocks exposed in Ironton and Fredericktown quadrangles in Missouri. Above quadrangles are approximately 35 miles north of the study area, and the author has assumed for lack of better knowledge the susceptibility values of the basement rocks exposed north of area E to be the same as those of Ironton and Fredericktown quadrangles.

4 - Changes in the relief of the basement.

Appreciable susceptibility differences in folded sediments may cause anomalies similar to those in the thesis areas. Since the Cambrian and Ordovician sediments of Missouri are lacking[1] in magnetic minerals, folded sediments can not account for the magnetic anomalies present in the thesis areas.

Concentration of magnetic minerals in sediments will usually give rise to high anomalies in the order of thousands of gammas. Also due to the irregular distribution of the ore in general the successive station values would not be in the order of uniform increasing or decreasing magnitude as is the case along the different traverses of the magnetic survey. For these reasons concentration of magnetic minerals is excluded as a possible cause of the anomalies of the thesis areas.

Changes in the susceptibilities and in the relief of basement rocks would produce anomalies of the same order of magnitude as were obtained in the surveyed areas. However, the anomalies due to changes in susceptibilities of the basement rocks are usually somewhat higher than those due to differences in relief. Magnitude of the anomalies present in the thesis areas (except area H) indicate that they are more likely to be caused by changes in relief of the basement rocks. The magnitude of the anomaly of area H is well over 700 gammas and is part of a large anomalous area on the magnetic map of Missouri.

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[1] Personal communication with Dr. G. A Muilenburg, Assistant State Geologist, Missouri Geological Survey.

The anomaly of which area H is a part may be caused by changes in the type of basement rocks rather than by basement relief. A support to this idea comes from the exposure of two different types of basement rocks in the region around area H. Eight miles north of area H a rhyolite porphyry knob is exposed (Geologic Reconnaissance Maps, Missouri Geological Survey) at sec. 32, T. 31 N., R. 7 E. Seven miles west of area H two granite exposures are present (Geologic Reconnaissance Maps, Missouri Geological Survey).

It should be emphasized that the magnetic interpretation of the thesis areas is inconclusive. All that can be said is that the anomalies are more likely to be due to increased relief of the basement rocks than to any other cause.

CONCLUSIONS

Drainage pattern analysis from aerial photos was successful in revealing drainage anomalies in Reynolds and Wayne Counties in southeast Missouri. Radial and annular drainage patterns were recognized in small areas located in a region characterized by dendritic drainage.

To determine whether these drainage anomalies signified buried basement highs, field mapping, photogeologic mapping, and magnetic investigation were undertaken. Field mapping proved unfruitful. Photogeologic mapping was partially successful. The photogeologic map of only one area, shows quaquaversal dips. Magnetic investigation was the most successful.

Aerial photo examination of area L (Reynolds County) prior to the field work indicated the presence of exposed bedrock hills which could be of igneous nature. Field check proved that such was the case.

The outline of anomalous drainage (Plate VIII), in area A (Wayne County) and the character of its magnetic profile (Plate XXI) indicate the possible presence of a basement high that is approximately half elliptical in shape. Its longest dimension is inferred to be in an east-west direction and its highest elevation is to be near its western boundary.

The detailed drainage tracing (Plate X) of area B (Wayne County) exhibits a poorly defined oval pattern. The inferred shape of the basement high that causes such an anomalous pattern is more or less equidimensional. The magnetic map (Plate XXIII) of the area shows a nose which extends south with increasing intensity. The axis of the nose is located near the eastern limit of the area. The inferred shape of the basement high based on the magnetic map, does not conform with that inferred from the detailed drainage tracing. This discrepency could be due either to the possibility that the anomalous drainage pattern of the area is not related to the magnetic nose, or if it is, that it has been distorted by the irregular shape of the basement high causing the magnetic nose.

The presence of a buried basement high in area E (Wayne County) is strongly supported by a well defined drainage anomaly (Plate IX), dipping beds (Plate. XVIII) and magnetic anomaly (Plate XXIV), all of which coincide approximately in position. The inferred shape of the basement high is cylindrical.

The drainage tracing (Plate XI) for area H (Wayne County) shows anomalous patterns favorable for the presence of basement highs. The photogeologic map (Plate XIX), and the magnetic map (Plate XXV) do not indicate any anomalies which, on the basis of this study, could be attributed to relief in the basement rocks. The magnetic map of the area is part of a larger anomaly which may be due to changes in susceptibility of the basement rocks.

Of the five areas selected on the basis of anomalous drainage patterns for field investigation, one is positively known to contain basement highs. In two areas the possibility of the presence of such features is excellent. In the fourth area the presence of a basement high which conforms to the drainage pattern on the surface is less likely. In the fifth area the presence of a basement high is improbable. Therefore, it can be concluded that drainage pattern analysis from aerial photos can be used with moderate success in locating buried basement highs in Reynolds and Wayne Counties in Missouri.

SUMMARY

1.- The object of this study was to determine if it is possible to detect buried basement highs by surface drainage pattern analysis from aerial photos.

2 - The general drainage map of Wayne County and south half of Reynolds County was traced from aerial photo mosaics. On this map were indicated the possible anomalous patterns that could be caused by buried basement highs.

3 - Detailed drainage tracings from individual aerial photos were made for those anomalous patterns which merited further study. The selection of the areas to be checked in the field was based on the study of these detailed tracings.

4 - Field work proved to be unfruitful because of the presence of residuum in the areas selected for field investigation.

5 - The photogeologic character of the Roubidoux and Gasconade formations in the Eminence-Cardareva quadrangles were studied. The results of the study were applied to the selected thesis areas. Mapping of these areas in this manner was a partial success in indicating the possibility of buried basement highs.

6 - Magnetic investigation of the selected areas were undertaken. This method proved to be the most successful.

7 - Of the five areas of anomalous drainage selected for field investigation, one is positively known to contain basement highs. Two offer excellent chances for containing such features. In one area the presence of a basement high is less likely. In the last area it is improbable.

APPENDIX I

ANOMALOUS DRAINAGE PATTERNS OF WAYNE AND REYNOLDS COUNTIES

PLATES XII & XIV

Anomalous Drainage Areas in Reynolds County

Area A.— This area shows the same manner of development as area L, described below, but does not possess as strong an anomalous expression. Examination of this area on the topographic map does not favor further study. The stage of dissection is not advanced enough to be classed as mature[1]. This factor casts some doubt as to whether the anomalous drainage pattern of the area means anything.

Areas B, E, H, I.— These areas were considered anomalous because of the sharp sudden curves the streams made in an otherwise straight course. These curves look very similar to those around some of the porphyry hills in the mosaic tracing of the igneous area of Eminence-Cardareva quadrangles. These areas were not selected for further study because the topographic maps suggest entrenched meanders as the cause of the sharp curves in the stream courses .

Areas C and D.— These areas were indicated because of the curved parallelism that exists between neighboring streams. The curved streams are pointed out on the tracing by arrows. Although this parallelism catches the attention of the observor, it is non-symmetrical. The parallel streams in both areas are concave in one direction, and the "other half" is missing. If the "other half" were present, then both areas would have exhibited well developed annular patterns. Furthermore, no radial pattern can be distinguished within either area. Both areas show negative

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[1] See page 19 .

results for the purposes of this report.

Area F.-- This area presents a well developed radial and slightly developed annular patterns that deserve further consideration. It is possible that the drainage pattern shown in this area may be due just to an erosional remnant of sedimentary rock with no structural significance whatsoever. Detailed tracing was made of this area.

Area G.-- The streams indicated by numbers within area G represent an interesting feature developed on a large scale. Number 1 represents Logan Creek, number 2, Dickens Creek, and number 3, Ellington Hollow. The three streams show a striking curved parallelism to each other too conspicuous to pass unnoticed. Over the entire drainage tracing, streams as large as 1 and 2 have southeasterly courses in general. Those of area G make a large curve which changes directions from due south to, due east. After the three streams meet, the resultant stream (Logan Creek) assumes the "normal" southeasterly trend like the rest of the streams in the area. The curves swept by the streams 1 and 2 give the notion that they are trying to avoid "something" or are running parallel to "it". In this manner they have great resemblance to that segement of Current River indicated by number 8 in the mosaic tracing of the drainage pattern of Eminence-Cardareva quadrangles (Plate IV).

Area G was not considered for any further investigations because of its very large size.

Area J.-- The only reason this area was taken into consideration is because of the unusual way the stream that is indicated by the arrow joins the master stream. The drainage tracing shows that tributaries in general make either acute angles pointing downstream or almost right angles when they join larger streams. But the particular stream in this area makes an acute angle with master stream which points upstream instead of downstream. It is possible that a buried basement high would cause such a feature. But the writer jointing seems a more plausible explanation. Besides, the area does not show any annular or radial drainage patterns that can be considered as anomalous.

Areas K and N.-- These two areas have annular and especially radial patterns developed within them. These patterns fall far short of those in area L, below. However, they still afford some possibilities. It is possible that these two areas get their anomalous look from the right angled curve made by the river indicated by the arrow. This right angled curve can be either the result of jointing, or it can be a deflection from the original course as a consequence of encountering a resistant igneous mass concealed by the sediments (like some of the streams in Eminence-Cardareva quadrangles). Detailed tracings were made of both of these areas.

Area L.-- This area shows excellent development of both annular and radial drainage patterns. All the streams involved, from the smallest to the largest, seem to contribute to make this area a very well developed anomalous locality. It looks very much similar to the hypothetical anomous drainage pattern illustrated in figure 1, page 19. Area L was selected for further study.

Anomalous Drainage Areas of Wayne County (Plate XIV)

A glance at the mosaic drainage tracing of Wayne County will bring to attention the low drainage density in the northern and northwestern portion of the county as compared to the rest of it. A closer local examination of the low drainage density will show great similarity to the drainage pattern shown in Plate IV. To be noted especially are the areas labeled 1 and 2 (Plate XIV). These areas are inferred to be exposed igneous hills. This prediction is verified by examination of the same areas on the topographic maps (Piedmont and Des Arc quadrangles) and unpublished geologic reconnaissance maps (Missouri Geological Survey).

These areas could not be considered for investigation because the theme of this report concerns buried knobs and not any that are exposed to such a large degree.

Another point to note about the drainage tracing of Wayne County concerns the extreme southeast part of it. In the area labeled "Lowlands" the photo mosaic does not show enough drainage to make the area worth tracing. Most of the streams which leave the upland disappear as soon as they cross the dividing line between the upland and the lowland. Only the larger streams can be traced in the lowlands area. Also, there seems to be a notable absence of streams originating in this area. Considering all of these factors just mentioned no drainage whatsoever was traced in the "Lowlands" area.

As for the areas considered as anomalous, they are indicated by letters as in Reynolds County, and they are discussed below.

Area A and E.-- These areas have a well developed radial pattern. They have good annular patterns which involve only two streams, in each of the areas. However, examination of the topographic maps (Piedmont quadrangle for area A, Greenville quadrangle for area E) show that other streams not detected on the tracing contribute in making these areas more anomalous. A detailed tracing was made of areas A and E.

Area B.-- The anomalous drainage pattern of this area does not look as good as that of area A or E. But the writer thinks it is better than those of areas D and G. The radial pattern is not too well developed, but the annular pattern shows a somewhat better development. As a whole the drainage pattern of the area exhibits a vaguely defined oval outline. This area was included in the detailed studies.

Areas C and F.-- The drainage pattern of these areas and especially that of C, shows somewhat annular development. The radial pattern is poorly developed in both areas. The annular pattern involves only one or two medium size streams in these areas. As shown by dashed lines on the drainage tracing both areas occur in slightly dissected uplands which do not exhibit stages of maturity. Examination of these areas on the corresponding topographic maps (Piedmont quadrangle for area C; Greenville quadrangle for area F) makes this fact clear.

Because of rather poorly developed anomalous drainage patterns, and because of lack of mature dissection in these areas, they were not considered for further investigation.

Areas D and G.-- Area D exhibits a poor radial drainage pattern, and a rather well defined annular one. The annular pattern involves only the two large streams bounding the area. The assemblage of streams observed as a whole in area D does not seem to contribute to its anomalous appearance.

Area G exhibits the same drainage characteristics as area D except for a better radial pattern. The northern half of area G is located in slightly dissected upland, and this fact makes the area unfavorable.for further study. Area D was selected for further study.

<u>Area H</u>.-- This area has a somewhat well developed radial pattern. Its annular pattern is not as well defined as its radial pattern. If all the streams in the area are considered as a whole this area shows an anomalous pattern that is worth considering, hence it received further study.

<u>Area I</u>.-- Area I falls in the same catagory as area C. Except for an annular pattern that is partly well developed, it does not process any characteristics that make it desirable for further investigation.

<u>Area J</u>.-- Area J was indicated simply because of the anomalous half circular course of the large stream within it. The area does not show any further anomalous drainage pattern to make it eligible for further consideration. This conclusion is strengthened by examination of the topographic map.

<u>Area K</u>.-- A vague anomalous pattern is present in the drainage of this area. Both radial and annular patterns can be distinguished but they are not very outstanding. Although the anomalous character of the

drainage of this area is better than that of area J, it cannot match those of areas E and A.

A feature to be noticed on the mosaic tracing of Wayne County is the deflection of Black River (where labeled by number 2) from its SSE course. Before it deflects, Black River runs in the SSE direction. Then it goes around a large curve, and in this resembles the curves pointed out in area G of Reynolds County. It continues its SSE course after going around the curve. It is interesting to note the location of areas C and B in relation to the deflection position of the Black River.

APPENDIX II

ANOMALOUS DRAINAGE AREAS STUDIED IN DETAIL

From among the anomalous areas discussed in Appendix I the author selected areas F, K, L, and N in Reynolds County, and areas A, B, D, E, and H in Wayne County for purposes of further investigation. For each of these areas a detailed tracing from individual aerial photos was made with the aid of the stereoscopes. Area L in Reynolds County and areas A, B, E, and H in Wayne County, for which magnetometer surveys were made, are described on pages 66 to 81of the text. The remaining areas are discussed below.

<u>Area F</u> (Reynolds County)

Aerial photos: BMB 4-23 to 25, 4-79 to 81

Topographic map: Lesterville quadrangle, SE$\frac{1}{4}$ sec. 34, SW$\frac{1}{4}$ sec. 35, T. 31 N., R. 1 E.
W$\frac{1}{2}$ sec. 2, sec. 3, N$\frac{1}{2}$ sec. 10, T. 10 N., R. 1 E.

The second tracing of area F revealed quite a few first magnitude streams which could not be detected in the first mosiac tracing. Although the medium size streams still exhibited the radial pattern as in the first mosaic tracing, the lower magnitude streams which were brought to attention in the detailed tracing did not help to strengthen the anomalous pattern of the medium size streams. The lower magnitude streams do not display any radial or annular patterns to make the area favorable for further consideration.

<u>Areas N and K</u> (Reynolds County)

Aerial photos: Area N: BMI 10-25 to 28, 1-4 to 7
Area K: BMB 1-28 to 31, 2-38 to 44

Topographic map: Area N: Ellington quadrangle, sec. 23, S$\frac{1}{2}$ sec. 24, sec. 25, NE$\frac{1}{4}$ sec. 26, N$\frac{1}{2}$ sec. 36, T. 29 N., R. 2 E.
W$\frac{1}{2}$ sec. 30, T. 29 N., R. 3 E.

Area K: Ellington and Piedmont quadrangles, W½ sec. 4, E½ NW¼ sec. 5, T. 28 N., R. 3 E.
SW¼ sec. 29, SE¼ sec. 30, E½ sec. 31, sec. 32, T. 29 N., R. 3 E.

The detailed tracings of areas N and K reveal many lower magnitude streams which were undetected previously. The drainage of area K shows a somewhat anomalous pattern. The medium size streams possess a recognizable radial character, and the lower magnitude ones reveal both radial and annular patterns that are not as well defined as those of the medium streams.

Area N does not seem as anomalous as area K. The radial pattern is not well developed in any of the streams. The annular pattern is even less promising.

Area D (Wayne County)

Aerial photos: BMI 4-64 to 67, 4-24 to 29, 3-71 to 74

Topographic map: Piedmont quadrangle, SW¼ sec. 5, secs. 6, 7, 8, W½ sec. 9, N½ SW¼ sec. 17, E½ NW¼ sec. 18, T. 28 N., R. 5 E.
sec. 1, E½ sec. 12, T. 28 N., R. 4 E.

Drainage pattern of area D on the detailed tracing possesses strikingly similar features to those in the drainage patterns around some of the porphyry knobs in Eminence-Cardareva quadrangles.

If all except the two large streams which bound the area and a few first and second magnitude streams are removed from the drainage tracing of area D it will look very much like the drainage pattern around the porphyry knobs in Plate IV. The sharp deflection of Lake Creek is very notable and can be compared with the deflection of streams 6 and 7 in Plate IV. The half circular course of Lake Creek is also very anomalous and forms a nice annular pattern with Wet Creek.

If the assemblage of streams in this area are examined, local anomalous patterns can be recognized. The most conspicuous of these is that labeled number 1 on Plate XXVI. A local radial pattern can be distinguished. Also to be noted is the deflection of Lake Creek further south as it approaches this area. Other less conspicuous anomalous patterns can be detected in areas 2 and 3. It is worth noting the right angled deflection of Lake Creek to avoid area 3.

All these pecularities mentioned above about area D were not noticed when it was first examined. At that time a close relationship between all the streams of the area was being sought. The area was dismissed for its failure to reveal any anomalous pattern involving all streams. Later examination brought the facts mentioned above to the attention of the author.

APPENDIX III

AERIAL PHOTO REFERENCES TO PHOTOGEOLOGIC CHARACTERISTICS OF GASCONADE AND ROUBIDOUX FORMATIONS

Example 8 - Gasconade and Roubidoux cannot be separated from each other
- a - BMD 1-18 (3.7, 1.4) No evidence of Gasconade
- b - BMD 10- 7 (-1.3, -2.4) No evidence of Gasconade
- c - BMD 10-77 & 78 many ridges indicate Gasconade on the geologic map, but on the photos they have the expression and tone of Roubidoux
- d - BMD 10-50 (0.8, 2.2) No evidence of Roubidoux
- e - BMD 10-12 (0.0, -1.7) No evidence of Roubidoux
- f - BMD 1-28 (1.2, 1.8) No evidence of Roubidoux

Example 9 - Reef areas that show Roubidoux characteristics
- a - BMD 10-63 (-1.6, -2.4)
- b - BMD 10-63 (-0.5, 1.8)
- c - BMD 10-64 (-2.0, 2.5)
- d - BMD 10-99 (-3.0, -1.1)

Example 10 - The Gasconade cryptozoan reef
BMD 1-21 to 28

Example 11 - Isolated small patches of Gasconade on Gunter ridge top
- a - BMD 10-57 (0.5, 2.5)
- b - BMD 10-66 (1.6, 2.3)

Example 12 - Gunter sandstone well exposed
- a - BMD 10-63 (-2.9, -2.5)
- b - BMD 10-64 (-2.7, 2.7)
- c - BMD 10-65 (1.6, 2.5),
- d - BMD 10-57 (1.4, 1.5)
- e - BMD 10-14 Gunter forms distinctive ledges at the hills south of the river

Example 13 - Gunter indicated by vegetation
- a - BMD 10-32 (-3.1, -1.5)
- b - BMD 9-40 (0.9, -2.2)

Example 14 - Gunter cannot be detected
- a - BMD 6-82 (-1.8, 1.6)
- b - BMD 6-81 (+2.6, -2.4)

Example 15 - Igneous hills well exposed
- a - BMD 10-24 (1.4, 1.7)
- b - BMD 10-26 (-3.3, -3.1)
- c - BMD 10-27 (1.7, -2.7)
- d - BMD 9-27 & 28

Example 16 - Igneous hills not well exposed
- a - BMD 7-62 (1.7, 1.7)
- b - BMD 7-62 (1.0, 2.6)
- c - BMD 7-72 (-0.5, -2.9)
- d - BMD 10-27 (2.7, -1.4)

The above photos were taken for the Commodity Stabilization Service, U. S. Department of Agriculture, Washington 25, D. C.

The first number in the following examples, e.g. BMD 10-63, refers to the aerial photos. The two numbers within the parenthesis e.g. (-0.5, 0.2) refer to the cartesian coordinates of the feature discussed. The coordinates are given in inches and are measured from the principal point of the aerial photo, with the positive abscissa in the geographic east direction.

Example 1 - Roubidoux in upland areas
a - Photos BMD 1-19, 20, 21
b - Photos BMD 1-28 to 31

Example 2 - Ridges made up of Roubidoux or capped by Roubidoux
a - BMD 10-63 (-0.5, 0.2) topographic expression, tone contrast
b - BMD 10- 2 (-1.2, -1.9) topographic expression, little tone contrast
c - BMD 10--7 (-1.0, 2.3) topographic expression, grades into Gasconade
d - BMD 1-21 to 22 Roubidoux capping ridges of Gasconade

Example 3 - Isolated patches of Roubidoux on ridges made up Gasconade
a - BMD 10-68 (0.4, -1.8) topographic expression
b - BMD 10-52 (-2.9, -1.6) topographic expression, tone contrast
c - BMD 10- 7 (1.2, -3.0) topographic expression, tone contrast
d - BMD 10-11 (-2.4, -2.6) topographic expression, tone contrast
e - BMD 10-12 (-1.9, -2.1) topographic expression, tone contrast

Example 4 - Ridges made up of Gasconade or capped by Gasconade
a - BMD 10-63 (0.4, 3.1)
b - BMD 10-64 (-0.3, 2.0)
c - BMD 10- 7 (-0.3, 1.9)

Example 5 - Good topographic break between Roubidoux and Gasconade
BMD 1-21 to 28

Example 6 - Contact between Roubidoux and Gasconade indistinct
a - BMD 10-50 (-2.5, +1.9)
b - BMD 10- 2 (-1.2, -1.9)
c - BMD 10- 5 (+1.0, -2.3)
d - BMD 10-28 (-1.5, +1.9)

Example 7 - Good tone contrast between Roubidoux and Gasconade
a - BMD 10-63 (-0.5, 0.2)
b - BMD 10-50 (-2.5, 1.9)
c - BMD 10- 8 (1.9, -1.8)
d - BMD 1-21 to 25

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