# THE STRUCTURAL GEOLOGY OF THE COTTONWOOD LIMESTONE IN RILEY COUNTY, KANSAS

by

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# INTRODUCTION

The area (Plate I) covered by the research project lies in the southeast portion of Riley County. It is bounded on the east by Wabaunsee County and on the northeast by the Blue River. It extends 16 miles north of the Geary County line, and westward to the Fort Riley Military Reservation.

The purpose of the investigation was (1) to gain a knowledge of the local geologic structure, (2) to work out a possible theory for its origin, and (3) to compare the drainage pattern with the structural pattern for possible causal relationships.

In order to carry out such a research project, a good base map showing the drainage in considerable detail was essential. Since such a map was not available, it was necessary to construct one from aerial photographs. This entailed a considerable amount of preliminary work and presented a most difficult problem of photographic reduction in order to reproduce the maps as a single sheet. The maps as originally drawn were in eight separate sections, covered an area of approximately 64 square feet, and represented a land area of about 200 square miles.

The area chosen for the study was the one in which the Cottonwood limestone outcrops because the Cottonwood is particularly well suited as a key bed for structural mapping. It is easily identified because of its cherty character and fusulinid fossils. It makes conspicuous outcrops and is relatively thin. No other rock layer in the immediate vicinity

## EXPLANATION OF PLATE I

Roads

- Federal (US) highways
- State, county, township roads
- Poor roads

Bridges

Railroads

Boundary lines

- County
- Township
- Military Reservation

Streams

- Major streams
- Minor streams
- Intermittent streams
- Drainage

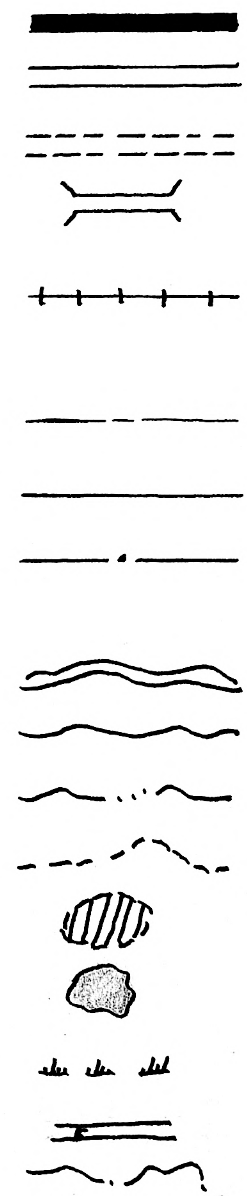
Intermittent lakes

Floodplain

Marsh

Dams

Cottonwood limestone outcrop

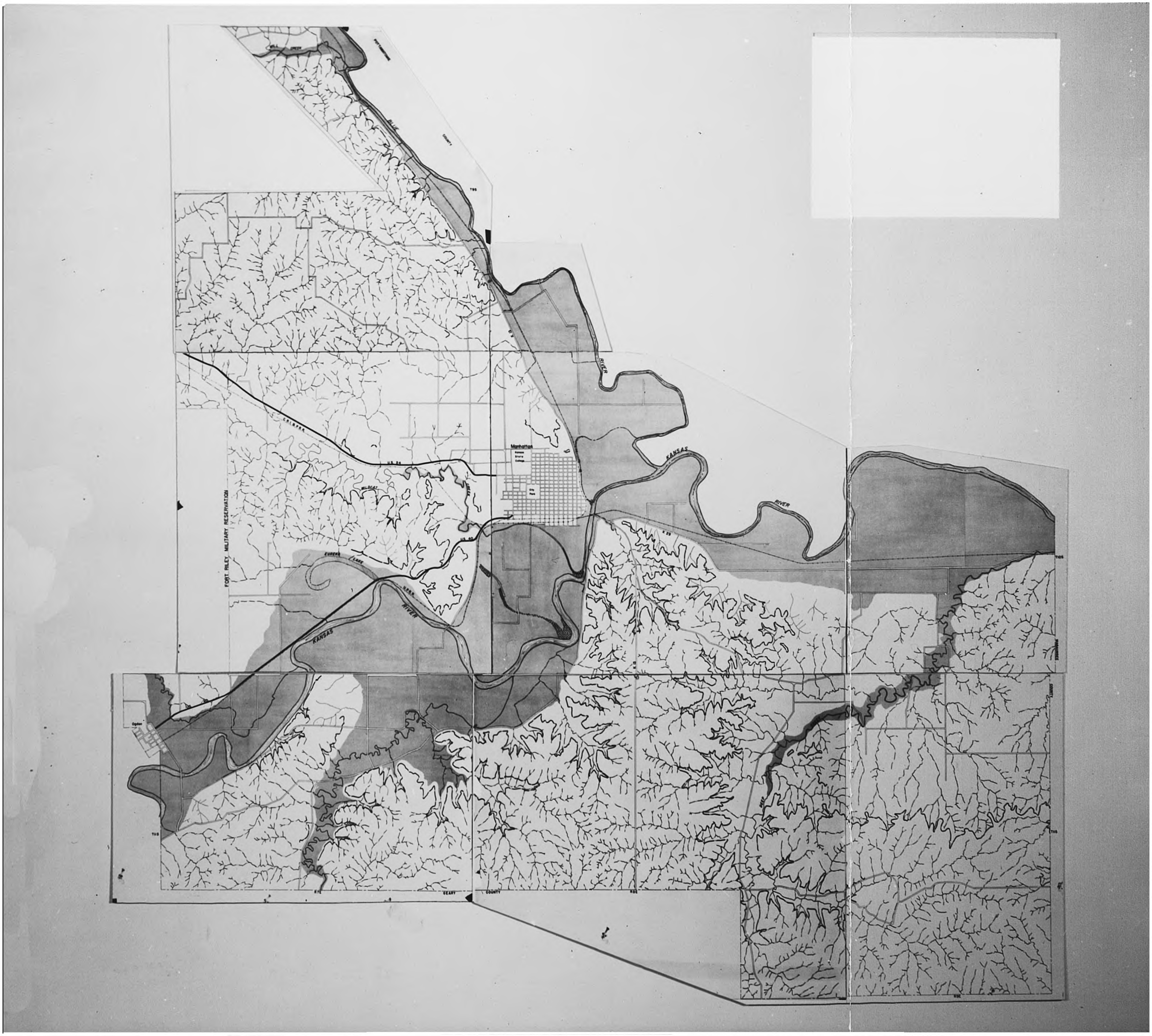


North

Scale 1" = ½ mile, approx.

1948

PLATE I



BLUE
RIVER
KANSAS
RIVER
Manhattan
FORT RILEY MILITARY RESERVATION
WILDCAT
EUREKA
LAKE
KANSAS
RIVER
Ogden
GEARY
COUNTY

possessed these desirable qualities. However, since the outcrop area covered about 200 square miles, another serious problem arose, namely, the method to be used in mapping such a large area accurately and in a reasonable length of time. It was decided that this might be accomplished by using aerial photographs in the field. A plan of procedure, which will be described subsequently, was worked out, but since the method was new in many aspects it was necessary to make a careful analysis of its accuracy.

## TOPOGRAPHY AND GEOLOGIC SETTING

The region is a portion of the Great Plains Physiographic Province and is in the mature stage of the cycle of erosion. Its maximum relief is between 300 and 400 feet. Because of the moderately high relief and the mature stage in the cycle of erosion, the rock formations are generally well exposed. The major rivers are the Kansas and the Blue. The Blue River is smaller and is a tributary of the Kansas. Both of these streams are in maturity and have broad flood plains, Plate I. The major creeks are the Wildcat, Deep, McDowell and Mill Creek. These streams also have flood plains, but since they are relatively narrow, they do not cover as large a bedrock area. Along both the major and the minor streams, terraces representing the former level of glacio-fluvial deposition are present.

The drainage pattern in the region is dendritic and the hills are pronouncedly terraced. The terraces resulted from the differential weathering and erosion of the Permian limestones and shales which underlie the region. Since these sediments are relatively thin as compared with the nearly 400 feet of relief, the rock terraces are quite numerous. The more pronounced terraces represent the more resistant limestones and the Cottonwood is one of these. The mantle covering over the hills is relatively thin and the vegetation sparse. Trees grow only on the lower slopes and along stream courses. The topographic and geologic conditions make the area particularly well suited for the type of mapping used in this investigation.

## PREPARATION OF THE BASE MAP

In recent years the Department of Agriculture has taken aerial photographs of all the major farm and forest lands of the United States. These photographs can be purchased from the Department of Agriculture and have been used in various engineering and geologic projects. The photographs from which the base map was made were obtained from this agency. They are 5/3 enlargements of 9x7 and 9x9 contact prints and have a scale of 1" = 1,000 feet.

The equipment used for tracing the necessary detail off the aerial photographs in the preparation of the base map were transparent overlay sheets of "frosted" celluloid and a stereoscope. The stereoscope helped to distinguish features which could not be recognized easily and to trace stream courses through thickly wooded areas.

Two methods were used in aligning the photographs under the celluloid overlay: the section grid method (Birdseye, 1928) and the radial line plot method (Smith, 1943).

The section grid method was the simpler of the two. It was used in the preparation of approximately two-thirds of the base map. The method was especially successful in this area as most of the section lines are marked by roads or fences which are easily recognized on the photographs.

In some regions where the section grid method could not be used successfully because of a lack of section line roads and fences, the radial line plot was used. It was also employed in aligning photographs where there were offsets in the section lines due to the convergence of the meridians. These areas could have been scaled off onto the overlay and the section grid method continued, but this would have necessitated the scaling of the distance from maps which may be inaccurate, or measuring the exact distance in the field which would have necessitated additional work.

Each township was mapped separately and after it was completed, it was mounted on a white board. Since the completed maps of all the townships when fitted together would have been 8 feet square using a scale of 1 inch to 1,000 feet, it was necessary to reduce them to a convenient size. After this was done to each township map, all were fitted together in their proper order and photographed as a single unit. The map, Plate I, was then ready for use as a base map on which the structural elevations were marked and the structural contouring carried out.

## MAPPING PROCEDURE

The equipment used in the structural mapping of the area consisted of a scale, a plane table, an alidade, and a table of tangents in addition to the base map and the aerial photographs. No rod or stadia board was required because all distances were measured directly from the photo or the base map. In a preliminary reconnaissance of the area, the outcrops of the Cottonwood limestone were traced directly upon the aerial photographs and possible instrument stations were spotted in the most advantageous positions. This was done to obtain the greatest number of rock shots from one setup. In addition to the tracing of the Cottonwood outcrops and the spotting of the instrument stations, sites within easy visibility of the instrument stations were selected as secondary bench marks. They were set in any high object such as water towers, silos, chimneys, and other land marks that could be identified and located on the photographs. The college smokestack was chosen as the primary bench because it overtopped all the hills in its immediate vicinity and was visible from the majority of the instrument stations. The actual structural mapping was comparatively simple. It consisted of eight major steps:

1. The instrument was set up on an instrument station.

2. A middle-hair backsight was taken either on the primary bench or a secondary bench and the vertical angular difference in elevation read off the tangent scale.

3. The photo-distance between the instrument station and the bench was measured.

4. The vertical difference in feet was computed from a table of tangents and an average of at least three readings was taken to determine the height of the instrument.

5. A middle-hair foresight was taken to the top of as many Cottonwood outcrops as possible and the vertical angular differences in elevations were read off the tangent scale.

6. The photo-distances between the instrument station and the rock shots were measured.

7. The vertical differences in feet were computed from a table of tangents and the calculated rock elevations were spotted on the photographs.

8. The elevations of the tops of the Cottonwood were transferred to an overlay sheet covering the base map, and were finally contoured.

The conditions pertaining to the first four steps are diagramed in Fig. 1; while the conditions pertaining to steps five, six and seven are diagramed in Fig. 2. In these diagrams A-B and X-Y are the respective horizontal distances as measured on a photo from the instrument station to the College smokestack and from the instrument station to a Cotton-

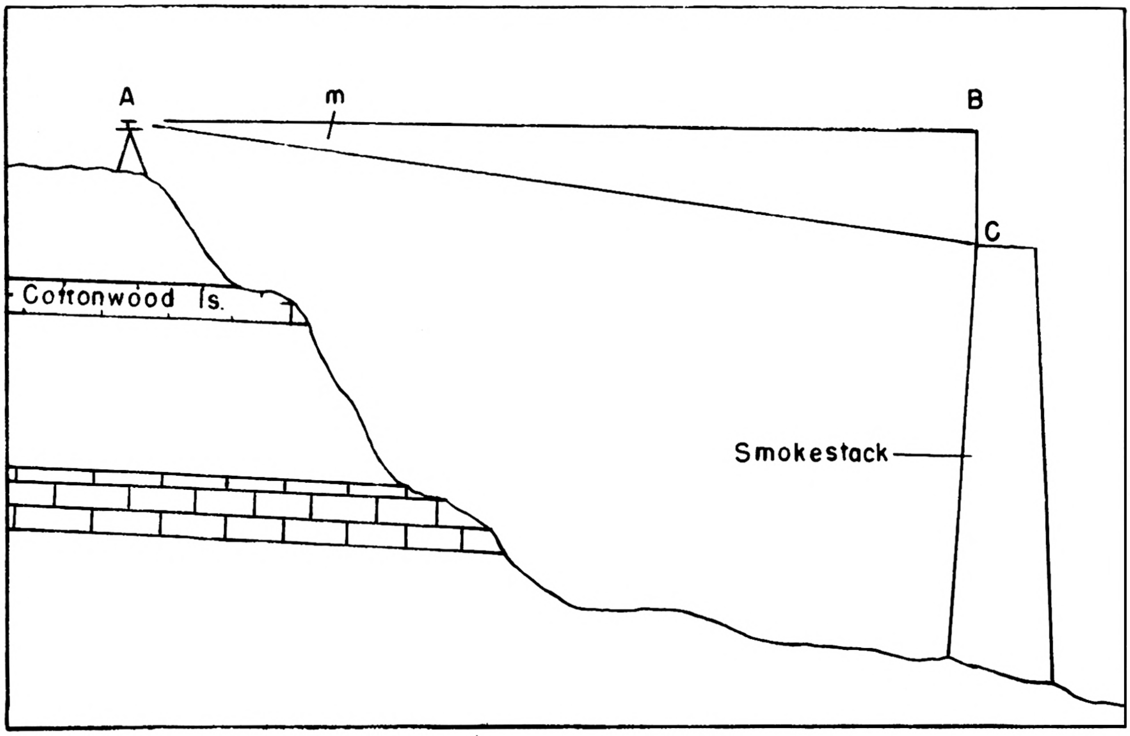



Fig. 1. Instrument setup for backsight to primary benchmark.

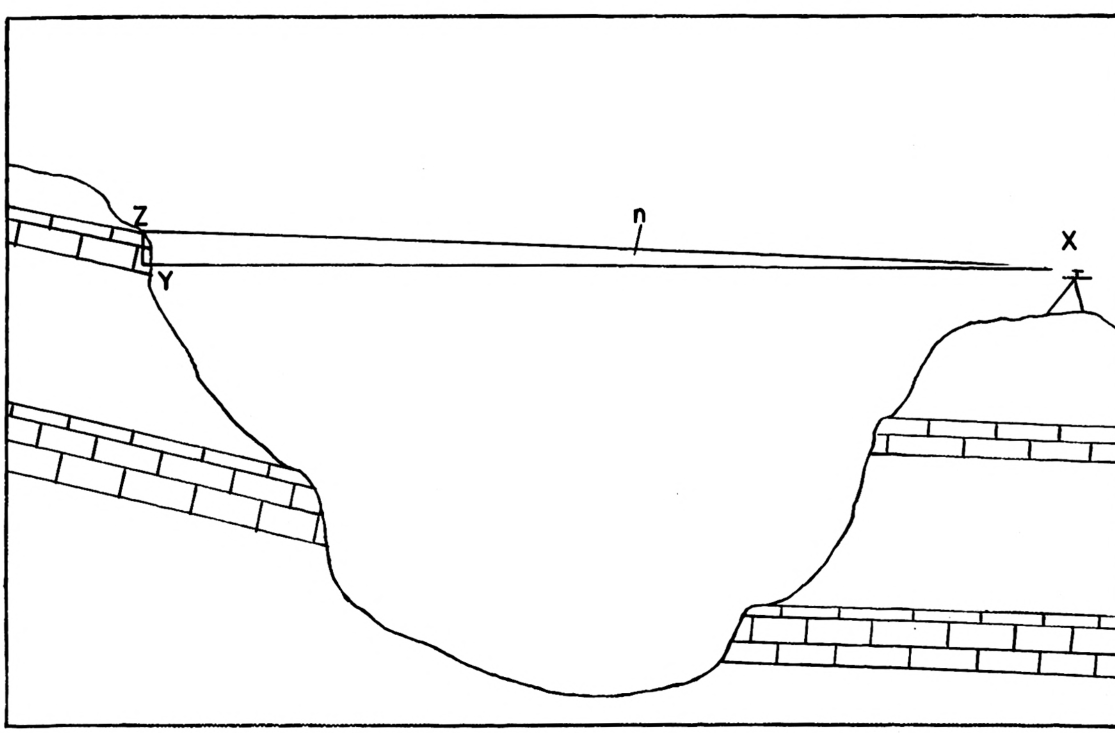



Fig. 2. Instrument setup for foresight to rock outcrop.

wood outcrop. The angles m and n are the respective vertical angular distances as read on the tangent scale. It is apparent from a study of these diagrams that the vertical differences in elevation B-C and Y-Z are functions of the tangent of the angles m and n, and that

BC = Tan m x AB

YZ = Tan n x XY

If the following values are assumed

AB = 2,500 feet (as scaled off the photo)

XY = 2,000 feet (as scaled off the photo)

m = 0 degrees and 45 minutes

n = 0 degrees and 30 minutes

Then BC = Tan 0 degrees and 45 minutes x 2,500 feet

or BC = .01309 x 2500

or BC = 32.7 feet

The height of the instrument would be

1284.5 feet (elevation of smokestack top) plus

32.7 feet or 1317.2 feet

Calculating the value of YZ

YZ = Tan 0 degrees and 30 minutes x 2,000 feet

or YZ = .00875 x 2,000

or YZ = 17.5 feet

The elevation of the top of the Cottonwood would be 1317.2 feet (height of instrument) plus 17.5 or 1334.7 feet.

Corrections for curvature and refraction were made for all back sight shots to bench marks in excess of 2,500 feet horizontal distance, and for all rock shots in excess of one mile horizontal distance. To make certain that the rock shot elevations revealed the true directions of dip, they were spaced at least 1,000 feet apart. It was thought that at 1,000 feet the dip factor would dominate over the effect of any local slumping and the error factor in determining the true top of the Cottonwood. Since the Cottonwood averaged only about six feet over the entire area, it would be impossible to make more than a six foot error in estimating its top. Rock shots to the nose of a ridge or to the head of a draw were avoided as much as possible because at those points the slump factor was the greatest.

## FACTORS OF ERROR

In view of the fact that the method employed in the structural mapping was new in many respects, it was advisable to make an analysis of all error factors so that the validity of the structural map might be ascertained. The error factors were classified as follows:

- Human factors of error:
    - Errors in mathematical computations
    - Errors in scaling photo-distances
        - Faulty spotting of locations
        - Reading the scale incorrectly
- Errors in reading vertical angles
- Errors in estimating the top of the key bed

Failure to detect mechanical defects in the instrument

Photographic factors of error: (these affect photo-distances)

Horizontal displacements because of tilt

Horizontal displacements because of relief

Horizontal displacements because of spherical abberation

Since human errors are largely due to carelessness, careful work and frequent check-backs reduce them to a minimum. However, because of human limitations, small errors in reading vertical angles, and in spotting locations for the measurement of photo-distances can not be avoided altogether. A slight error made in measuring a short distance together with a slight error made in reading a very small vertical angle has a negligible effect on the accuracy of the vertical difference in elevation. But, reading a large angle with an error of the same percent magnitude as a small angle, produces a considerable error in the vertical difference in elevation. To remedy this situation, the instrument was always set as near level as possible to the point sighted and at a distance of at least 2,000 feet (an error of 100 feet in spotting a location at this distance would be relatively insignificant).

The photographic factors of error can not be eliminated from the photos since they are inherent qualities. It was, therefore, necessary to evaluate their magnitude in order to determine their effects.

McCurdy (1940) has calculated the maximum amount of displacement that could occur in a 9x9 inch print with a tilt of three degrees. The displacement amounted to .23 inch. In terms of ground distances (photo scale of 1 inch equals 1666 feet), this would represent a 383 foot displacement in 9996 feet (6" x 1666 feet). The scale used in these computations is based on the contact print but since the process of enlargement does not in any way affect relative ground distances, the error factor in the 5/3 enlargements would also be 383 feet. It is doubtful whether any of the photos used in the field had a tilt of as much as three degrees, and since a displacement of 383 feet out of 9996 amounts to a vertical error of only 13 feet when an angle of 2 degrees is read on the tangent scale (2 degrees is larger than the average angle measured for long distances), the tilt factor is appreciably less than the dip factor of the Cottonwood. It is apparent that tilt can be dismissed as a serious error factor in the structural mapping.

The amount of horizontal displacement due to relief can be calculated from the formula given by McCurdy (1940). For a rock shot six inches away from the principal point at an elevation of 300 feet above the Kansas River floodplain, the amount of horizontal displacement (photo scale of one inch equals 1660 feet) would be about 300 feet in a horizontal distance of 9996 feet (6" x 1666 feet). Since the instrument stations were always set as near to the Cottonwood datum as possible, this error factor was essentially eliminated.

The magnitude of displacements due to spherical abberation is essentially of the same order as that calculated for the tilt and relief, but since displacements of this magnitude were restricted primarily to approximately a 2 inch wide zone around the outer edge of the photos, no measurements were made here. In fact since all the photographic factors of error, tilt, relief, and spherical abberation increase toward the margins of the photos, particular care was taken to avoid marginal measurements.

## MERITS OF MAPPING PROCEDURE

This method of mapping is relatively new; however, it is not the first time that aerial photographs have been used in mapping. The method is extremely useful in a region such as was mapped. The outcrops are well exposed and are easily traced. The method eliminated the services of one man as the rod man's place is taken by the aerial photographs. There is no need of orienting the plane table since all points are located and spotted on the photos. The method is also much faster than conventional methods since there is no need of walking outcrops. Very minor structures can be found but there is a chance that some of the supposed structures are due to unavoidable error factors in the method. Unevenness of bedding, eroded bed rock surfaces, and slump due to weathering introduce error factors about the same magnitude of the limits of error of the method; however, these error factors would also occur in the conventional methods. Using a method of greater accuracy would not be of any great practical value in determining structure. The method was as fast or faster than most conventional methods and the amount of man hours was cut over 50 percent on the entire survey.

DESCRIPTION OF THE STRUCTURE

The area (Plate I) has a general regional dip of about 15 feet per mile to the northwest. The dominant type of structures in these gently dipping strata is a series of four asymmetrical noses, and three asymmetrical pitching synclines. The axes of the noses run approximately at right angles to the regional strike of the strata. All of them close in the direction of regional dip to the west. Their maximum pitch is about 30 feet per mile and the average about 20 feet per mile. The maximum dip is found at the head of the steeply pitching syncline in the southeastern part of the area. It is about 180 feet per mile. The highest nose rises about 75 feet above the average regional dip. The pitching synclines trend parallel to the anticlinal axes and have approximately the same amount of pitch.

RELATION OF STRUCTURE TO DRAINAGE

The three synclines in the central part of the area lie

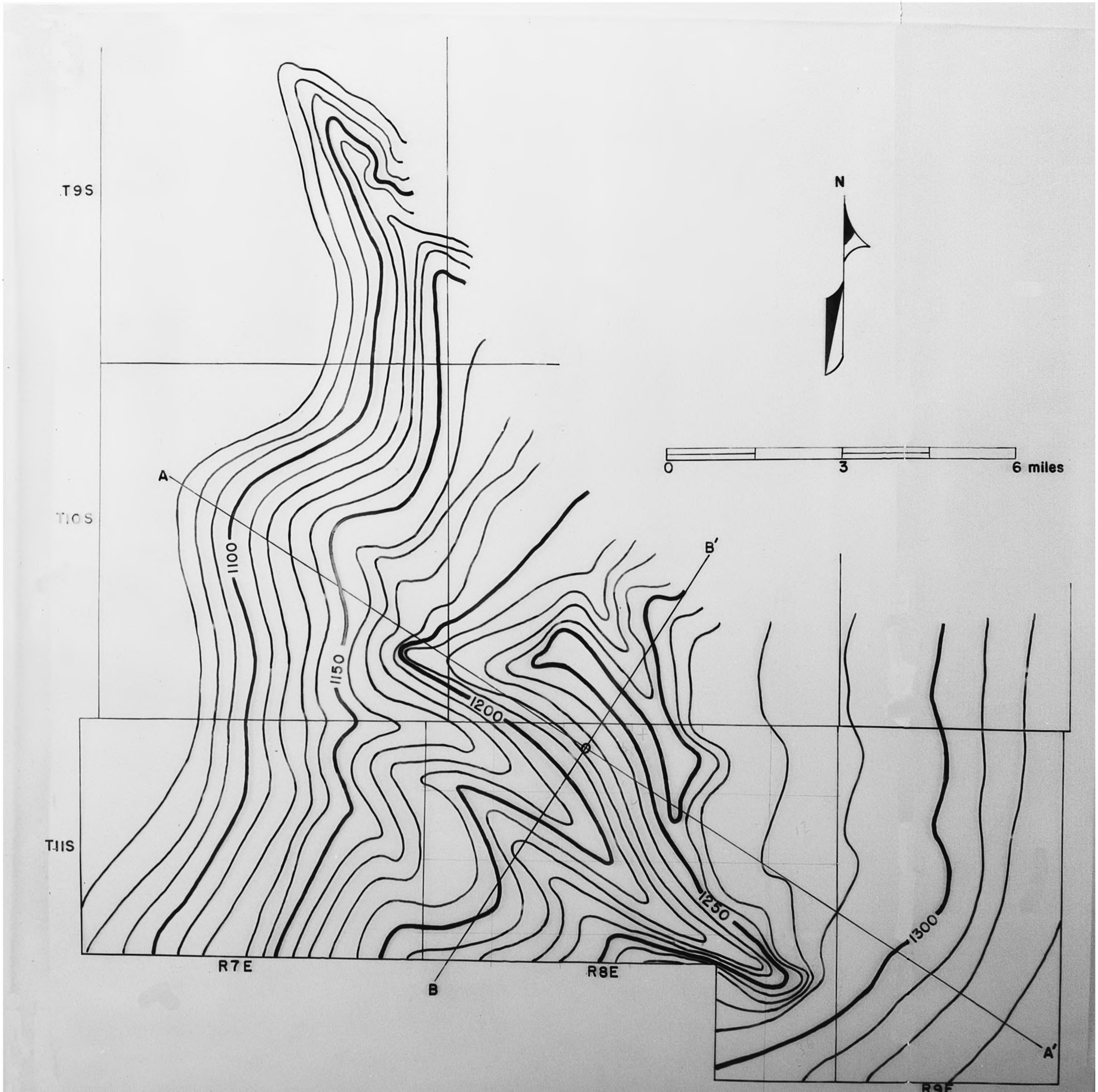



Fig. 3. Structural map at base of Cottonwood limestone.

in stream valleys. The northernmost one occupies the valley immediately to the east of the "K" hill, southeast of Manhattan, Plate I. The southernmost syncline occupies the valley in the eastern half of T. 10 S. R. 7 E. about five miles east of Ogden. The central syncline occupies the valley three miles south of Manhattan, in the northwestern part of T. 10 S. R. 8 E. All these synclines pitch to the northwest which is also the flow direction of the streams. These synclinal valleys could have been formed by the partial solution of the limestones and calcareous rock underlying the surface or the valleys could be true structural synclines. If the latter is true, partial solution of the calcareous rock could have served to increase the synclinal effect. Considerable subsurface erosion would take place in the locations where the surface "runoff" was concentrated because here there would be a greater amount of "run in." Since not all of the streams, for example, the one in the southwestern part of the area, Plate I, are not synclinal valleys, it seems logical to conclude that the synclinal valleys are true synclines which may or may not have been modified by subsurface solution. An additional fact in support of this idea is that the Wildcat is not synclinal but rather a broad anticlinal valley.

Subsurface water in the synclinal areas has a tendency to become concentrated in the synclinal troughs. Therefore, the persistent springs are usually on the down-dip or down-pitch side of the structures. The largest springs occur at the bottoms of the synclines. This is notably reflected along old K-13 south of Manhattan, where the largest syncline, the central one, intersects the road. In this area there is a considerable amount of slump along the east side of the old highway and the springs are numerous. In the wet season of the year, a considerable flow of water crosses the road. In this region most of the springs are found on the northwest sides of the hills.

Since structure is responsible for the major direction of flow of the ground water in this area, it is only natural that the vegetation immediately below the areas of bedrock outcrop should reflect some of the major structures. This is particularly noticeable below the rim of the divide on which the present highway K-13 runs. On the east side of the divide, the vegetation along the outcrop of the Cottonwood limestone is sparse while on the west side of the ridge the vegetation is fairly dense. This serves to identify the basal Cottonwood outcrop zone. The Cottonwood is a good aquifer and the water tends to run down-dip at the base of the member. This accounts for the abundant vegetation on the west side of the ridge and the sparse vegetation on the east side. It should be noted that the vegetation reflects the regional dip more than it does the individual structures.

## CLASSIFICATION OF STRUCTURE

Powers (1922) states that the structure in Kansas in the vicinity of the Nemaha Granite Ridge is the result of compaction over buried hills. He also states that the structural reflection of the Nemaha Mountains in the surface strata of shale and limestone consists of a pronounced interruption of the west dip of from 20 to 50 feet per mile by long asymetrical anticlinal ridges and domes and that these structures have little topographic manifestations. The structures and the intensity of folding are related to depth and may be due to the compaction of the sediments.

Nevin (1942) states that noses are common in areas of gentle regional dip and, although usually of small size, are of importance because they may indicate the presence of a much larger structure at depth.

Clark (1932) states that Plains Type of Folding, referred to by Powers and Nevin, is not due to horizontal forces but vertical forces and is due neither to lateral compression nor differential compaction. He states four characteristics which are typical of the Plains Type of Folding: (1) there are no true synclines, only anticlines, domes, and noses raised above the normal homocline (straight line at the base of the structure section, Fig. 4); (2) the structures should become more pronounced at depth and there should be a definite thinning of sediments over the crests of buried hills; (3) the structures should be asymmetrical; and (4) normal faulting should be common and if thrust faulting is found then lateral pressures should be looked for. Clark also states that the features are exactly

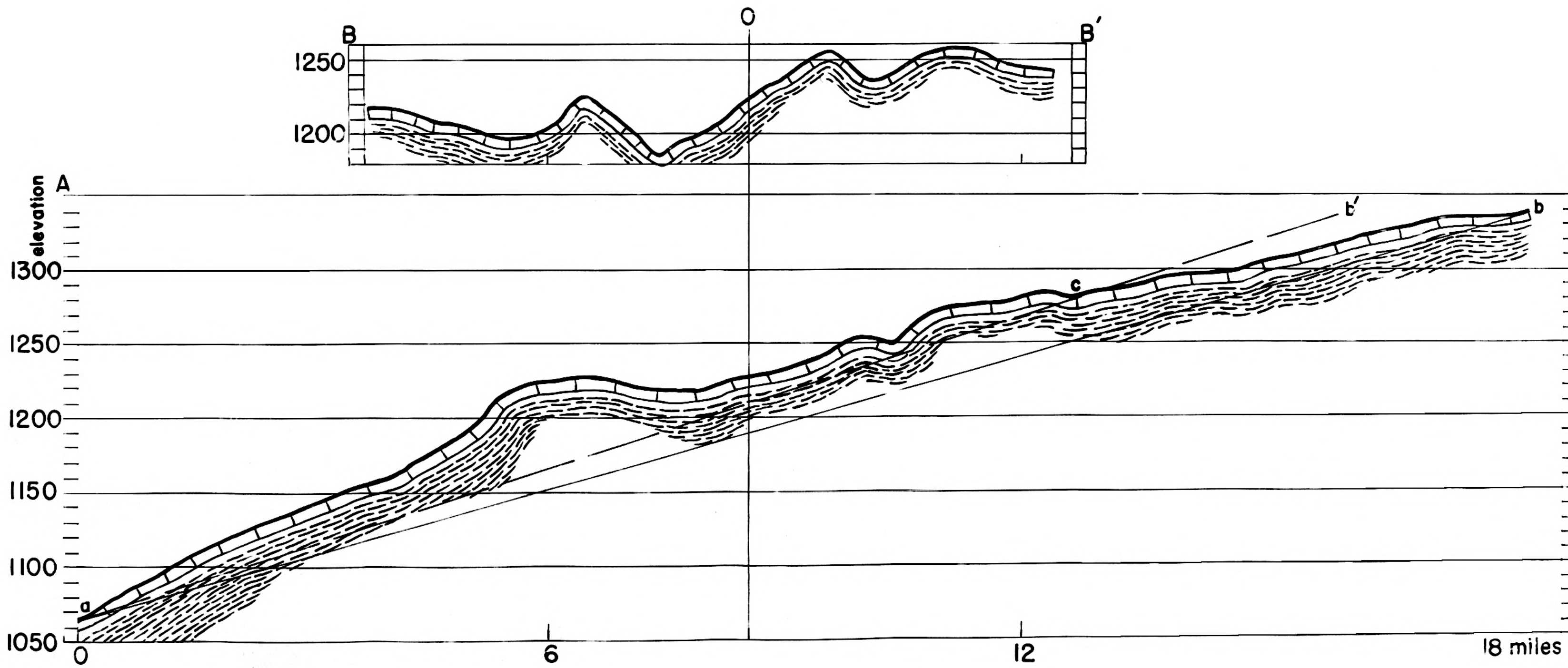



Fig. 4. Cross-sections along lines B-B' and A-A'.

those which would be developed as a result of incompetent folding of the type due to a relative uplift along an old fault plane in the basement complex. In the absence of any evidence of thrust faulting in the area, a geologist should be wary of attributing the folds within that area to horizontal compression.

Nevin (1942) states that this type of folding, the Plains Type, could have any of the three causes: progressive folding during deposition, differential compaction during and shortly after deposition, and expression of regional vertical stresses at points of local weaknesses. Nevin, as Clark (1932) believes that this type of folding is due to vertical stresses, either the result of differential uplift or the result of differential subsidence.

The structure in the area is very closely related to the Plains Type of Folding described by Powers, Nevin, and Clark. Combining the three descriptions, Plains Type of Folding should be found in a region of gentle regional dips and consist of rather small, asymmetrical anticlinal ridges and domes or noses. The pressures responsible for the structures should be vertical and not horizontal. The general structure of this area is a fairly gentle regional dip of about 15 feet per mile toward the northwest. The local structures consist of a series of asymmetrical small noses and pitching synclines. The few faults found in the area are dip-slip normal faults, one about one mile upstream on Cedar Creek, one at the lowermost Tuttle

Creek dam site, and one in the southeast corner of T. 11 S., R. 8 E.

The determination of whether or not there are true synclines as put forth by Clark in his first characteristic of Plains Type of Folding, would seem to be determined by how the regional dip line is drawn on the profile. Figure 4 is a cross-section of the area and was constructed in accordance with Clark's idea. The dip line, a - b, (the general homocline structure) was drawn by connecting the highest point of dip at one end of the section to the lowest point of dip at the other end. However, if a shorter line across only a fraction of the map had been used, such as, a - c, the dip would have been steeper and a portion of the line now between b' and C would have been above the line of regional dip. This demonstrates facts that Clark failed to bring out in his paper; namely, the idea applies only when a large area is worked and the placing of the normal homoclinal line at the base of the syncline is purely arbitrary. The line could just as well be placed at the tops of all the anticlines. Figure 4 (B - B') is a cross section taken at right angles to the direction of dip and shows the lack of symmetry of the dipping noses. Point O is the top point of the vertical line of intersection between structure section AA and BB.

## CONCLUSIONS

It is concluded that the structure of the Cottonwood limestone in the southeast corner of Riley County is of the

Plains Type of Folding, first named by Powers (1922). The forces responsible were vertical and not horizontal and were probably a combination of the reflection of buried hills, differential compaction across buried hills, and compaction of the overlying sediments.

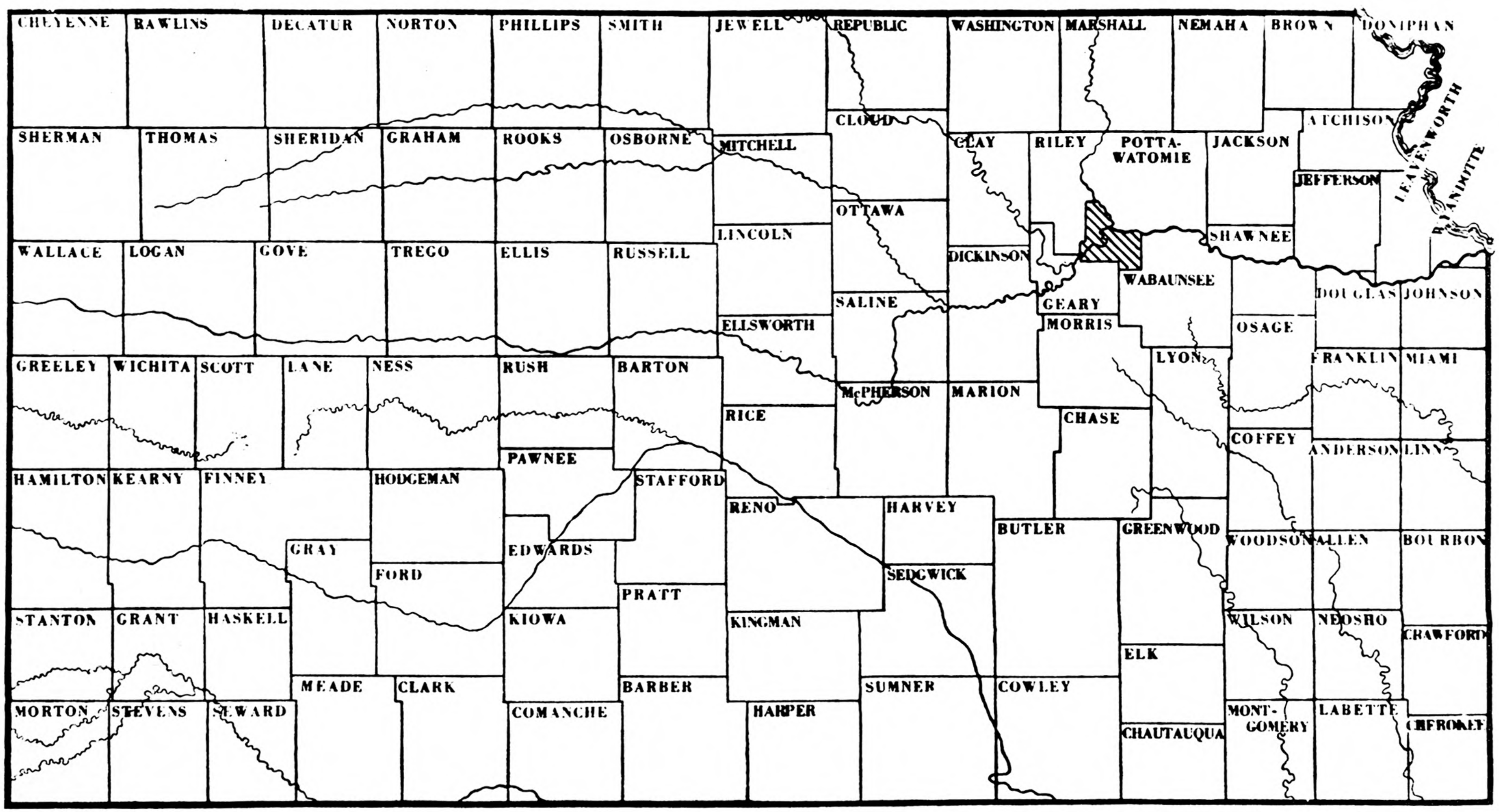



Fig. 5. Map showing area covered by this report.

## ACKNOWLEDGMENT

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