THE REFLECTION OF THE BASEMENT COMPLEX IN THE SURFACE STRUCTURES OF THE MARSHALL-RILEY COUNTY AREA OF KANSAS

by

PAUL DANHEIM NELSON

B. S., Kansas State College
of Agriculture and Applied Science, 1950

A THESIS

Submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1952

TABLE OF CONTENTS

INTRODUCTION

Purpose and Location

The purpose of this paper is to review and to extend the structural surveys by Neff (16) and Taylor (19) for Riley county into Marshall county and the surrounding area. This was done to establish the relationship of structures between the surface and the subsurface, with the hope that the correlation may shed some light on the fundamental cause of these relationships. The area covered is that of Marshall, Riley and a part of Pottawatomie counties in the State of Kansas.

Preliminary Notes

Most of the earth's surface is blanketed by relatively thin and mildly disturbed sediments. It is, therefore, not surprising that most of our geologic efforts are directed to a study of sedimentation and sedimentary structures. The lack of numerous outcrops of the basement complex is responsible for an inadequate appreciation of the nature of what lies beneath the sediments. Without a knowledge of what lies underneath the sediments, the complete overall perspective of surface geology is lacking, and is often erroneous. It is of fundamental importance that the crystalline subsurface be fully appreciated. Perhaps the difficulty could be overcome if more time and thought were devoted to detailed studies of those areas where drill hole data have given information concerning the underlying basement complex. If this were done, it would be possible to make better correlations between the surface and the subsurface and perhaps even make possible the final establishment of positive criteria for the recognition of subsurface conditions from a study of surface structures. Thus, in the final analysis, a knowledge of the basement complex structures is helpful in explaining surface structures in the sediments, and by proper correlations, a correct understanding of surface structures helps to reveal the basement complex conditions.

An excellent region for making a study of the relationship between surface and subsurface conditions is the area of the Barneston-Winkler and Nemaha ridge system in northeast Kansas. In this area numerous drill holes have revealed the general structure of the basement complex below, and the sedimentary cover is thin enough to reflect closely the structure and topography of the crystalline mass below. Joints, faults, flexures and several igneous intrusions are well exposed in this area, and correlations with the regional basement complex structures at depth appear to be quite obvious.

MAPPING PROCEDURE

Joints

The strike and dips of the joints were determined by the use of a Brunton compass. At each location the intensity and frequency of the joints of each set were established by observation. Each location was plotted on a field map and then transferred to a base map.

Marshall county is a relatively flat region where roads occur along almost every section line. This made it possible to standardize the field work by traveling nearly equal distances and routes in each of the townships. The number of joint readings per township, however, was variable because of the outcrop limitations imposed locally by glacial mantle. The writer feels that except for these local limitations uniformity for the area covered was attained. A total of 2,422 readings were taken in 20 of the 25 townships, averaging 122.1 readings per township.

A similar method was used by Neff (16) in his survey of Riley county. By using Neff's plates for data, it was possible to analyze and replot his work on a regional map showing both Riley and Marshall counties. This was done by using a polar coordinate scale to read the average data of 408 readings.

In order that the joint pattern in a sedimentary region may be compared with that of a crystalline area, Mayo's (13) joint map of the Sierra Nevada front, Mt. Lyell to Mt. Whitney, California, was studied and replotted. The procedure employed was to trace the joints onto a sheet of tracing paper. Then the sheet was ruled into a square grid system so that the strike of the 1,333 joints could be read with a protractor. The data were then recorded and plotted on a polar coordinate system to produce the regional joint "butterfly" diagram and establish a standard pattern of joints for crystalline rocks.

For this paper a grand total or 4,163 joint readings, covering an area of 4,473 square miles was analyzed and plotted. Of this total area, 1,305 square miles are in Riley and Marshall counties. J. M. Parker (18) analyzed and plotted 6,000 joints in horizontal Paleozoic strata of New York and Pennsylvania, covering an area of 5,304 square miles. This averaged slightly more than one joint reading per square mile. In Mayo's area nearly two and one-half joints were read per square mile. Marshall county averaged nearly three and one-half joint readings per square mile. For Riley county, less than one joint reading per square mile was used in developing its joint pattern.

Each joint reading was entered on an AF (angular frequency) table as a permanent record. This table was developed for rapidity and efficiency in analyzing and tabulating data. The "A" in the initials of the table indicates the strike or angle of the joints measured east or west of north, while the "F" indicates the number, or frequency, of joints occurring in that direction. The "F" value was plotted as the length or frequency of the radial line drawn when the "butterfly" was plotted on polar coordinate paper.

As an illustration of the procedure in recording joints, one might read the following joint strikes at a given location: N-S; N 15 W; N 85 E; N 22 E; N 85 E; N-S; N 85 E; N 30 W; N 85 E; N 15 W and E-W for an outcrop of Threemile limestone at the southeast corner of the southwest one-quarter of Section 27 Township 5 South, Range 7 East (SEc, SW, Sec 27, T8S R7E). For ease in plotting, each township was divided into four quarters, A, B, C and D ("A" for the NE, "B" for the SE, "C" for the SW and "D" for the NW).

In the permanent record, the data for a single outcrop would appear as follows:

5-7 SEc SW Sec 27 Threemile

West	North	East
//	0°	//
//	15°	
	22°	/
/	30°	
	85°	////

In the center column only the numbers for the degrees occuring in the field were recorded. The west and east directions appear as they do on a map with north at the top of the central column. The joint reading for each angular direction was indicated by a tally mark under the appropriate East or West column. A reading that was due N-S or E-W was recorded by placing one tally mark under both the East and the West columns.

The "5-7" for the number of the township appears only at the top of the page as an immediate page reference recorded in red. The "B" was recorded in red and accompanied each location giving one a ready quarter-township reference followed by the section and subsection location. The "Sec" before a number indicated the section.

If one desired to combine quarter-townships into townships or townships into counties, the process was the same as it was for an outcrop record. It convenient to list all the degrees from zero to ninety in the central column for a large number of readings.

Before plotting a butterfly, all the joints for an area were averaged to the nearest five degrees. If one desired to maintain a constant size for the butterflies, equating factors were used.

Determination of the average for the major sets which were ninety degrees apart was done as follows:

Set II	West	N	East	Set I
0° = 2x0	//	0	//	
30° = 2x15	//	15		
22° = 1x22		22	/	
30° = 1x30	/	30		
		85	////	85x4 = 340°
	/	90	/	90x1 = 90°
82° for 6 joints				430° for 5 joints
Ave = 82/6 = 13 40'				Ave = 430/5 - 86°

From the preceding table it was obvious that Set I was N 85 E and that the average lay nearby since four readings occurred in the direction and the average for Set II was between N 0 and N 15 W. Since N 22 E and due N-S lay nearer Set II than Set I, they would be figured in the Set II column, and because the E-W joint lay closer to Set I than Set II it would be figured in the Set I column. This method was employed in part in averaging the joints for Marshall and Riley counties shown on the Surface Fracture Pattern map (Plate I).

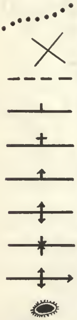
For the sake of simplicity and ease of reading, only the most frequent components were represented on the Riley-Marshall counties map. Three regional butterfly patterns were made, one for the Sierra Nevada front, another for the whole of Riley county and the third for the whole of Marshall county. The butterflies were drawn directly from the tabulated data of the AF tables without analysis.

Other Structural Features

The field procedure for mapping the other structural features was much the same as employed in mapping joints. A Brunton compass was used to determine the trend and the dip direction of the flanks of conspicuous flexures. The faults were measured by a Brunton compass to determine the strikes and dips of the fault planes while the displacements were measured by a hand level and a stadia rod. The intrusions were surveyed by a dipping needle, Taylor (19) and recently by the U.S.G.S., using a vertical magnetometer.

EXPLANATION OF PLATE I

Illustrating the Permian surface structure pattern of the location of named structures as listed in the "Catalogue of Structures".



.....regional trend of the E-W set

.....trends of the most frequent joints

.....major subsurface faults

.....normal faults - downside indicated by (–)

.....thrust faults - footwall indicated by (+)

.....direction of dip of major flexures

.....minor wrinkles (anticline)

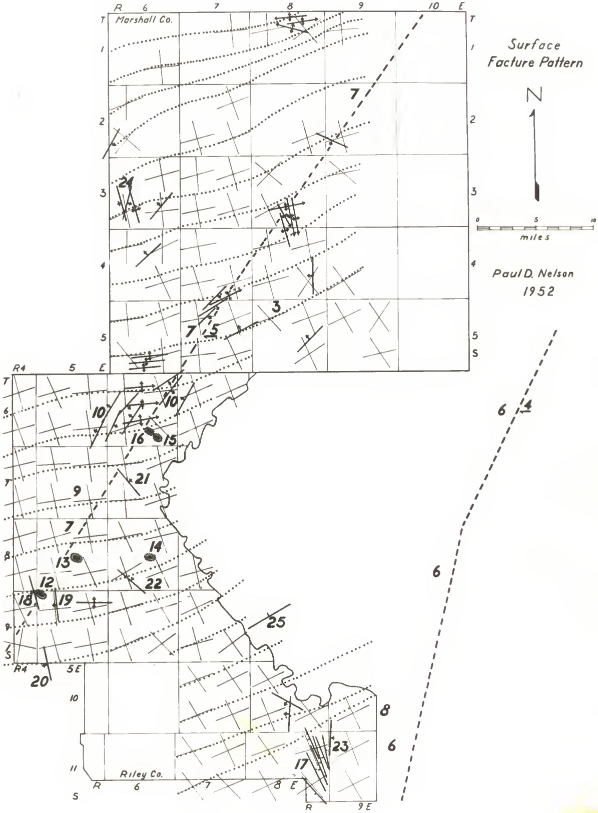
.....minor wrinkles (syncline)

.....plunging minor wrinkle

.....intrusion

3. Irving syncline
4. Humboldt fault
5. Big Blue fault
6. Nemaha anticline
7. Barneston-Winkler anticline
8. Zeandale dome
9. Winkler dome
10. major wrinkles
12. Bala intrusion
13. Leonardville intrusion
14. Stockdale intrusion
15. Randolph intrusion No. 1
16. Randolph intrusion No. 2
17. normal faults of SE Riley county
18. Bala thrust
19. Bala flexure thrust
20. Milford thrust
21. Randolph thrust system
22. Riley thrust
23. Deep Creek thrust
24. Waterville thrust
25. Cedar Creek fault system

PLATE I


Surface
Facture Pattern
N
0 5 10
miles
Paul D. Nelson
1952
Marshall Co.
Riley Co.

In each instance, the strike of the structure was plotted on the base map by a line greater in length than the actual scaled distance for ease of reading. The true location of the feature is near the midpoint on the strike line.

THE SURFACE STRUCTURE PATTERN

The pattern of surface structures in the region appeared to be controlled and dominated by a subsurface fundamental pattern which determined the orientation and placement of the structural elements.

General Description of the Joint System

The general joint pattern throughout the region was found to be consistent except for some deviations and to be parallel to all the structures observed.

Major Sets. In general, the area has two dominant sets of joints which are the more frequently and the more intensely developed than any of the other sets.

Joint Set I (east-west) is the most frequent and the most intensely developed, while the joints of Set II (north-south) are less frequent and are not as intensely developed.

The two sets may be locally characterized as follows, Parker (18, 397):

Set I	Set II
1) Shear joints (double)	1) Tension joints (single)
2) Straight smooth planes	2) Curved planes
3) Vertical	3) Hade variable
4) Most numerous	4) Less numerous
5) Consistent strikes	5) Variable strikes
6) Plumose markings occasionally	6) No conspicuous plumose markings

At any given location, one joint set usually dominates over the other, while at some locations both sets are of equal strength. It was not uncommon to find the major sets of joints alternating their positions; for example, Set I had an east-west strike at one location and at another a north-south trend. For the region as a whole, the east-west joints dominate over the north-south joints.

It is further noted by following a set of joints across the region (Plate I) from west to east that a deflection or rotation of the joint system had been in a counterclockwise direction. This deflection tends to become more apparent in the eastern and southern portions of the region in Marshall and Riley counties. Over the Barneston-Winkler ridge in Riley county the rotational trend reverses and tends to orient the sets with the cardinal directions before resuming the counterclockwise trend.

In many areas throughout the region, Set I had developed conjugate shears and in a few areas was accompanied by plumose markings in the thinly bedded limestones and massive layers of chert.

The horizontally spaced interval between the joints depends upon the direction of the sets. The east-west Set I is usually uniform while the north-south Set II is variable.

The joints of some areas have an irregular or jagged appearance while those in other areas are clean cut and very distinct.

For each area an individual pattern will be found but in each case they have similar characteristics. These characteristics are that one set usually dominates and forms an angle of nearly ninety degrees with the other major set.

Dipping joints are found throughout the entire region. They occur, mainly, in areas that have been structurally disturbed, such as the faulted areas of southeastern Riley county and southwestern Pottawatomie county and the folded areas of Riley and Marshall counties. In the faulted areas the dipping joints appear to parallel the fault plane with their greatest occurrence usually near the fault zone and where the strata dip most pronouncedly. In the folded areas the dips of the dipping joints are somewhat haphazardly arranged except where the dips are caused by the folding of the rock layers.

Minor Sets. The number of minor sets varies throughout the region. At some locations no minor set is present while at other locations several minor sets occur. The joints of these sets are not as consistent in strike nor as frequent in the outcrop nor as intensely developed as the major sets.

General Description of the Faults

Whereas normal and reverse faults may be found anywhere in the area, the normal faults appear to be most numerous in the area of the Nemaha ridge and the thrust faults most numerous in the area of the Barneston-Winkler ridge. In each instance the strike of the faults appears to be parallel one of the joint sets and/or a major subsurface structure.

Normal Faults. The majority of normal faults occur in a zone in southern Riley county (Plate I). According to Neff (16), the area contains six faults striking N 22 W to N 41 W with length ranging from a third of a mile to one and two-thirds miles and throws as great as twenty-five feet. The other normal faults are located in the SW¼ Sec 9, T9S, R8E in SW Pottawatomie county. Here two steeply dipping normal faults strike N 60 E with displacements of twenty-two feet and five feet respectively, while a hundred yards away the displacements are twelve feet and nine feet. Another normal fault is SE¼ W½ Sec 18, T9S, R8E in southwest Pottawatomie county striking N 60 E with a displacement of twenty-two feet. These faults in Pottawatomie county are believed to be continuous, making a total length of two and three-quarters miles (Plate I-25), thus making it the longest known surface fault in this area. For this fault, the name "Cedar Creek fault" is proposed after Cedar Creek, a small stream in southwest Pottawatomie county, Kansas.

These two zones of normal faults occur along the western flank of the Nemaha ridge. Each of the faults was found to parallel a joint of one of the major sets.

Thrust Faults. Most of the thrust faults in Riley and Marshall counties are exposed in highway and railroad cuts. Due to the lack of exposures, they are hard to recognize elsewhere because they produce small local structures with very small escarpments, if any. Most of the thrust faults exist in the Stovall limestone and in the thinnly bedded limestone portion of the Cresswell limestone.

Undoubtedly, there are many more thrust faults in the region. Neff (16) mentioned six thrust faults in Riley county. The writer found one in western Marshall county. Most of the thrust faults are in the general vicinity of an intrusion. Each has a small throw ranging from one to four feet and appears to be thrust toward an open valley which parallels a joint in one of the major sets. In general, the heave is twice that of the throw.

General Description of the Flexures

The flexures of the region should be considered in separate groups according to magnitude. For this classification it is proposed that "welts" for the major and "wrinkles" for the minor flexures be used.

Welts. The welts (Plate I-6 and 7) of the region are observed as regional structural dips which tend to parallel the major subsurface structures.

Wrinkles. The most obvious minor wrinkles are found in a belt of en echelon folds running from the southwest corner of Riley county through Marshall county to the Nebraska line over the crest of the Barneston-Winkler ridge. At some locations in Marshall county and probably around the intrusions (Plate I), the folds trend nearly at right angles to each other. In each case they parallel a major set of joints.

Major wrinkles occur as local dips and are found, mainly, in northern Riley and southern Marshall counties (Plate I-10). In each case they are semi-parallel to the flanks of the Nemaha ridge.

General Description of the Intrusions

Five basic igneous intrusions (Serpenitized peridotite) are now known to exist in Riley county (Plate I-12 to 16). These are probably steeply plunging dikes elongated in an east-westerly direction. The elongations may be observed in the field or from aerial photographs. They have been further established by Taylor's (19) dipping needle survey of the Leonardville and Stockdale intrusions in 1950 and Dreyer's (3) vertical magnetometer survey of the Bala intrusion in 1947.

The location of each major structural feature of importance will be found in the "Catalogue of Structures" for the region in the Appendix at the end of this paper.

THE SUBSURFACE STRUCTURE PATTERN AND TOPOGRAPHY

The Expression of the Subsurface

The topographic expression of the basement complex is far from a level peneplain. It is an ancient buried plain repeatedly subjected to weathering and erosion and has been repeatedly wrinkled, warped, folded, intruded by magmas and faulted (Plate III). All of these processes have produced an irregular surface which has influenced the localization and orientation of subsequent anticlines, synclines and fracture patterns.

The composition of the basement complex has been found to be far from homogeneous. It is a mottled mass of granite or gneiss with patches of schist, quartz porphyry and quartzite as determined from oil well cuttings.

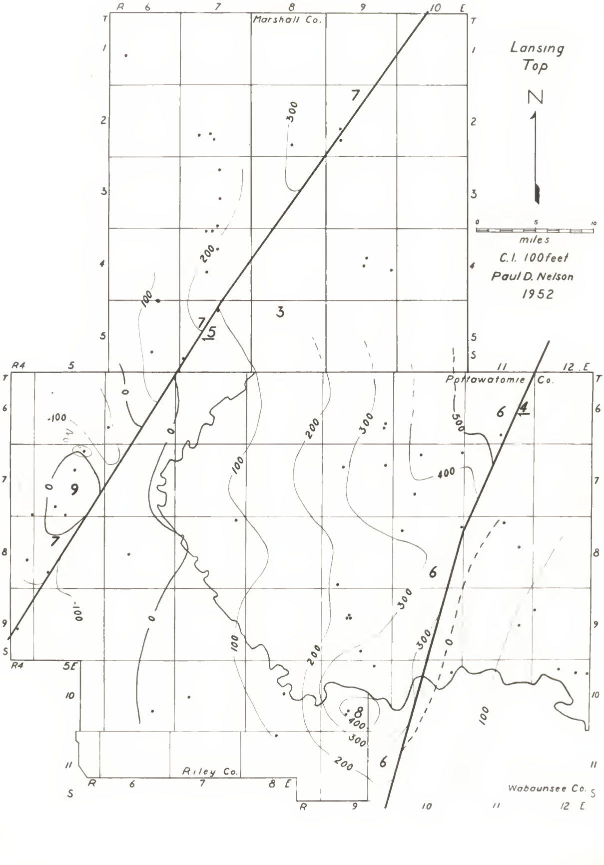
The Marshall-Riley county area of the basement complex is in the Central North American stable region Eardley (4) which is the southwestern extension of the Canadian shield, the nucleus and core of the North American continent. The North American stable region is surrounded by ancient Pre-Paleozoic Algoman and Laurentian mountains to the northeast, younger Paleozoic Appalachian mountains to the east and Oklahoma mountains to the south and by the Paleozoic Colorado mountains and the more youthful Rocky Mountains of the Meso-Cenozoic periods to the west. With so many geosynclines forming and being smashed into mountains around the margins of the stable area, it seems unlikely that these forces would not affect to at least a limited degree the disposition of the rocks in the midcontinent area.

EXPLANATION OF PLATE II

Illustrating the surface of the Lansing group. Contoured on 100 foot intervals as determined from well data, numbered by counties (see Appendix, page 64). The named structures are as follows:

3. Irving syncline
4. Humboldt fault
5. Big Blue fault
6. Nemaha anticline
7. Barneston-Winkler anticline
8. Zeandale dome
9. Winkler dome

PLATE II


Lansing Top
N
0 5 10
miles
C.I. 100 feet
Paul D. Nelson
1952
Marshall Co.
Pottawatomie Co.
Riley Co.
Wabaunsee Co.

General Description of the Faults

North of Humboldt, Nebraska, a surface fault with a maximum upthrow of 100 feet on the west was described and named the Humboldt fault by Condra in 1927 Jewett (6). This fault, the largest to concern the problem, probably is the reflection of a subsurface fault that forms the eastern flank of the Nemaha ridge throughout its entire course from Humboldt, Nebraska, to Oklahoma City, with subsurface displacements as great as 2,400 feet at the latter place (Plate III-4).

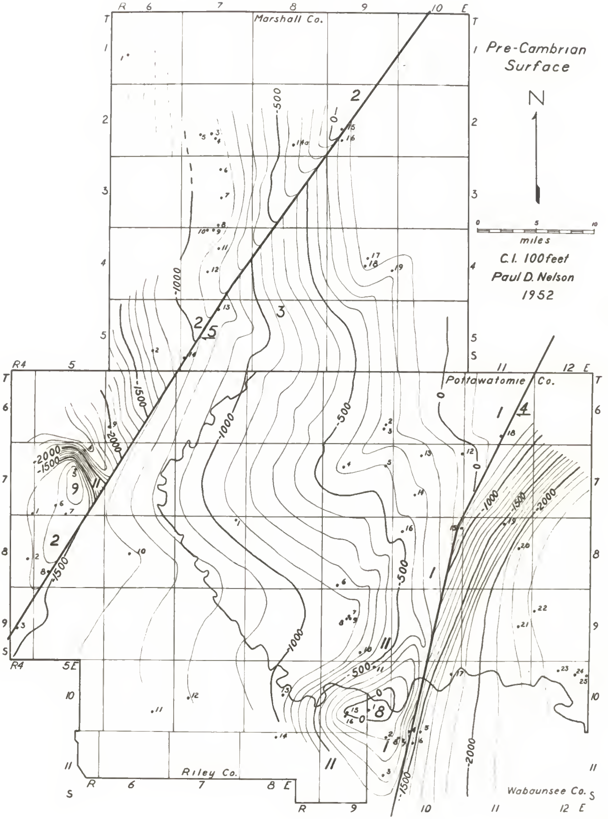
Another major subsurface fault in the region forms the eastern flank of a subsurface structure, the Barneston-Winkler ridge, in western Marshall and north central Riley counties. Southeast of Blue Rapids, in Marshall county, the Pre-Cambrian surface was displaced nearly 400 feet by this fault, causing obvious dips in the surface formations of nearly 200 feet per mile to the southeast (Plates I-5, II-5 and III-5). The fault was classed as an oblique-slip fault with a steep normal dip-slip element as indicated at the surface by the dipping formations and at depth by displacement of the Pre-Cambrian surface. The strike-slip element was a minor component of the oblique-slip and is a clockwise rotation of the joint pattern and by the emplacement of igneous intrusions in joints opened by the strike-slip friction. For this fault, the name "Big Blue fault" is proposed from the name of the Big Blue river that flows in part along its strike.

EXPLANATION OF PLATE III

Illustrating the surface of the basement complex. Contoured on 100 foot intervals as determined from well data, numbered by counties (see Appendix, page 64). The named structures are as follows:

1. Nemaha ridge
2. Barneston-Winkler ridge
3. Irving syncline
4. Humboldt fault
5. Big Blue fault
8. Zeandale dome
9. Winkler dome
11. Cross faults

PLATE III



Pre-Cambrian Surface
N
miles
C.I. 100 feet
Paul D. Nelson
1952
Marshall Co.
Pottawatomie Co.
Riley Co.
Wabaunsee Co.

Both the Big Blue and the Humboldt faults are nearly parallel with steeply dipping fault planes which carry to the surface as asymmetrical anticlines (Plate I).

General Description of the Flexures

Major Flexures. The major surface flexures of the region seem to be controlled by two types of subsurface structures, the two primary ridges or welts and the secondary series of domes or knobs along the crest of each ridge or welt. The welts are considered the major structures, the domes, minor structures.

The Nemaha ridge was known early in the geologic history of this region by the crystalline rocks encountered in drill holes at the center of a series of north-easterly trending domes that extend across eastern Kansas. This situation was first noted in 1888 by Russell who sank a well 552 feet into Pre-Cambrian rock in Pawnee county, Nebraska. Since that time the ridge has been known by the following names Jewett (6, 146): Nemaha mountains, Table Rock anticline, Nemaha anticline, Granite ridge, Nemaha Granite ridge and Nemaha-Oklahoma City uplift.

It is certainly one of Kansas' major positive areas extending from Omaha, Nebraska, to Oklahoma City, Oklahoma. In the northern portion of Nemaha county, Kansas, Pre-Cambrian rock is 500 feet and in the southern portion in Sumner county, Kansas, it is 3,000 feet below the surface. The trend of the anticlinal ridge is N 18 E (Plates II-6 and III-1).

The Barneston-Winkler ridge in western Riley and Marshall counties is an inferior granite ridge paralleling the superior

Nemaha ridge in Nemaha and Pottawatomie counties. Like the Nemaha ridge, the inferior ridge is recognized at the surface by southeasterly dipping formations in Riley and southern Marshall counties. In Marshall county this ridge is known as the Barneston Jewell (6, 117) and in Riley county as the Winkler dome. The Barneston-Winkler structure had been connected previously by various writers with the Graber Oil Field anticline in McPherson county and named the Abilene anticline after the city of Abilene, the mid-way point between the two structures. Since the Barneston-Winkler ridge dies out rapidly to the south, it seems improbable that the ridge extends beyond the southeast corner of Clay county. Jewett (6, 114) states that it was not likely that the Graber anticline and the Barneston-Winkler are connected and work done by others in the Abilene, Kansas, area shows no evidence that a subsurface ridge exists at the locality. It is, therefore, proposed that the name Abilene anticline be discarded and that the structure on the basement complex of the local area be named "Barneston-Winkler ridge" for the Barneston anticlinal ridge in Nebraska and in Marshall county, Kansas, and for the Winkler dome at the town of Winkler, Riley county, Kansas. At Winkler the last predominant dome in the southern extension of the Barneston ridge is located. The term "ridge" is being proposed rather than "anticline" because the east flank of the structure is bounded by a subsurface fault scarp (Plate III-2). "Anticline" will be used for the flexured rock over the ridge.

The Barneston-Winkler ridge continues into Nebraska where it appears to merge with the Nemaha ridge as indicated by the well log data in Marshall county (Plates I, II and III) and from the strikes of the Big Blue fault and the Humboldt fault. Both ridges have irregular crests with granite knobs along their entire lengths that form local domes in the overlying rocks, presumably by differential compaction. Both ridges are fault blocks sloping gently to the west and bounded on the east by nearly vertical fault scarps. The crests of both scarps plunge southward on the average of twelve feet per mile for the Nemaha ridge across the State of Kansas and twenty-two feet per mile for the Barneston-Winkler ridge in Marshall and Riley counties.

The Irving syncline is a distinct structural feature as indicated by the dips in the surface formations (Plates I-3, II-3 and III-3). This syncline lies between the Barneston-Winkler ridge to the west and the Nemaha ridge on the east with its axis lying near the mouth of the Big Blue River on the Riley-Marshall county boundary and extending a short distance into Nebraska Jewett (6, 14).

Minor Dome Flexures. The dome-like knobs along the crest of the Nemaha and the Barneston-Winkler ridges may be reflections of buried erosional hills or steeply tilted blocks resulting from cross faulting.

The Zeandale dome on the granite crest of the Nemaha ridge in the southeast corner of Riley county (Plates III-8, II-8 and I-8) is reflected at the surface by two zones of faults, one in southeast Riley county trending N 20 W, the other zone in southwest Pottawatomie county trending N 60 E. Jewett (7, 99) mentions the inclined formations in the vicinity of Deep Creek, northeast of the fault zone. The apex of the dome is probably near Zeandale. At Zeandale a well was sunk by Bloom in 1914 in the NW corner of the SW¼ Sec 28, T10S, R9E to a depth of 928 feet reaching the Pre-Cambrian granite surface at thirteen feet below sea-level, which is high for the vicinity Jewett (8, 271).

A second dome of importance in the region is the Winkler dome on the granite crest of the Barneston-Winkler ridge in northern Riley county. At the surface this dome is reflected in formations dipping as much as 500 feet per mile near the village of Winkler (Plates I-9, II-9 and III-9). On the geological map of Riley county by Jewett (7, 100) it appears as an extensive area covering about four square townships northwest of Randolph, Kansas, and is dissected by Fancy Creek. Along the crest of the Barneston-Winkler ridge the relief on the Pre-Cambrian surface is about 1,177 feet. This information was obtained from two wells about three miles apart located near the center of the structure in SE¼ SW¼ NW¼ Sec 2, T7S, R5E and NE¼ NE¼ NW¼ Sec 15, T7S, R5E.

Most of the smaller domes along the crests of the ridges are known to have granite cores. Others away from the crests of the ridges may or may not have granite cores. All of these domes and flexures throughout the region appear as small local closures and/or as locally dipping formations. The smaller structures will be listed in the "Catalogue of Structures" in the Appendix.

DISCUSSION OF PROBLEMS AND SOLUTIONS

The solution of the problems in the area investigated lies in a careful analysis and interpretation of the available data.

Joint Problem and Solution

Joints, the most common and fundamental of all structural features, promise an excellent opportunity to solve many geologic problems. However, joints themselves must first be understood.

The solution of the joint problem requires the consideration of the following:

1. The origin of joints
2. The pattern of joints
3. The structural influence of joints

The Origin of Joints. It must be remembered that in the local area it is less than four-tenths of a mile, on the average, to the basement complex. The configuration and structural complexion of the granite surface must be reflected in some way in the sediments at the surface.

In an extensive discussion of the Riley county area Neff (16) points out that the causal factor for the set of joints with a strike of N 80 E - S 80 W is an active tensile stress acting in a N 10 W - S 10 E direction during the time of regional uplift at the end of the Paleozoic. The other set of joints striking N 20 W - S 20 E was formed about the same time by the interaction of combined forces of differential compaction and uplift over buried ridges of the region.

It has frequently been stated Nevin (17, 158) that in a region once broken by systematic joints, it is doubtful whether a later deformation could produce another joint system. It has also been said that two sets of joints forming a system are not caused by two separate periods of diastrophism.

Both sets of joints in a joint system appear to be essentially the same age. Little or no mention has been made in the literature concerning the rotation of joint systems. The joint pattern observed in any region is a complex that shows a fundamental system as well as numerous fractures inclined to, and deviating from, the fundamental system which, at least in part, appears to be due to local forces. Rotations and deflections of the fundamental pattern have been observed in some instances. The agents and forces of regional magnitude which may cause rotations and deflections are probably strike-slip movements between blocks in the basement complex and differential compaction between sedimentary basins and adjoining highs. The agents and forces of local magnitude which cause minor jointing and smaller local deviations are differential weathering, unequal local compaction and local movements at the time of lithification.

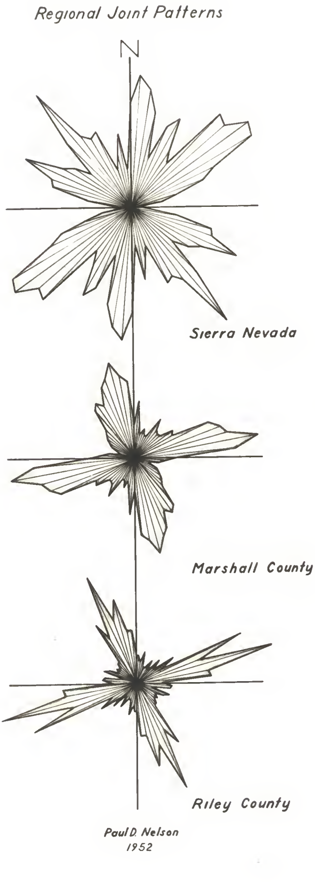
The Pattern of Joints. The fundamental basement structural pattern for the eastern part of the state of Kansas appears to be N 15 to 30 E - S 15 to 30 W and N 40 to 60 W - S 40 to 60 E as determined from subsurface studies. The surface structures appear to be conformable with these directions. The NW-SE trend appears to be the trend of the ancient structural grain while the NE-SW trend seems to be the result of transverse fault scarps and features resulting from fault movements. The basement joint pattern is assumed to be parallel to these trends. A study of the surface trend of the joint system of the Marshall-Riley county region shows a counterclockwise deflection with respect to the basement joints increasing toward the southern and the western portions of the region. A distinct deflection in the opposite direction is located in Riley county over the Barneston-Winkler ridge where the joint system is rotated for a short distance in a clockwise direction. The points of inflection (rotation) for the east-west set lie near the Big Blue fault. This seems to indicate that there has been strike-slip movement along the fault and between blocks paralleling the fault in the basement complex.

A regional butterfly for Marshall county, Riley county and for the Sierra Nevada (Plate IV) will be used in comparing the joint pattern in sedimentary rocks with that in igneous rocks. It would be impractical to try to compare orientation between the Sierra Nevada butterfly and the Marshall-Riley county butterflies due to the great distance that separates the two areas. The general appearance of the butterflies is somewhat the same with the majority of the joints trending in essentially the same directions. The Sierra Nevada pattern is somewhat less distinct than the other butterflies, probably because the area represented by the Sierra butterfly is about seven times the size of either Marshall or Riley counties. In such a large area there are numerous rotations and deflections in the joint pattern which were not corrected in drafting the Sierra butterfly.

EXPLANATION OF PLATE IV

Shows the relationship between the sedimentary joint pattern of Marshall and Riley counties with a comparison of the Sierra Nevada igneous joint pattern.

PLATE IV


Regional Joint Patterns
N
Sierra Nevada
Marshall County
Riley County
Paul D. Nelson
1952

The comparison of the sedimentary area of Marshall and Riley counties shows that the east-west set of joints in Riley county is rotated five degrees counterclockwise to those of Marshall county, while the north-south set of joints in Riley county is rotated ten degrees counterclockwise to those of Marshall county. The counterclockwise rotation in Riley county seems to indicate greater movement and differential compaction in Riley county than in Marshall county. In the Riley county butterfly the east-west conjugate shears Parker (18, 395) are very obvious and apparently well developed for the county, while in Marshall county these shear joints are not so obvious or well developed.

The Structural Influence of Joints. The influence of joints on geological processes appears to be considerable. This is not surprising since joints are so numerous, consistent and permanent a part of the earth's crust. In the field numerous features are found to parallel a joint set or to be controlled by the joint pattern. Joints are the first and easiest lines of relief for tectonic forces. Therefore, it is not surprising that faults, folds and surface erosion are found to parallel the joint pattern. It is even quite probable that uplifts, mountain chains, batholiths, geosynclines and even the continental outlines are controlled by the fracture pattern.

Fault Problem and Solution

This problem is concerned with the pattern of faults and the factors that determine the pattern.

The problem is specifically concerned with:

1. The origin of faults
2. The location of faults
3. The orientation of faults

The Origin of Faults. Faults result locally from either simple tension or compression acting in a horizontal plane. From a study of the effects of faulting it may be possible to gain some idea as to their fundamental cause.

Strike-slip faults may be more common than any other type of fault since there is no force needed to overcome gravitation and the majority of stresses are horizontal due to the lateral displacement of eroded material causing shifts in the rock at depth to compensate in isostatic adjustment. They are difficult to recognize at the surface because they create little or no escarpments and because they are frequently buried under sediments which take up the differential movement plastically. The Big Blue strike-slip fault was caused by both vertical and horizontal movements parallel the Barneston-Winkler ridge. The Humboldt fault, causing the Nemaha ridge seems to be predominately due to vertical movement.

Many small normal hinge faults with throws as great as twenty-five feet occur around the Zeandale dome in southeast Riley and southwest Pottawatomie counties. The blocks were rotated in a vertical plane along zones of weakness parallel to the surface joint pattern with the upside toward the Nemaha ridge. These faults may be due to tension resulting from differential compaction in the Salina basin and from vertical uplift of the Nemaha ridge. The vertical uplift may be due in most part to isostatic readjustment because of a negative gravity anomaly that developed as the ice sheet retreated to the northeast. Faulting probably occurred along preexisting faults in the basement complex. To the west a positive anomaly may have existed as a result of increased loading of the region by glacial and piedmont deposits while the continental and mountain glaciers were at their maximum. It is thought that these surface faults are fairly recent because locally the fault scarps are still conspicuous.

The thrust faults are due to 1) active compressive stresses probably resulting from rotation of the subsurface blocks as a result of strike-slip movement in the basement complex and 2) to the compression following immediately after the emplacement of the intrusions of basic magmas. The compressive energy that produced these faults was retained in the thick plastic shales until it was released by the removal of the overburden along valleys by stream action. As the overburden along a stream was diminished, plastic flowage in the thick shale caused blisters or small flexures to form. These blisters did not rupture until the thin interbedded limestones failed and fractured parallel to existing joints. Most of these faults are in the vicinity of the Big Blue fault and near an igneous intrusion.

The throws of the thrust faults are of a magnitude of about one to four feet or about one-half the heave. The heave, from two to eight feet, is equal to the shortening of the surface rocks produced by the small folds that occur in the same area. This would seem to indicate that the same amount of energy was required to form both the small folds and the thrusts. Physical factors of the rocks determined whether the energy was relieved by folding or faulting.

<u>The Location of Faults</u>. The location of all faults in determined by differentials in tension or compression and will not be executed until these forces overcome the strength of the rocks for a given environment. This must also be the case for the local faults which must have been located in weak zones where the proper stress relationships existed, the weak zones localized the stresses. It is easier for stresses to be relieved along preexisting fractures by fault movements than it is to form new folds by flexing. maybe

The location of thrust faults result from the removal of overburden by streams to release the differential forces of compression developed in the thick plastic shales, thus giving easy lateral relief to the confined stresses.

<u>The Orientation of Faults</u>. The direction of strike or orientation of a fault may be determined primarily, or in part, by the joint pattern and the direction the force is acting.

The parallelism observed in the field for the faults and the other structures can not be purely coincidental (Plate I). Since the basement complex joint pattern can not be seen in this region, only an inferred pattern from the orientation of the major subsurface structures can be considered. Drill hole data for the region shows that the Big Blue fault and the Humboldt fault (Plate III) are nearly parallel, thus causing the two major ridge crests to be parallel, striking on the average of N 27 E - S 27 W. This parallelism merits some consideration since all structures must have infinitesimal beginnings, presumably along some favored joint as a zone of easy relief for the active forces. The favored joint in the case of rotational forces acting in a horizontal plane would produce a strike-slip fault. When the forces act at right angles to a joint set, folds and thrusts may result from compression and normal faults from tension. If the force is acting at an angle to the joint set, the force will act along each set as components of the initial force in proportions determined by the angle in which the force is acting upon the joint sets, producing strike-slip faults of varying magnitude.

The strikes of the normal faults of southeast Riley and southwest Pottawatomie counties (Plate I-17 and 25) are 80 degrees apart and the angle between the major sets of joints for Riley county is, also, 80 degrees. These faults parallel the two sets of joints perfectly. In Riley county the majority of normal faults parallel the joint set, striking N 20 W - S 20 E and the normal faults of Pottawatomie county parallel the joint set, striking N 60 E - S 60 W.

All the thrust faults of western Riley county and the thrust fault of western Marshall county appear to be thrust toward an open valley. In each case the strike seems to parallel a joint set.

Flexure Problem and Solution

Flexures are secondary features developed along preexisting lines of weakness parallel to the sets of a fundamental joint pattern already in existence. The flexures may be divided on the basis of magnitude into welts (domes) and major and minor wrinkles. Synclines are considered counterparts of anticlines in a plains region.

The flexure problem requires consideration of the following situations:

1. The existence of flexures
2. The location of flexures
3. The orientation of flexures

<u>The Existence of Flexures</u>. The existence of flexures is governed largely by the disposition of original dips, 1) file of equilibrium slopes, 2) differential compaction over buried hills and between lagoonal areas and 3) subsidence during sedimentation. When diastrophic forces come into play they are controlled and directed by these dips. major Joints and reactivated buried faults also appear to exert strong controlling influences. The welts, and some of the domes, of the Riley-Marshall county area resulted from differential compaction over the Barneston-Winkler and the Nemaha fault scarp ridges and partly from differential vertical movement of the Big Blue and Humboldt faults forming two asymmetrical anticlines with the Irving syncline in between.

The major wrinkles of northern Riley and southern Marshall counties were probably caused by 1) differential compaction along initial dips, over minor ridges or small subsurface fault scarps, or by 2) east-west compressive stresses resulting from strike-slip movement and vertical rotation of the major fault blocks along the Big Blue fault, or by combination of the two.

The en echelon zone of minor wrinkles on the crest of the Barneston-Winkler ridge probably was caused by compressive forces due to strike-slip movement of the Big Blue fault (Plate I). The minor wrinkles that trend at right angles to the en echelon folds may also have been produced by the same strike-slip movement or may have resulted from the compression due to the igneous intrusions.

The Location of Flexures. The flexure location is determined, in addition to factors already mentioned, by the proximity of the force and the physical environment of the rock. Deformation seems to decrease from the source area of the stress and is greatest in those rocks that are weakest. The forces producing the minor wrinkles appear to have been of shallow origin localized near intrusions. The forces producing the larger wrinkles appear to have been deeper and of a greater magnitude, being reflected in thicker, deeper subsurface rocks. They appear to be controlled by the subsurface joint pattern and other deeper-seated conditions localized near the Big Blue fault.

The welts are located over the buried ridges by differential compaction and repeated uplift along the faults that flank the ridges. The major wrinkles are located over the Barneston-Winkler anticline due to possible minor faults, buried ridges, original dips and movements along preexisting faults. The minor wrinkles were probably located by plastic flow of shales resulting from erosional relief of compression produced by the intrusions.

The Orientation of Flexures. Flexures of each magnitude were found to approximate parallelism with a major set of joints. That is, the major flexures (welts and major wrinkles) parallel one component of the fundamental or basic joint pattern of the basement complex and strike N 12 to 36 E - S 12 to 36 W (Plate I-6, 7 and 10). The minor flexures (minor wrinkles) parallel one or the other of the two surface sets of joints (Plate I). The minor wrinkles paralleling Set I (east-west set) outnumber the minor wrinkles paralleling Set II (north-south set) for the region as a whole.

Intrusion Problem and Solution

Basic intrusions are usually associated with the initial phases of orogeny in areas of geosynclinal deposition. Thus, in the transition area from the Lowland Plains to the Highland Plains of the stable region of North America, the occurrence of intrusions make an unusual and curious spectacle. It would seem that these intrusions should accompany the superior Nemaha structure rather than the inferior Barneston-Winkler structure of the region.

The intrusion problem requires an explanation of the following situations for its solution:

1. The origin of intrusions
2. The location of intrusions
3. The orientation of intrusions

<u>The Origin of Intrusions</u>. The basic igneous material of the intrusive bodies was probably derived from below the granite crust which is believed to be rather thin in the stable region of North America. Under confining pressures the basic rocks below the granite do not have much strength but are highly rigid.

It should be remembered that the Big Blue and the Humboldt faults in the basement complex probably die out at great depth in the basaltic zone below where the rocks are so plastic that open fractures can exist only momentarily.

The Big Blue fault was reactivated in post Dakota times. The pressure on the faces of the fault generated frictional heat which, plus the latent heat of the basic rocks, was more than enough to melt the rocks at atmospheric pressure. Aided by a momentary release of pressure, local areas along the fault plane became damp with melted basaltic rock. Subsequent strike-slip movement along this zone, now well lubricated, ripped the jointed rocks along the fault plane, much as a card shark ripplies a deck, causing the tightly closed joints nearly perpendicular to the fault plane to open momentarily. The maximum effect of this movement appears to be in Riley county. The momentary opening of the joints caused local releases of pressure, permitting magma to flash into being and start toward the surface. The opened joints were immediately "slammed shut" by the elastic rebound of the strong granite and Lower Paleozoic dolomites, thus injecting a "droplet" of magma into the overlying more plastic formation where it finally came to rest by reaching an equilibrium in the thick shales of Lower Permian age. The space problem that resulted from the intrusion produced compressive energy in the plastic shales, causing small compression folds, minor wrinkles and thrust faults, paralleling the surface joint sets wherever the removal of overburden by erosion released the stored compressive energy.

The absence of lava flows and the presence of numerous xenoliths in the intrusions indicate that they never reached the surface. All the known intrusive masses have been unroofed by erosion. The surface in Cretaceous times was probably several hundred feet above the present surface. The sedimentary xenoliths show a preponderance of shattered flint and other sedimentary rocks. Since all the intrusions occurred in a matter of seconds throughout the region, the xenoliths were not altered until the magma came to rest. Due to the small volume of magma and the release of pressure, the magmatic material cooled rapidly, producing very little contact metamorphism of the country rock. When the magma, mixed with xenoliths, came to rest, it was probably of a consistency of putty or wet cement. Some flow structure can be noted in some of the intrusions by the orientation of xenoliths. Very little drag resulted in the country rock. The shales and thin limestone are upturned about 45 degrees at the Randolph No. I intrusion (Plate I-15) where Dr. F. E. Bryne supervised a series of excavations to determine the nature of the contact of the intrusion. The upturned rock existed for only a few feet around the intrusion and was probably due to elastic rebound more than drag. Some of the coloration of the surrounding rocks is probably due to leaching along the contact of the intrusion and is not entirely the result of contact action. The amount of stoping after the magma was emplaced is not known, but the great amount of xenoliths indicates that stoping was not great.

Most of the intrusions are reflected in the topography as positive relief. They are more resistant to erosion than shale and more resistant to weathering than limestone. The only exception is the Stockdale intrusion (Plate I-14) which at the present time is being cut by a small intermittent stream. This intrusion appears to be slightly more resistant to erosion than the surrounding shale. The Stockdale intrusion seems to be mineralized to a greater extent than the other intrusions. This may be a reason for its peculiar weathering habit of flaking or spalling while the other intrusions fracture into small irregular blocks when exposed to the atmosphere. On the downstream side of the Stockdale intrusion many small placers are found containing ilmenite and serpentine and several other more resistant minerals. Only the resistant minerals remain with little or no serpentine in the ancient placers at the base of the glacio-fluvial deposits and in the modern reworked glacio-fluvial placers away from the present outcrops.

The rapid cooling of the magma after it has been emplaced produced a fine textured gray-green rock mottled by numerous xenoliths. The composition is that of a serpenitized peridotite. In addition to serpentine and partly altered olivine, ilmenite, garnet, spinel, biotite and probably some magnetite and chromite were formed during the magmatic and immediately aftor the magmatic phase of crystallization. The rapid differential cooling of the crystallized mass caused it to become badly shattered. Subsequent hydrothermal action produced small crystals of spinel and garnet in the fractures of the shattered intrusion. The mineral calcite was deposited by ground water in the remaining open spaces. Stream erosion of the serpenitized peridotite intrusions has produced placer deposits of ilmenite with some spinel and garnet. The best developed placers are located around the Stockdale intrusion. The largest garnet pebble found by the writer measured nearly one and one-half inches in diameter. It it believed to be the largest native garnet that has ever been found in Kansas.

Due to the small size of the intrusions, it is doubted that they will be of practical value for road or construction materials or processing for chromium and other minerals which exist in limited amounts. In the Stockdale intrusion the red spinels, or garnets, vary greatly in color from light yellow-orange to dark wine-red and vary in size from minute crystals to grains a little over a quarter of an inch in diameter. The green (chrome bearing?) spinels are a brilliant green to dark green in color with sizes less than a quarter of an inch. Both these red and green crystals are worth little as gem stones due to imperfections and very small size.

The Location of the Intrusions. The five known intrusions occur along jointological anomalies.[17] There seems to be a definite relationship between the location of an intrusion and the number of joints per unit area. Intrusions do not occur where the number of joints per unit area is very great, nor do they occur where the number is very low, but rather in intermediate zones of fracture. In areas of highly jointed rocks, no intrusions should be expected since the energy of the forces producing open joints was spread too thin over too many cracks and not concentrated enough to permit the opening of any one localized crack for the magmas to rise. In areas where the rock is sparcely fractured no intrusions should be expected because of the greater resistance to opening a joint where the joint blocks are more massive or the surface pattern did not favor the subsurface pattern in orientation and coincidence. Thus, the energy was resolved along favored fracture zones at right angles to the strike-slip movement between basement complex blocks.

The opened magma-bearing joints die out rapidly away from the Big Blue fault and the other associated zones of strike-slip movement. The strike-slip movement undoubtedly was not concentrated along one single fault but also occurred with variable, though progressively diminishing, displacements between parallel zones of joint blocks to the east of the Big Blue fault. Thus, each tier of blocks suffered some rotation and opening of the joints for some distance from the Big Blue fault along which the greatest movement probably took place. The intrusions, therefore, should not be expected to lie far from the ridge.

The intrusions are small, slightly elliptical, in plane view and less than an acre in area. They probably pinch out toward the basement complex where the elastic rebound following the intrusion probably squeezed the plug to a thickness of a few inches or less. The overall shape of an intrusion should therefore be an elongated, pear-shaped, bulbous, upward mass. Since east-west joints were apparently in control, the intrusions are somewhat elongate east-west. In plane view the intrusions appear to dot the area as intermittent small patches of serpentinized peridotite dying out in frequency and size away from the zones of greatest stike-slip movement. In a cross section through the area several other intrusions would probably be found at different heights with some at depth and others nearly exposed, depending upon the amount of igneous material injected, the degree of jointing of the area, the amount of rotation of the blocks and the distance from the zones of strike-slip movement. This situation has been noted by Dr. J. R. Chelikowsky (2) in the Mammoth Embayment of California.

The Orientation of the Intrusions. The intrusions were oriented, not with the surface joint pattern, but with the fundamental subsurface pattern of the basement complex. This situation arises from the fact that the intrusions were injected through the basement complex into the sedimentary rock so rapidly and violently that it was not possible for the intrusion to follow the previously rotated surface pattern of joints. All the intrusions of the region strike N 59 to 82 W - S 59 to 82 E or nearly perpendicular to the Big Blue fault and parallel to the basement complex, set of joints trending in that direction (Plate I). It will be found that the nearer the intrusion is to the major zone of strike-slip movement, the greater the discrepancy between the elongation direction of the intrusion and the rotated surface joint pattern.

Drainage Problem and Solution

The drainage pattern of the region is a composite of several types of stream patterns; dendritic, rectangular and glacially deflected. The dendritic pattern occurs to the west and north of the Marshall-Riley county area where the homogeneous material, with little variation in resistance, was deposited as part of the thick cover of the Rocky Mountain piedmont plain. The rectangular drainage pattern exists in the areas of exposed Lower Permian limestones and shales which have well developed joints in southwestern Marshall and northern Riley counties. The glacially deflected drainage pattern occurs in the northern and eastern portions of the Marshall-Riley county area where many stream valleys were filled by glacial material, forcing the streams to seek new channels west and south of the advancing ice front.

The regional pattern before glaciation probably was mainly dendritic due to the piedmont deposits with some rectangular drainage where streams had cut through the piedmont sediments. The streams probably drained eastward to what is now the Mississippi River. After the Nebraskan and Kansas glaciers advanced into the region, many valleys in eastern and northern Marshall county were filled and the streams were forced to follow new courses around the ice front.

Since drainage is controlled by surface structure and the surface structure is apparently controlled by joints, it is not surprising that many streams are found paralleling the strike and dip joints. Probably more than 75 percent of the streams in Riley county show some joint control.

Streams follow the joints because they are zones of least resistance, along which a sapping action can take place by undercutting the joint blocks. This is done in two ways; 1) at rapids or waterfalls, but undercutting the shales below a resistant formation and 2) as the stream widens downstream from the headwaters, by undercutting the resistant rocks parallel to the flow of the stream, causing the banks to part, creep away and slump from the other jointed blocks of rock. In more mature streams where flood plains have been developed, the meanders obviously will not necessarily parallel the joint pattern. When a swinging meander undercuts a valley wall, however, slump will cause bed rock to part along a joint plane, thus retaining the parallelism of the valley to the joint pattern.

The gradient and the direction of flow for a stream is an equilibrium condition established between the strike of the joint pattern and the dip of the formations (compare Plates I, II and III). The joint-stream parallelism is not restricted to small upland streams but can be found along some of the major streams such as the Big Blue River along the south end of the east boundary of Riley county from Randolph to Manhattan, Kansas (Plate I). Before a stream can become joint controlled, it must cut through the unconsolidated material into the consolidated jointed rock. The writer feels that many of the buried valleys, particularly the smaller ones, are being recut along the old joint controlled valleys, since the glacial material is less resistant than the older country rock. In most areas there are enough random joints so that a stream can have almost any trend.

THE TECTONIC PANORAMA

The discussion of the tectonic panorama includes works by Eardley (4), King (9) and Lee, Leatherock and Botinelly (11) with the majority of the information coming from The Stratigraphy and Structural Development of the Salina Basin of Kansas by Lee, Leatherock and Botinelly.

Tectonically the Marshall-Riley county area is a small portion of the stable region of North America, the southern extension of the Canadian or Laurentian shield, which came into existence early in the history of the earth during Archeozoic and Proterozoic time. The Pre-Paleozoic subsurface structure of the stable area is not well known since it is buried under sediments. The Canadian shield has been high during most of its Paleozoic existence, thus the ancient structure is exposed. According to King (9), the structural trend of the Canadian shield and the relatively stable Transcontinental Arch, together with its transverse structures, is very similar to that inferred for Kansas by the writer. From this, it must be apparent that the structural pattern and trends of the local area, as well as the entire continent, are very archaic. During the enormously expanded Lipalian interval of many tens of millions of years, much of the relief and structure were removed, leaving only the structural trends and the joint pattern with traces of ancient orogenies. In Kansas, the only means by which the location and trends of Pre-Paleozoic orogenies can be determined, other than inferred by jointology, is by extensive drilling to the basement complex.

During Middle Paleozoic times, the Trans-Continental Arch, trending NE-SW, was elevated in Kansas along with a cross structure, the Cambridge-Ellis-Chautauqua-Ozark Arch, trending NW-SE. These two trends presumably parallel the archaic, or fundamental joint sets in the basement complex.

This pattern of arches persisted until it dissipated in late Paleozoic times into individual highs paralleling the fundamental basement complex pattern.

The Marshall-Riley county area lies near the edge of the Trans-Continental Arch, the major NE-SW trending structure. The first evidence in Paleozoic times of a high was in the Cambrian when the Southeast Nebraska arch was elevated. Plunging southward across Kansas, it paralleled the Ozark basin to the east and Pre-Roubidoux syncline to the west.

During the Ordovician the area was warped, causing a long period of differential subsidence in northeast Kansas and an uplift of the Ozark region of Missouri, the Chautauqua arch and the Central Kansas uplift, trending NW-SE. The disturbance was intermittent and interrupted sedimentation locally.

At the end of the Silurian, the entire region was raised above sealevel and eroded. During the Devonian, the North Kansas basin sank for the second time with the Nemaha ridge forming and separating the Chautauqua arch from the Central Kansas uplift.

During the Mississippian, several important structural events took place. The Nemaha ridge was reelevated while the region was tilted toward the north with subsidence to the northeast in Iowa while southeast Kansas remained stable. Then the region was tilted toward the south in Osagian times to become part of the Ouachita basin. At the end of the Mississippian, the northwest trending highs were reelevated, along with renewed faults and uplift of the Nemaha ridge, together with many northeasterly trending highs, including the Barneston-Winkler ridge. This disturbance terminated the existence of the North Kansas basin and produced the Forest City and Salina basins. Southeast Kansas remained stable while the Nemaha ridge was eroded to granite where the elevation was the greatest, particularly in the north.

During Pennsylvanian times the Marshall-Riley county area was a part of the regional Ouachita basin which was dominated by the deep Ouachita geosyncline in west central Arkansas and southeastern Oklahoma. The southern areas of the Ouachita basin received from 18,000 to 20,000 feet of clastic sediments derived from the rising land mass to the south compared with 200 feet in the Salina basin and 800 feet in the Forest City basin Lee, Leatherock and Botinelly (11, 142). The difference in the amount of sediments received by the Forest City and Salina basins was due to the earlier and greater submergence of the Forest City basin. Throughout the entire Ouachita basin, the limestones remain remarkably constant in thickness while the shales thicken rapidly to the south and grade into sandstones.? This is because the limestones were deposited in the relatively quiet water farthest from the old shorelines and were not affected by rapid offlap conditions.

In the Marshall-Riley county area the Nemaha ridge remained above sealevel until Marmaton times in the Pennsylvanian while the Central Kansas uplift continued to develop until later Pennsylvanian times when the entire region become more stable.

The base of the Permian is marked by a low angular unconformity with the deposition of the Indian Cave sandstone in buried river valleys. Very little deformation took place in Kansas at this time except for a possible 50 foot displacement along the Barneston-Winkler ridge and a 40 foot displacement along the Nemaha ridge.

In Triassic and Jurassic times much of Kansas was eroded and most of the Permian rocks west to the Salina basin were removed. A limited area of sedimentation occurred in southwest Kansas which has been correlated with the Triassic and the Upper Jurassic or Morrison formation.

During the Cretaceous, the region was blanketed with thick deposits in western Kansas, thinning to the east perhaps well into the Mississippi valley. But the eastern thin edge was subsequently stripped back by erosion to the Salina basin area.

In Pre-Dakota times, the Salina basin dipped about 10 feet per mile to the southwest away from the Nemaha ridge. This was caused by the warping of the region during the interval between Permian and Cretaceous times. After Dakota times, the region was tilted to the northwest, causing the Salina basin to dip from six to ten feet per mile to the northwest. The writer feels that the warping and shifting of the axis of the Salina basin in post

Dakota times probably caused the strike-slip movement and rotation of the joints and minor structures along the Barneston-Winkler ridge. It seems very probable that the intrusion of basic igneous rocks was emplaced at this time as well as the formation of the major and minor wrinkles with local clockwise rotation of the joint pattern.

The Tertiary deposits, which were derived from the Rocky Mountains, occur in western Kansas as vast piedmont plain deposits. The Tertiary deposits in eastern Kansas occur in the Flint Hills and are composed of upland chert gravels south of the glacial till area and now found at the base of the loess.

In Quaternary times, some faulting occurred in western Kansas and the writer feels that in the Marshall-Riley county area, faulting occurred along the western flank of the Nemaha ridge, particularly around the Zeandale dome. This faulting may have resulted from readjustments in northeast Kansas as the ice front advanced and retreated.

CONCLUSIONS

All structures have an infinitesimally small beginning. When one zone of weakness has been favored, it will always forever after exert the same control on the structure of the region. Joint patterns, the most immense faults, folds and intrusions grew from insignificant beginnings and developed by successive diastrophic increments. Thus, one should not expect to find immense forces and conditions causing immense structures since the time for each feature may vary considerably.

After a structural grain and fracture pattern have been established in the basement complex, diastrophism and oscillations of the earth's crust intensify the structural pattern already in existence and transmit it upward into the younger rocks which are laid down on the old pattern. The strength to carry tectonic forces and adjustment lies in the basement complex, not in the relatively plastic sediments above. It is the basement complex that controls the nature and disposition of the overlying sediments. Thus, the surface sedimentary rocks cannot have a major fault, joint system or major fold independent of the basement complex. However, minor faults, joints and folds may be possible in the sediments due to minor tectonic adjustments between the blocks of the basement complex and to weathering and erosion.

As a joint pattern is transmitted upward it is affected by differential compaction, subsidence, elevation and rotation of fault blocks due to strike-slip movement (Plates I and V). Each of these adjustments in the basement complex causes repeated

EXPLANATION OF PLATE V

Illustrating the repeated counterclockwise rotation of the joint pattern from the Cambrian to the Permian. In each case the Pre-Cambrian pattern is indicated by a heavy dashed line. The shaded area represents previous rotation. The solid heavy line is the fundamental pattern at the end of each of the six geologic periods indicated.

It will be noted that the N-S set (shaded) has rotated less than the E-W conjugate shear set. The major structures for the Marshall-Riley county area occur along the N-S set, while the transverse minor structures occur along the E-W set. See "Catalogue of Structures", page 67.

I. Cambrian

II. Ordovician

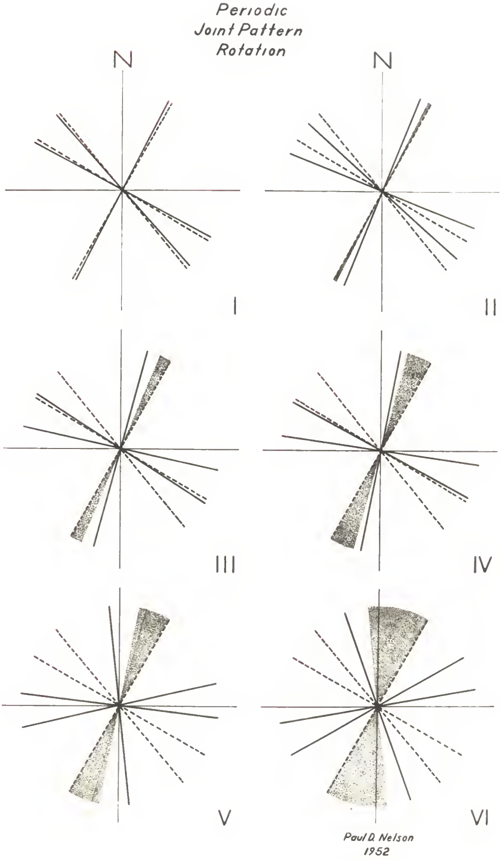
III. Devonian

IV. Mississippian

V. Pennsylvanian

VI. Permian

PLATE V


Periodic
Joint Pattern
Rotation
N
N
I
II
III
IV
V
VI
Paul D. Nelson
1952

deflection in the surface pattern as new formations are laid down (Plate V). Therefore, the major surface joint pattern is an extension of the subsurface pattern but with distortion and rotation as the new joints are developed in the successively newly deposited formations.

The joints at the surface in Riley and Marshall counties form a definite pattern. When traced across the area, two types of variations in trend are noted; 1) a regional deflection and 2) a local rotation. The deflection increases to the south and west of the area and rotation increases to the southwest in Riley county. The deflection is due to vertical rotation of fault blocks, warping and differential compaction. The rotation probably resulted from strike-slip movement in the basement complex (Plate I).

The regional ridges (welts), domes, anticlines, faults, basins and synclines possess a pattern parallel to that of the basement complex pattern resulting from regional forces and adjustments (Plates I, II and III). The basins and synclines must be considered merely counterparts of adjoining highs since they are features that can only be identified because of the existence of the positive ridges. The positive areas existed as zones of weakness for many periods and experienced periodic uplifts although at times they are areas of sedimentation. In other words, highs may temporarily be warped down but the majority of the time the movement is upward.

The secondary structures of the surface occur as very local features paralleling the surface joint pattern (Plate I). These structures are the minor wrinkles, thrust and normal faults resulting from minor adjustments in the basement complex and very local surface forces. The local forces were effected by intrusions and rotation in strike-slip movement, weathering, erosion or the local effect of regional adjustment.

It has been noted that a sharp division exists between the different magnitudes of structures resulting from the magnitude of the force. A minor local force will be far below the threshold of tectonic movement for the Pre-Cambrian granite or the Early Paleozoic dolomites but it may be above the threshold for the plastic shale and thin limestone acting in a short-time stress. In this case, the force will be resolved into movement parallel to the surface joint pattern to form local and minor structures. When a regional force is just below the threshold of tectonic movement for the basement complex but is above the threshold for the surface rocks acting during a long-time stress, it will only accent the subsurface structure along the existing lines of weakness. For a regional force above the threshold of deformation for the basement complex and far above the threshold for the surface formation may cause the formation of new structure in the basement complex along the pattern and may warp the existing highs into lows. + change the jt. pattern

The intrusions resulted from local release of pressure by the regional strike-slip movement along several planes of weakness due to regional causes. These structures are oriented along the basement complex fracture pattern which does not coincide with the surface joint pattern because of rotation. ? The largest intrusions are probably located near the Big Blue fault where the major movement took place. The largest intrusion may not make the largest outcrop at the surface. This can only be determined by subsurface surveys.

The surface topography is a result of regional structure and joint pattern controlling the majority of the streams that have cut into the consolidated rock in the Marshall-Riley county area.

The writer realizes that no one joint would exist from the basement complex to the surface as joints are formed discontinuously in successive formations paralleling the previous joint pattern. ? how?

ACKNOWLEDGMENT

The writer wishes to extend grateful acknowledgment and appreciation to Dr. J. R. Chelikowsky, under whose supervision this work was completed, for advice, personal conferences and numerous field trips.

The writer also wishes to express his indebtedness to W. L. Cline for numerous well logs.

REFERENCES

(1) Bucher, W. H.
The deformation of the earth's crust. Princeton; Princeton University Press, 1933.

(2) Chelikowsky, J. R.
Tectonics of the rhyolite in the mammoth embayment California. Jour. of Geol., Vol. XLVIII, No. 4. 1940.

(3) Dreyer, R. M.
Magnetic survey of the Bala intrusive, Riley county, Kansas. State Geol. Surv. of Kans. Bul. 70, Part 2. 1947.

(4) Eardley, A. J.
Structural geology of North America. New York: Harper & Brothers, 1951.

(5) Holmes, A.
Principles of physical geology. New York: The Ronald Press Company, 1945.

(6) Jewett, J. M.
Geologic structures in Kansas. State Geol. Surv. of Kans. Bul. 90, Part 6. 1951.

(7) Jewett, J. M.
The geology of Riley and Geary counties, Kansas. State Geol. Surv. of Kans. Bul. 39. 1941.

(8) Jewett, J. M.
Oil and gas in eastern Kansas. State Geol. Surv. of Kans. Bul. 77. 1949.

(9) King, P. B.
The tectonics of middle North America. Princeton: Princeton University Press, 1951.

(10) Lee, W.
The stratigraphic and structural development of the Forest City basin in Kansas. State Geol. Surv. of Kans. Bul. 51. 1943.

(11) Lee, W., C. Leatherock and T. Botinelly
The stratigraphy and structural development of the Salina basin of Kansas. State Geol. Surv. of Kans. Bul. 20. 1948.

(12) Ockerman, J. W.
Subsurface studies in northeast Kansas. State Geol. Surv. of Kans. Bul. 20. 39 p. 1935.

(13) Mayo, E. B.
Deformation of the interval Mt. Lyell - Mt. Whitney, California. Geol. Soc. of Amer. Bul., Vol 52: 1001-1084. 1941.

(14) Moore, R. C., and others
The Kansas rock column. State Geol. Surv. of Kans., Bul. 89. 1951.

(15) Moore, R. C., J. C. Frye and J. M. Jewett
Tabular description of outcropping rocks in Kansas. State Geol. Surv. of Kans., Bul. 52, Part 4. 1944.

(16) Neff, A. W.
A study of the fracture patterns of Riley county, Kansas. Master's thesis, Kansas State College, Manhattan, Kansas. 1949.

(17) Nevin, C. N.
Structural geology. 4th ed. New York: John Wiley and Sons, 1949.

(18) Parker 3rd, J. M.
Regional systematic jointing in slightly deformed sedimentary rock. Geol. Soc. of Amer. Bul., Vol 53. 381-408. 1942.

(19) Taylor, W. K.
Study of the structural relationship of the Riley county intrusions to the Abilene arch. Master's thesis, Kansas State College, Manhattan, Kansas. 1950.

APPENDIX

TABLE OF THE LANSING GROUP OF THE PRE-CAMBRIAN TOPS

The following well data were used for the subsurface maps (Plates III and II). The initial of the county appears in capital letters before the well numbers as follows: "M" for Marshall county, "R" for Riley county, "P" for Pottawatomie county and "W" for Wabaunsee county.

The tops are given in relation to sealevel datum. The underscored numbers are uncertain and questionable.

Well Number	Location	Elevation	Lansing	Pre-Cambrian
M1	20-T1S R6E	1257	24	-1441
M2	27-T5S R6E	1368	146	-1188
M3	28-T2S R7E	1158	---	----
M4	28-T2S R7E	1158	---	----
M5	29-T2S R7E	1163	---	----
M6	10-T3S R7E	1334	---	----
M7	22-T3S R7E	1309	159	-986
M8	34-T3S R7E	1373	---	----
M9	4-T4S R7E	1328	---	-937
M10	4-T4S R7E	1328	---	----
M11	10-T4S R7E	1295	213	-880
M12	21-T4S R7E	1132	265	-868
M13	3-T5S R7E	1270	99	-1270
M14	30-T5S R7E	1407	175	-1088
M14a	34-T2S R8E	1325	304	-387
M15	20-T2S R9E	1293	---	+28
M16	29-T2S R9E	1293	---	-127
M17	15-T4S R9E	1185	---	----
M18	22-T4S R9E	1142	---	-83

M19	24-T4S R9E	1142	---	-198
R1	36-T7S R4E	1410	---	----
R2	24-T8S R4E	1328	-77	-1402
R3	14-T9S R4E	1216	-124	-1544
R4	2-T7S R5E	1127	---	-2393
R5	15-T7S R5E	1345	65	-1206
R6	32-T7S R5E	1415	---	----
R7	33-T7S R5E	1387	---	----
R8	29-T8S R5E	1398	-82	-1317
R9	30-T6S R6E	1242	-116	----
R10	21-T8S R6E	1258	-87	-1418
R11	26-T10S R6E	1213	8	----
R12	20-T10S R7E	1264	14	----
R13	16-T10S R8E	1006	166	-983
R14	4-T11S R8E	1369	109	----
R15	28-T10S R9E	1007	402	+49
R16	28-T10S R9E	1007	---	-13
P1	1-T8S R7E	1430	---	----
P2	25-T6S R9E	1493	---	-277
P3	25-T6S R9E	1501	---	-252
P4	8-T7S R9E	1460	296	-365
P5	12-T7S R9E	1305	327	-400
P6	32-T8S R9E	1111	216	-864
P7	16-T9S R9E	1083	232	-992
P8	16-T9S R9E	1083	---	----
P9	16-T9S R9E	1083	233	----
P10	34-T9S R9E	1111	---	-739

P11	2-T10S R9E	----	---	----
P12	1-T7S R10E	1365	450	-84
P13	4-T7S R10E	1475	420	-240
P14	29-T7S R10E	1395	390	-312
P15	1-T8S R10E	1125	336	-878
P16	7-T8S R10E	1423	323	-455
P17	12-T10S R10E	977	---	----
P18	34-T6S R11E	1171	556	+196
P19	3-T8S R11E	1208	---	----
P20	14-T8S R11E	1292	-47	-2194
P21	23-T9S R11E	1185	-105	----
P22	7-T9S R12E	1257	-121	-2348
P23	4-T10S R12E	968	---	----
P24	10-T10S R12E	958	---	----
P25	11-T10S R12E	1085	---	----
W1	26-T10S R9E	1149	---	+56
W2	1-T11S R9E	1867	---	-28
W3	24-T11S R9E	1384	---	-213
W4	32-T10S R10E	1078	---	-642
W5	33-T10S R10E	1082	---	-1623
W6	5-T11S R10E	1093	---	-1396
W7	5-T11S R10E	1034	---	-389
W8	6-T11S R10E	1090	---	-144

CATALOGUE OUTLINE OF STRUCTURES

This catalogue was compiled to give the location of the structures in the Marshall-Riley-Pottawatomie county area of the state of Kansas. Also, to reemphasize the orientation, parallelism, time and magnitude of the structures with the oldest and largest structures usually being listed first under each of the four main headings. The numbers in parenthesis are reference numbers for the plates.

I. Subsurface Structural Pattern

A. Structures Paralleling the North-South Fundamental Joint Set (N 15 to 30 E - S 15 to 30 W)

1. Southeast Nebraska arch

2. Trans-Continental arch

(1) 3. Nemaha ridge

(2) 4. Barneston-Winkler ridge

(3) 5. Irving syncline

(4) 6. Humboldt fault

(5) 7. Big Blue fault

(6, 7) 8. Welts

(8, 9) 9. Domes

(10) 10. Major wrinkles

B. Structures Paralleling the East-West Fundamental Joint Set (N 40 to 60 W - S 40 to 60 E)

1. Central Kansas arch

2. Central Kansas uplift

3. Chautauqua arch

4. Bourbon arch

(11) 5. Cross faults (nearly perpendicular to major faults)

(12-16) 6. Basic igneous intrusions

II. Surface Structure Pattern

A. Structures Paralleling the North-South Surface Joint Set (N 10 to 30 W - S 10 to 30 E)

(17) 1. Normal faults southeast Riley county

(18-24) 2. Thrust faults

3. Minor wrinkles

4. Stream drainage

B. Structures Paralleling the East-West Surface Joint Set (N 60 to 80 E - S 60 to 80 W)

(25) 1. Normal faults southwest Pottawatomie county

2. Minor wrinkles

3. Stream drainage

CATALOGUE OF STRUCTURES

I. Subsurface Structural Patterns

A. Structures Paralleling the North-South Fundamental Joint Set (N 15 to 30 E - S 15 to 30 E)

1. Southeast Nebraska arch T1-11S, R1-14E
Cambrian--southward plunging arch Lee (9).

2. Trans-Continental arch
Middle Paleozoic--southwestern extension of the Canadian Shield through the mid-continent and Kansas. Eardley (3).

(1) 3. Nemaha ridge N 30 E - S 30 W
Middle Paleozoic--plunging southward 12 feet per mile in Riley county, faulted along the eastern flank.

(2) 4. Barneston-Winkler ridge N 30 E - S 30 W
Middle Paleozoic--plunging southward 22 feet per mile from Nebraska through west central Marshall and western Riley counties.

(3) 5. Irving syncline N 30 E - S 30 W
Middle Paleozoic--plunging southward from Nebraska through central Marshall and western Pottawatomie counties.

(4) 6. Humboldt fault N 12 to 27 E - S 12 to 27 W
Middle Paleozoic--forms the eastern flank of the Nemaha ridge with displacements as great as 2400 feet in Oklahoma.

(5) 7. Big Blue fault N 32 to 36 E - S 32 to 36 W
Middle Paleozoic--forms the eastern flank of the Barneston-Winkler ridge with displacements of 400 feet in southwestern Marshall county.

8. Welts N 30 E - S 30 W
Middle to Late Paleozoic--formed over the ridges by differential compaction. Found at the surface as regional dips forming the major anticlines of the region.

(6) a. Nemaha anticline N 20 E - S 20 W

(7) b. Barneston-Winkler anticline N 30 E - S 30 W

9. Domes

Middle to Late Paleozoic--formed by differential compaction over granite knobs on the ridges. Some of the other domes may or may not have granite cores.

(8) a. Zeandale dome T10S, R9E

Located on the Nemaha ridge in southeast Riley and southwest Pottawatomie counties. Is believed to be due to cross faulting.

(9) b. Winkler dome T7S, R5E

Located in the Barneston-Winkler ridge in northwest Riley county. May be due to cross faulting.

(10) 10. Major Wrinkles T6S, R5-7E; N 30 E - S 30 W

Late Paleozoic--caused by differential compaction along the Barneston-Winkler ridge and modified by compressive forces.

B. Structures Paralleling the East-West Fundamental Joint Set (N 40 to 60 W - S 40 to 60 E)

1. Central Kansas arch (Cambridge-Ellis-Chautauqua-Ozark arch) N 55 W - S 55 E

Ordovician--lies diagonally across Kansas from northwest to southeast, west and south of the Marshall-Riley county area.

2. Central Kansas uplift (Barton arch) N 40 W - S 40 E

Middle Paleozoic--lies diagonally across northwestern Kansas to the west of the Marshall-Riley county area.

3. Chautauqua arch N 60 W - S 60 E

Ordovician--lies diagonally across southeast Kansas to the south and east of the Marshall-Riley county area.

4. Bourbon arch N 60 W - S 60 E

Middle Paleozoic--located in eastern Kansas to the southeast of the Marshall-Riley county area.

(11) 5. Cross faults NW-SE

Middle Paleozoic--are believed to exist on both the Nemaha and the Barneston-Winkler ridges causing some of the granite knobs

6. Basic Igneous Intrusions N 59 to 82 W - S 59 to 82 E
Cretaceous--located along the Barneston-Winkler ridge in Riley county. Caused by momentary opening of the NW-SE joints by strike-slip movement.

(12) a. Bala Intrusion NWcor 6-T9S, R5E
Elongated N 59 W - S 59 E intruding Cresswell limestone.

(13) b. Leonardville Intrusion NW22 T8S, R5E
Elongated N 64 W - S 64 E intruding the Cresswell limestone.

(14) c. Stockdale Intrusion SE SW NE 23-T8S, R6E
Elongated N 82 W - S 82 E intruding the Holmesville shale.

(15) d. Randolph Intrusion No. 1 NW 35-T6S, R6E
Elongated NW-SE intruding Doyle shale formation.

(16) e. Randolph Intrusion No. 2 SE SE 27-T6S, R6E
Elongated NW-SE intruding Doyle shale formation.

II. Surface Structural Pattern

A. Structures Paralleling the North-South Surface Joint Set (N 10 to 30 W - S 10 to 30 E)

(17) 1. Normal faults of southeast Riley county N 22 W - S 22 E 13 and 24-T11S, R8E contains at least six normal faults with displacements as great as 25 feet with lengths of one and two-third miles.

2. Thrust faults
Result from the release of active compressive stresses by removing the overburden.

(18) a. Bala thrust NE 1-T9S, R4E
In Stovall limestone thrust 3 feet to the west.

(19) b. Bala Flexure thrust NE NE 8-T9S, R5E
In Stovall limestone

(20) c. Milford thrust SE 31-T9S, R5E
In Stovall and Cresswell limestones thrust to the west.

(21) d. Randolph Thrust System of Several Thrusts NE NE 30-T7S, R6E
In Stovall limestone thrust 1-3 feet to the east.

(22) e. Riley Thrust SW NW 33-T8S, R6E
In Stovall limestone thrust 3 feet to the northeast striking N 50 W - S 50 E.

(23) f. Deep Creek Thrust SW 6-T11S, R9E
Elmont limestone thrust about 3 feet.

(24) g. Waterville Thrust Cen S line 20-T3S, R6E
In Cresswell (?) limestone thrust about 3 feet to the west, striking N 15 W - S 15 E.

3. Minor Wrinkles
Due to compression resulting from strike-slip movement along the Barneston-Winkler ridge.

a. Marshall county system

(1) Cen S line 20-T3S R6E	axis N 15 W -	S 15 E
(2) Cen N line 33-T3S R8E	plunge 5	S 30 E
(3) Cen N line 33-T3S R8E	axis N 15 W -	S 15 E
(4) Cen N line 33-T3S R8E	plunge 15	S 10 E
(5) Cen N line 33-T3S R8E	plunge 25	S 10 E

b. Riley county system
No N-S wrinkles were recorded in Riley county; however, the writer believes that there are some in the vicinity of the intrusions.

4. Stream Drainage Pattern
Many instances were noted where the streams paralleled this set of joints.

B. Structures Paralleling the East-West Surface Joint Set (N 60 to 80 E - S 60 to 80 W)

(25) 1. Cedar Creek fault system in southwest Pottawatomie county.

a. SE¼ W½ 18-T9S R8E N 60 E - S 60 W
Downside to the north displaced 22 feet.

b. SW 9-T9S R8E N 60 E - S 60 W
Consists of two parallel faults, major and minor, with the downsides to the north. Between the faults a rotated block exists with displacements 22 feet and 5 feet,

100 yards to the southwest the block is displaced 12 feet and 9 feet, respectively.

2. Minor Wrinkles

a. Marshall county system

(1) Cen W line	34-T5S R6E	axis	N 85 E -	S 85 W
(2) SW NE	4-T5S R7E	plunge	5	N 65 E
(3) SW cor	3-T1S R8E	plunge	25	S 85 W
(4) SW cor	3-T1S R8E	plunge	12	N 75 W
(5) Cen W line	2-T1S R8E	plunge	8	N 82 E
(6) NE	33-T3S R8E	plunge	15	N 80 E

b. Riley county system

(1) NE cor	9-T6S R6E	plunge	5	N 85 E
(2) Cen W line	15-T6S R6E	plunge	20	N 85 E
(3) SE cor	21-T6S R6E	plunge	8	N 80 E

3. Stream Drainage Pattern

Many instances were noted where the streams paralleled this set of joints.

THE REFLECTION OF THE BASEMENT COMPLEX IN THE SURFACE STRUCTURES OF THE MARSHALL-RILEY COUNTY AREA OF KANSAS

by

PAUL DANHEIM NELSON

B. S., Kansas State College
of Agriculture and Applied Science, 1950

AN ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1952

ABSTRACT

The structural pattern of the Riley-Marshall county area is controlled by one regional basic fundamental system of joints repeatedly transmitted upward from the basement complex into the overlying sediments after each unit was deposited. Horizontal and vertical crustal movements accompanied by differential compaction of the sediments extended, distorted and rotated the fundamental basement complex joint pattern to the surface. The pattern in the basement complex controls the major structures and the intrusions of igneous rock. The surface joints controlling the minor post Permian structures have been rotated nearly fifty-five degrees counterclockwise with respect to the fundamental joints of the basement complex.

All structures have infinitesimally small beginnings along zones of weakness; no large forces should be expected in the formation of immense structures because of the time factor. After a structural grain and fracture pattern have been established in the basement complex, diastrophism and oscillations of the earth's crust intensify the structural joint pattern already in existence and transmit it upward into the younger rocks which are laid down over the older pattern. As a joint pattern is transmitted upward it may be rotated, deflected and distorted by differential compaction, subsidence, elevation and strike-slip movement between joint blocks. Each of these adjustments in the basement complex causes repeated deflections in the surface pattern as the new formations are laid down.

A sharp division exists between the different magnitudes and the orientation of the structures and the source and magnitude of the causal forces. A minor local structure may result along the surface joint pattern from a weak force which is below the threshold value of major tectonic movements for the Pre-Cambrian granite and the early Paleozoic dolomites, but above the threshold value for the Upper Paleozoic shales and thin limestones. Under such circumstances it is possible that adjustments along blocks in the basement complex may be reflected in the more plastic overlying sediments by the development of surface flexures and thrusts.

When a force is above the threshold value of major tectonic movement in the basement complex, the basement complex may be warped and faulted to produce such structures as the Nemaha, Barneston-Winkler ridges, Central Kansas uplift and the Irving syncline. These major structures reveal the joint pattern of the basement complex.

At the surface, the fundamental pattern of the joints is reflected in the topography by controlling flexures, faults and igneous intrusions. No one joint extends from the basement complex to the surface, as joints are formed discontinuously in successive formations paralleling the previous joint pattern underneath.