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# Exploring The Relationship Between The Nemaha Uplift And The Mid-Continent Rift Using 3D Mapping Visual Analysis

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EXPLORING THE RELATIONSHIP BETWEEN THE NEMAHA UPLIFT AND THE MID-CONTINENT RIFT USING 3D MAPPING VISUAL ANALYSIS

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# ABSTRACT

The present study presents and explains the relationship between Nemaha uplift and Mid-continent rift (MCR), where the understanding of the faulting systems around the study region were extremely important with regard to finding the relationship. The Nemaha is located in Kansas State in the Central United States with a total area of about 719 square miles. It was formed around the pre- Mississippian era.

The compression and rifting processes that led to formation of faults, volcanoes, ridges and oceanic plates controls the faulting in the Nemaha region. The MCR system is a major tectonic feature in North America that is believed to have been formed around 1100 Ma. MCR is generally a paleo-rift that is covered by the Phanerozoic in the craton of North America whose patterns, structure and degree are identified by geophysical means. In this study two methods; contour mapping and 3D analysis mapping, were used and the Surfer program and Geosoft software were used for the data contouring and presentation. In addition, pre-Cambrian wells that were drilled in 10 counties in the state of Kansas were used. The present study confirms that the two different structural features; namely Nemaha uplift and MCR rift are formed by two sets of reverse faults that have different, but related,  degrees of dipping and parallel strikes.

# ACKNOWLEDGEMENTS

As a matter of first importance, I am profoundly thankful to the Almighty Allah who gave me capacity to effectively complete this thesis**.** My genuine gratitude goes to my wife for love, supporting, bearing, and pushing me to succeed in finishing my degree. I might also want to offer my uncommon thanks to my advisor Dr. Schafer for priceless proposals, support, valuable advices and directions through my study in master degree. My profound thankfulness goes to for his help and persistent spur.

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# CHAPTER ONE

## 1. INTRODUCTION

### 1.1. BACKGROUND OVERVIEW

The Nemaha uplift is found in the Central United States. In the State of Kansas the Nemaha uplift is the most notable tectonic structure (Merriam 1963). It was formed around the pre- Mississippian era (prior to 354 Million years BP ). It is a buried seismic structure extending roughly from Omaha, Nebraska to the central part of Oklahoma City (Moores & Haynes, 1917).  The Nemaha region has an area of 719 square miles. The compression and rifting processes that led to formation of faults, volcanos, ridges and oceanic plates dominates the Nemaha region. The series of faults failed and it remains one of the only a few closed rifts. The Nemaha ridges contain blocks that have a width of 4 -15 miles and a length of 5 to 20 miles. These semi rectangular crustal blocks are believed to have resulted from the stress of the breaking of the Archean rock due to the opening of the Mid-Continent Rift.  This active movement of the fractured rocks is manifested on the surface as faults.

The Mid-continent rift is a failed rift because it failed to develop a seafloor but instead left a rift structure in the continent; when a rift succeeds there is stretching of the continental plates that split to form a new ocean between the two continental plates.

The Nemaha uplift eastern margin is faulted (Cole 1976). On the Northeastern part of Kansas there is the Humboldt fault though the effects of faulting are present all through the state (Condra, 1927; Jewett, 1951). The Nemaha uplift is associated with the complex faults revealed by the Viola Formation, the top of the Oswego Formation, and the base of the Pennsylvanian among other uplifts such as the Oklahoma City, Garber, Crescent and Novell uplifts which are believed to have been formed in the pre-Mississippian era ( prior to 354 Million years BP) . This description has been made in the discussions of 1943 by Lee, in 1951 by Jewett and Merriam 1963. Sepra, Setzer, and Brown (1989) discussed the Nemaha in Northeastern Kansas and illustrated the vertical faults rather than the reverse faults such as the Humboldt fault. There are other detailed discussions about the Nemaha uplift being a result of unwarping but not having the compression and shortening of these faults. Currently there are several documents illustrating the reverse faults (Gay, 1999, Bunte and Fortier, 1941) of the Nemaha system and thus concluding that it was formed as a result of compression.

There are also relaxation faults (normal faults) formed as a result of post compressional stresses; this is, according to Stander, (1981) a result tectonic forces that offset the Pennsylvanian and Permian basements. This process occurred over the entire Nemaha system. The isostatic adjustment that occurred after the ceasing of the compression is similar to the Rocky Mountain formation in front of the Wind River thrust (Stander, 1981).

Three tectonic events in the Appalachians and the orogeny that resulted from plate tectonic collision on the margin of the North America plate have similarities with the Nemaha System (Taconic, Acadian & Alleghenian; Shumaker and Wilson 1996). The collision and compressions of such a collision might have given rise to the Nemaha Uplift. The rise of the Appalachians and the Nemaha uplift at the same time led to unconformity in the whole US midcontinent.

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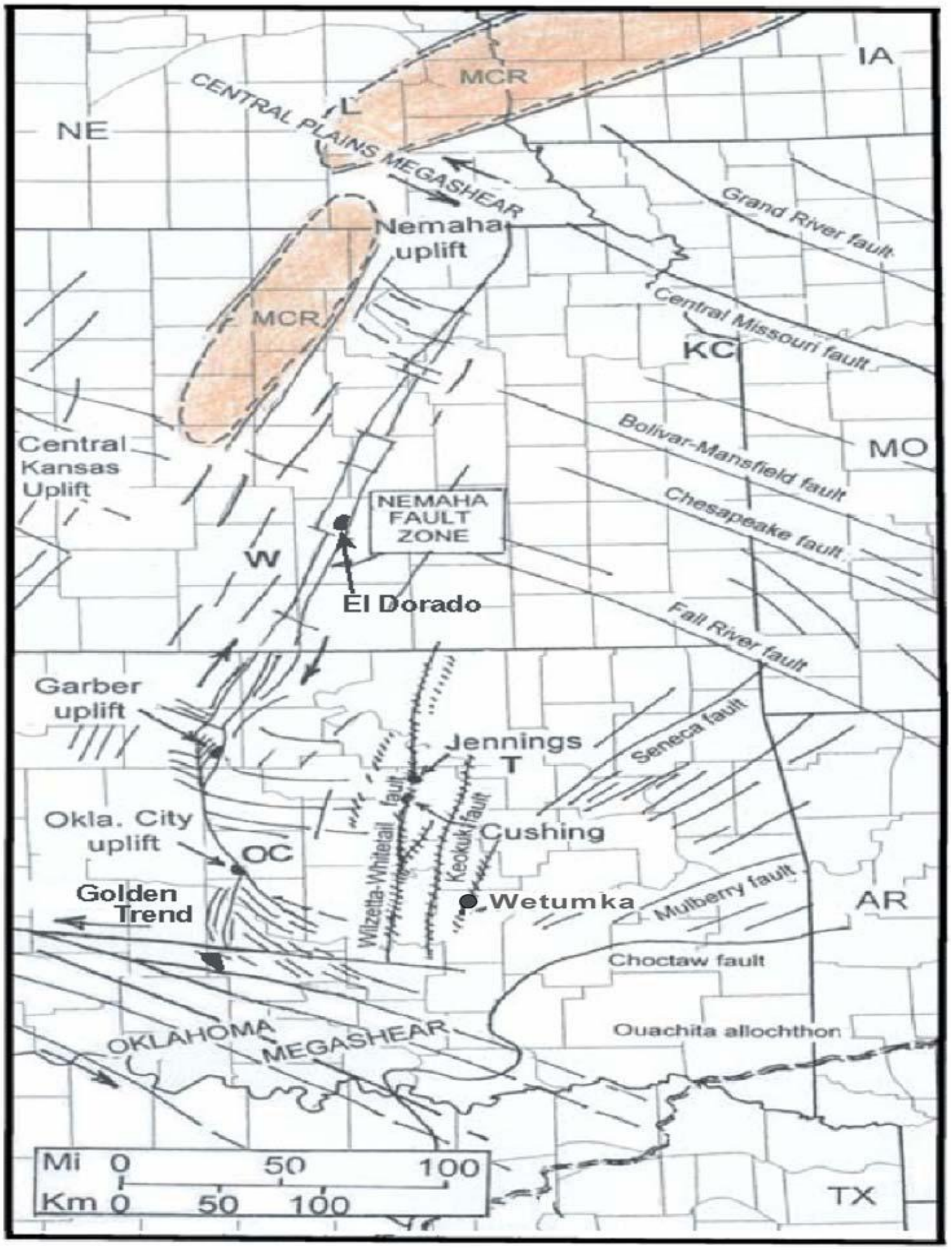



**Figure 1 : Generalized fault framework of the area encompassing the Nemaha zone, which lies between, and is terminated by, two northwest-trending, left-lateral mega shears, the Central Plains (to the north) and the Oklahoma (to the south). En echelon, northwest-south southeast surface faults east of the Nemaha zone in Oklahoma form north- to north-northeast-trends (Miser, 1954). The Nemaha zone and the other fault trends are sites of many productive structures, which originated by strike-slip movements. Trace of the Nemaha Fault adapted from Berendsen and Blair (1992). L= Lincoln; KC= Kansas City; OC= Oklahoma City; T Tulsa; W= Wichita (Johnson, 2008).**

## 1.2. PROBLEM STATEMENT AND JUSTIFICATION

The Nemaha uplift formation is dependent on mid-continent rift compression activities. This was tested by closely studying and reviewing the formation of the bordering structural features activities using the 3D maps and the contour maps. The present study is based on the Precambrian surface in Kansas and thus is able to arrive to a conclusive conclusion and answer the related following questions:

1. How is the Nemaha uplift related to the mid-continent rift?
2. How are other faults around the region of importance to the study of Nemaha uplift?

# CHAPTER TWO

## 2. Literature review

### 2.1 THE NEMAHA UPLIFT

The Nemaha uplift is believed to have begun to form around late Mississippian (in early Pennsylvanian time) during the Ouachita orogeny when pre-Pennsylvanian rocks underwent folding, faulting, uplifting and deep erosion (Jewett, 1951, Carlson 1971). This is disputed by Wells (1971) who suggested that the first movements of the uplift occurred during Kinderhookian deposition of clastic sediments. By Missourian time the surface was completely buried. The movements afterwards led to the creation of the ancestral Central Kansas uplift and the Chautauqua arch, which is between the North Kansas basin and the Oklahoma basin to the south (Lee, 1943; Rich, 1933). The Nemaha uplift is associated with complex faults revealed in the Viola Formation, the top of the Oswego Formation, and the base of the Pennsylvanian among other uplifts such as Oklahoma City, Garber, Crescent and Novell uplifts which are believed to have been formed in the pre- Mississippian era. (Adler
1971).

The Nemaha uplift is a complex feature with many associated faults. On the east is the Humboldt fault zone (Jewett, 1951; Berendsen and Blair, 1986). These faults are interpreted as high angle (Wells, 1971; Carlson, 1971). There are faults that are collateral faults impinging the Thurman-Redfield fault zone which is part of the Mid-Continent rift on the north (Jewett, 1951; Berendsen and Blair, 1986). On the south there is the Arbuckle Mountains uplift and the Paul's Valley uplift. There are many cases of reverse faulting (Gary, 1955; Cronenwett, 1958). Major faulting, downthrown to the west, is noted primarily along the margin of the uplift along the Central Oklahoma fault zone, adjoining the Anadarko basin (Jordan, 1962; Tarr et al., 1965; Amsden, 1975; Anderson et al., 1982). A strike- slip fault named the Humboldt fault forms the Eastern boundary of the Nemaha Ridge from Manhattan on the east to Wamego to the west. (McBee, 2003).

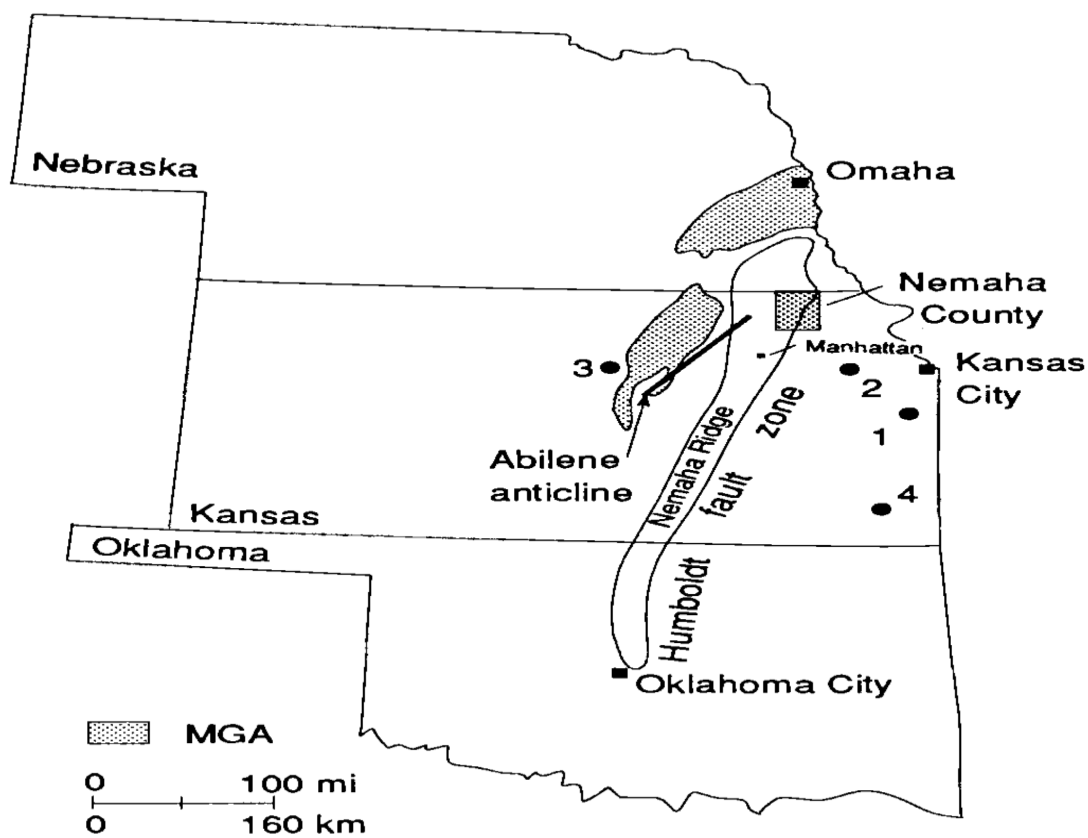



**Figure 2: The major tectonic structures associated with Nemaha uplift. (Kansas Geological Survey, Bulletin 226, 1989,)**

## 2.2 THE MIDCONTINENT RIFT

The midcontinent rift is believed to have come into being by tectonic activity; the process of compression and rifting which happened between 1109Ma and 1087Ma where rifting remained synchronized along the whole area while the pulling together occurred due to the compressional forces that were being exerted in the formation of Grenville ridges by collision (Anderson and McKay, 1997). From this finding it's presumed that the midcontinent rift inversion might have partially formed as a result of this compression processes of the normal faults. (Ensign et al.1968, Gatewood, 1970).

The mid-continent rift system (MCR) is a major tectonic feature in North America believed to have been formed around 1100 Ma (Kansas Geological Survey Bulletin 237, 2006). It is a largely buried paleorift under Phanerozoic cover in the craton of North America whose trends, structure and extent have been detected by deep drill holes and geophysical means. The mid-continent rift was first reported in Kansas by Woollard (1943) as a result of his transcontinental gravity profile and was later to be known as the Midcontinent Gravity High. Subsequent aeromagnetic investigations showed a correlative magnetic anomalies and the feature was renamed the Midcontinent Geophysical Anomaly (MGA).

This was believed to extend from Lake Superior, The north  Kansas (Van Schmus and Hinze, 1985) and southwards into Oklahoma. (Carlson 1971). The midcontinent geophysical anomaly associated rocks are only revealed in the Lake Superior basin which has classical association sedimentary, plutonic and bimodal volcanics and clastic sedimentary units of the "Keweenawan" suite (Morey and Green, 1982; Van Schmus and Hinze, 1985). Hinze and Braile (1988) interpret the mafic and clastic rocks of MGA and other related segments as a rift.

The mid-continent rift and Nemaha uplift displays similar patterns in the deformation process of the Phanerozoic; the basal movements resulted in flat top uplifts that are bordered by verging outward forced folds. The weak faults formed were reactivated by the compression forces of the faults.( Handin, 1969; Dewey, 1989; Williams et al., 1989; Ranalli, 2000; Del Ventisette et al., 2006).The midcontinent rift is also a prominent seismic feature situated between vibrating point (vp) 1400-2100. The Nemaha rift is at vp900. This implies that it is below the reverse fault formed at a magnetic at a magnetic high of over vp2000. This event is interpreted by seismic triplication of basin geometry and not the geological structure (Sibson, 1985). This is important to the exploring of the relationship between the Mid-Continent Rift and the Nemaha Uplift because of the surface of study as well as the faulting involved.

In Early Pennsylvanian time, the Nemaha structure divided the old North Kansas basin into the Forest City and Salina basins and produced a high standing block or series of uplifts, which extended south across the shelf to the Arbuckle Mountains uplift. Wells (1971) summarizes this as ...."rapid down warping and faulting on the east side of the Nemaha ridge resulted in an east facing scarp and the formation of an asymmetric basin that was deepest near the Nemaha uplift” and that "the Nemaha uplift remained exposed and the transgressed overlap of Cherokee, Marmaton, and Pleasanton sedimentation continued until early in the Kansas City deposition when the scarp finally was inundated and deposition became linked in the areas east and west of the uplift."

With respected to the reverse faulting on the Nemaha region, an illustration of Carson (1971) shows a cross section of Nemaha uplift that is seen to be similar to compression folds lacking vertical exaggeration. This reverse faults found in the Nemaha region includes PLSS coordinates 9- TIN- RIE in Nebraska (Ireland, 1966). In Kansas, Steeples (1989), describes a seismic profile revealing a reverse fault that was labeled in an inconclusive way as vertical or reverse faults at 3-T3S-R14E. Around 12 reverse faults are reported in T1S-4S-R13E.

(Ireland, 1966).. Sefrafian (1978) discussed the presence of two reverse faults.

With all the researched work available it leaves one wondering which side to identify with and thus the aim of this research.(Fath 1920, 1921, Smith and Anderson1951, Ali Seyrafian 1978).

The Pennsylvanian rocks in the region are strongly cyclothymic in sequence which is atypical of the mid-continent rift sediments (Fath 1920). The deposition of the Pennsylvanian rocks was followed by the uplift of Nemaha causing an overlap in the Forest City basin and Permian rocks that are located between the Wolfcampian to Leonardian region. According to Fath (1920, 1921) the uplift is a result of the vertical movement on the pre-existing Precambrian zone of weakness. Ali Seyrafian (1978) recognizes a reverse fault along the Humboldt major fault. Davis ranch field is reported for reverse faulting by three different sources namely Smith Andres (1951),

In 1990, seismic surveying north of the Augusta Field, El Dorado South revealed a reverse fault as well. The distribution of the pre-Pennsylvanian rocks is dependent on the level of stratigraphic truncation (Evan, Personal Communication, 1999).

During Pennsylvanian time, it is believed (Miser, 1954) that many strike-slip movement occurred by the reverse faulting separation, while in the Permian era normal faulting occurred. In the Nemaha zone, the earliest identified movement along it was in the middle Ordovician time that indicated the increase in the thickness in the Garber graben which is compared to the up thrown flanks. It is recorded that the latest movement was in middle Permian time (Carlson, 1971).

The Oklahoma City uplift is another structural feature found within the Nemaha uplift zone. It has a shared history, geometry and position with the Garber and El Dorado. It is reported as an up thrown, popup feature and a reverse fault (Carlson, 1971). This is disputable because it is straight and thus either a normal or vertical fault.

The Nemaha uplift is a complex and composite feature because of the many different faults that culminate alongside its length making it a cohesive element in structure. (Jewett, 1951). The Humboldt fault zone bounds the uplift to the east (Fig.3) (Berendsen and Blair, 1986). There are collateral faults that impinge the Thurman-

Redfield zone to the north in the mid-continent rift. To the south, there is Paul's Valley and the Arbuckle zone that are described as high angle (Wells, 1971; Carlson, 1971). Reverse faults in some instances are also described (Gary, 1995). To the west, there is a major down thrust that is noted along Nemaha uplift along the margin which borders the central Oklahoma zone. (Jordan 1962).

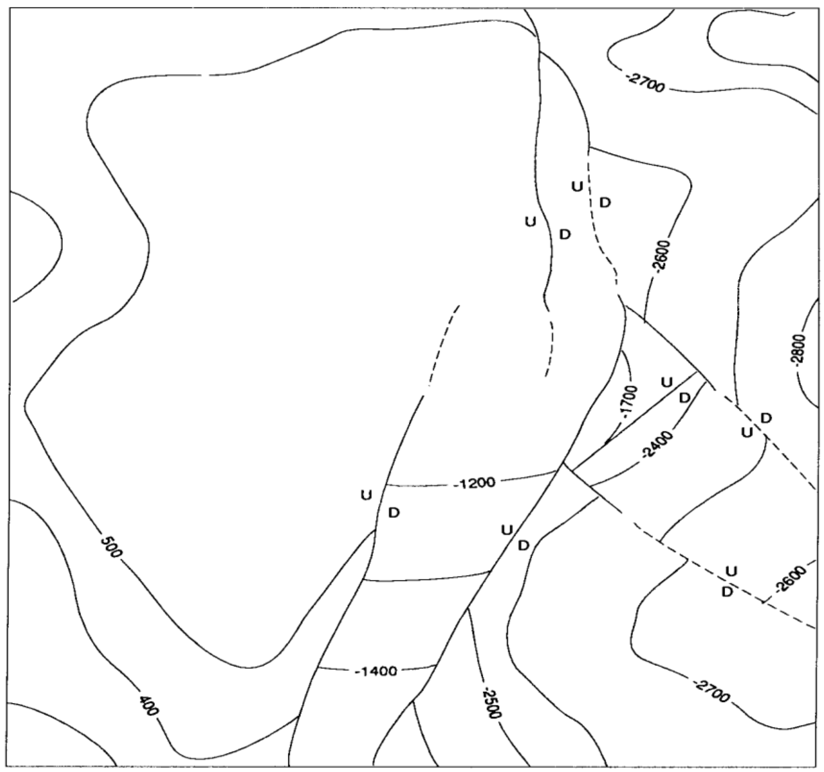



**Figure 3:Precambrian surface of Humboldt faults. Kansas Geological Survey Bulletin 226 (DuBois, 1978).**

According to Johnson et.al. (1994), there is a potential for seismicity that is rare on the continental plate interior based on the Phanerozoic history in the mid-continent system. The two major geological features, the tectonic zone of Nemaha and

Midcontinent rift system (Mooney et al., 2012), have been reported to cause most of seismic activities such as earthquakes in Kansas (Evan 1999).

During the formation of the midcontinent rift, significant tectonic activity was occurring which explains the tectonic and rifting processes that led to formation of faults, volcanoes and ridges which in this case failed and the MCR remains among the two discovered failed closed rifts, along with the East Africa Rift valley. The Nemaha ridge is a buried tectonic structure; this means that despite the tectonic movements that explicated both divergent and convergent forces, the uplift did not disappear with the forces and thus there was/is no division of continental plate by the oceanic plate. This is also seen in the MCR; despite the splitting of the continent core the rift failed and left rocks on the surface but buried some of the sedimentary formation. The rift formation resulted from the collisional forces of Grenville and its failure and closure is associated with Grenville compression in the later stage. The convergent forces experienced during this process enhance the formation of Nemaha ridge (Cole, 1969).

The steep dipping (fault) is the main boundary thrust that is mistaken for a normal fault. Reverse displacement that decreases in the intersection in wells decreases in dip as the basement depth increases forming a Listric thrust fault (**Fig.4**) (Dubois, 1978). Tectonic loading resulted in the crustal down warping of the front thrust. Normal faulting (relaxation) is a response to isotactic adjustment that followed the compressive phase in Permian time (Carlson, 1971).

In the present study area, use of 3D mapping in geological applications is somewhat common. For example, (Wilson, 2010), used 3D mapping in order to make connections with 3D seismic information for the construction of a 3D geological framework. In another example, (Keller et al., 2011; Mathers et al., 2011), used 3D mapping for sedimentary basin atlases depicting hand-drawn or machine-contoured structure contours, and (Kessler et al. 2009), used 3D mapping for the dynamic stereo capacity to recognisegeometric includes in the demonstrated bedrock surfaces.

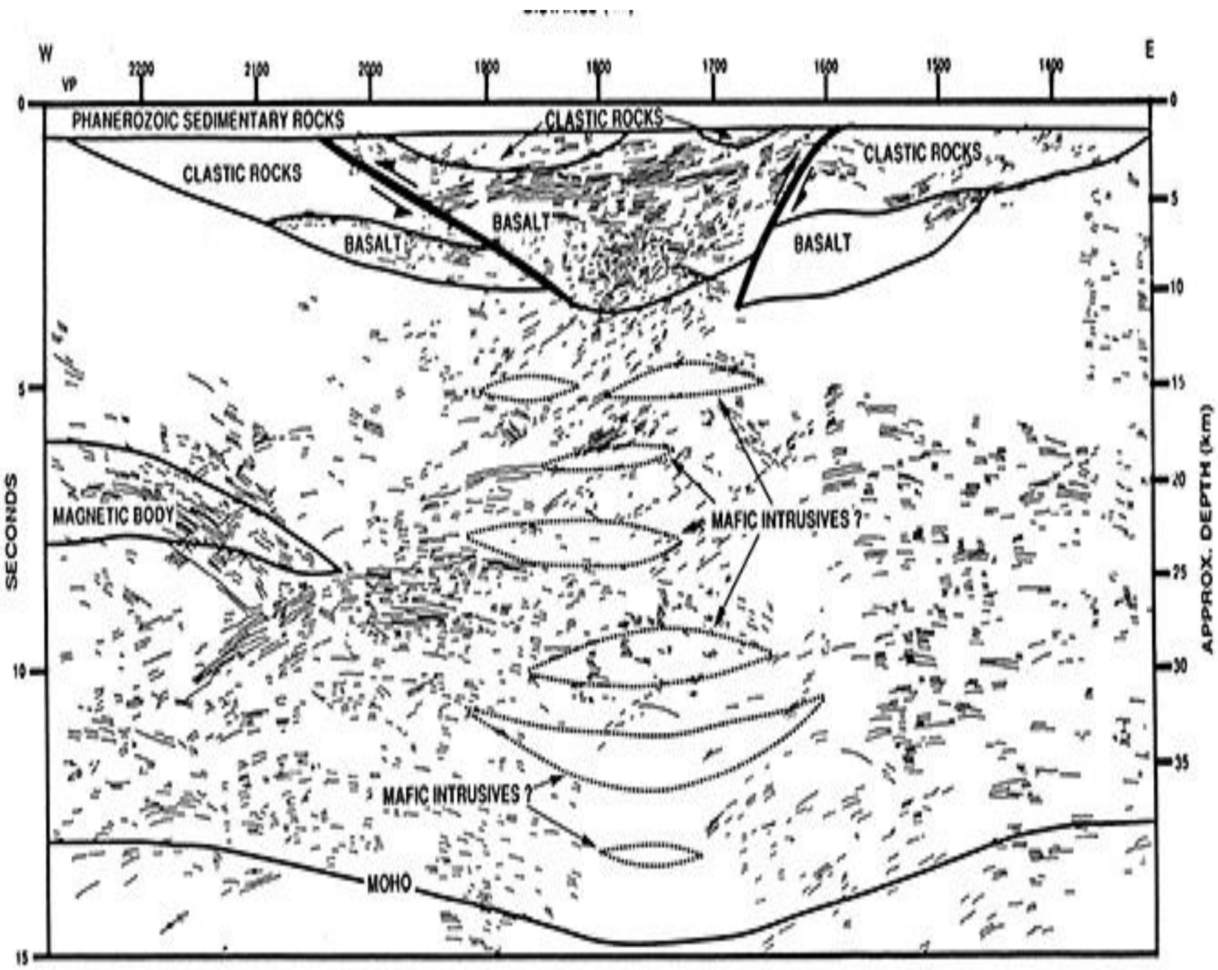



**Figure 4 : Graphic pass section across the Midcontinent Rift System that it display thrust faults along the west and west sides of the rift. From Woelk and Hinze (1995).**

# CHAPTER THREE

## 3. METHODOLOGY

The primary aim of the research was to establish if there exists any correlation between the Nemaha Uplift and the Midcontinent Rift using geostatistical methods; contour mapping and 3D analysis mapping.

### 3.1. CONTOURING AND 3D SURFACE MAPPING:

Contour maps are two dimensional representation of the relief of terrain using imaginary lines called contours, which connect points of measured or inferred equality derived from a sampled set of point data. The contour maps are created using three dimensional data from a grid file. The contours give the height above sea level of a surface as well as the gradient of a surface. In case of depressions such as wells, the contour lines are closed and the higher values located on the outside. Contour maps are useful for various purposes such as tracing the grade of certain routes and also locating physical features within a geographical region. Geosoft (Geosoft Inc., 2007) uses the minimum and maximum data values to determine the number of contours in a map. 3D surface mapping on the other hand shows three dimensional features with the height of the surface corresponding to the Z values. Colors can be used to obtain smooth gradation (Golden Software Inc, 2012)

## 3.2.METHODS USED:

In this research the main focus was contouring and 3D analyst mapping using the Surfer program and Geosoft (Geosoft Inc., 2007) software. Surfer software produced by the Golden Software Company, of Golden, Colorado is used for 3D mapping. Geosoft converts geographically referenced data into contour maps as well as that help engineers and scientists to display data in a more concise and accurate manner. Contour maps make it easy for scientists and engineers to visualize the useful parameters in a certain geographic region. The resulted contour maps and 3D plots that represent various parameters in a region. In the present study, the contour maps are used to establish the relationship between the Nemaha Uplift and the Midcontinent Rift.

## 3.3.Data analysis

To create the contour maps of our area of study, we first selected the region of study. The region selected was North East Kansas because it is the region where the Nemaha Uplift and Mid- Continent Rift are closest together. The research focused on Nemaha, Geary, Morris, North Lyon, Riley, Wabaunsee, Clay, Dickinson, Marshall, and Washington counties (**Fig.5**). Using the Kansas Geological Survey website, wells drilled into the Precambrian basement of Kansas in the selected counties were located. The Precambrian surface was utilized because it is the most easily accessible when wells are drilled in both the Nemaha and MCR. The Nemaha structure lies sub-parallel to the late Precambrian Midcontinent Rift system and in these surfaces, the nature of the faults that occur are available for analysis.. All the zip files were downloaded from the KGS website (http://www.kgs.ku.edu/Magellan/Precambrian/index.html ) and put in on file as well files. All the information about the wells in different counties was put in one txt file and the data transferred into an Excel file. The file was then opened to find the information about the wells and all columns were deleted except the columns containing the number of well, latitudes, longitudes, total depth, and evolution (**Fig.6**). The data was sorted by deleting any similar location wells. This was achieved using the filter command and then advanced command after which the file was saved.

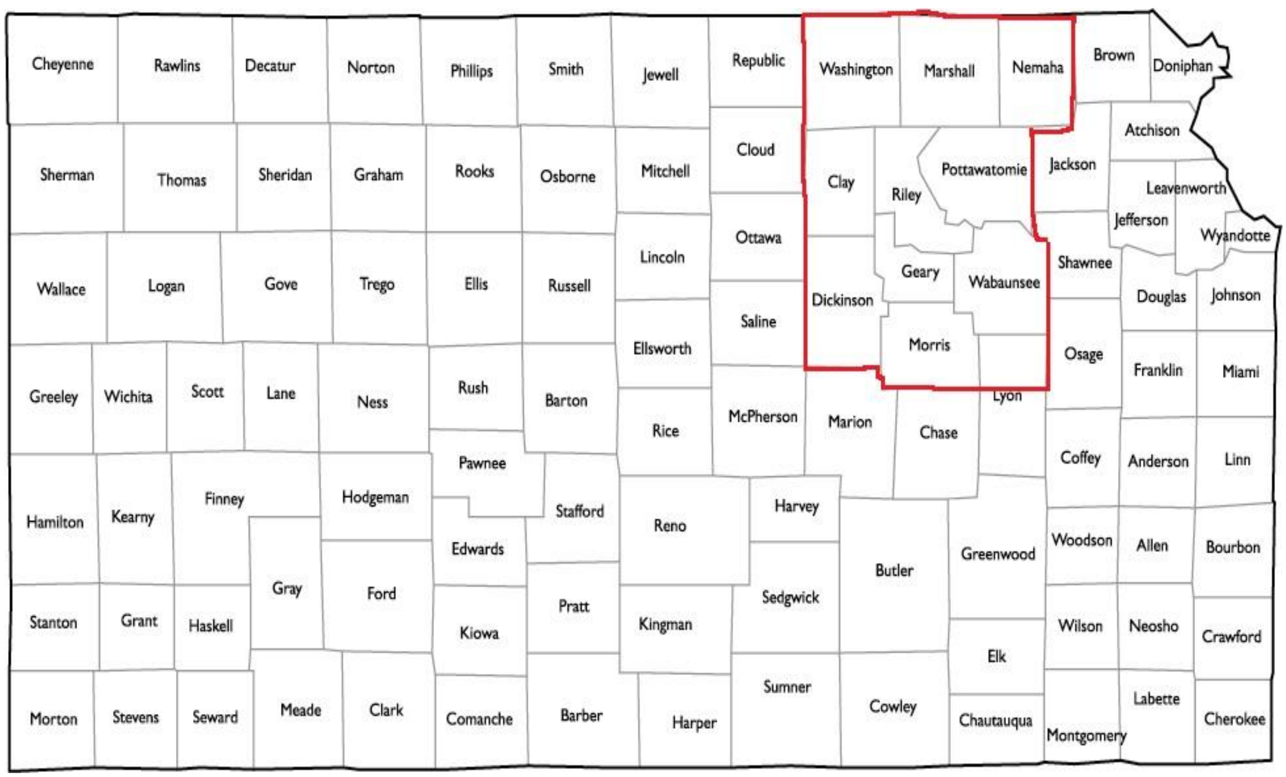
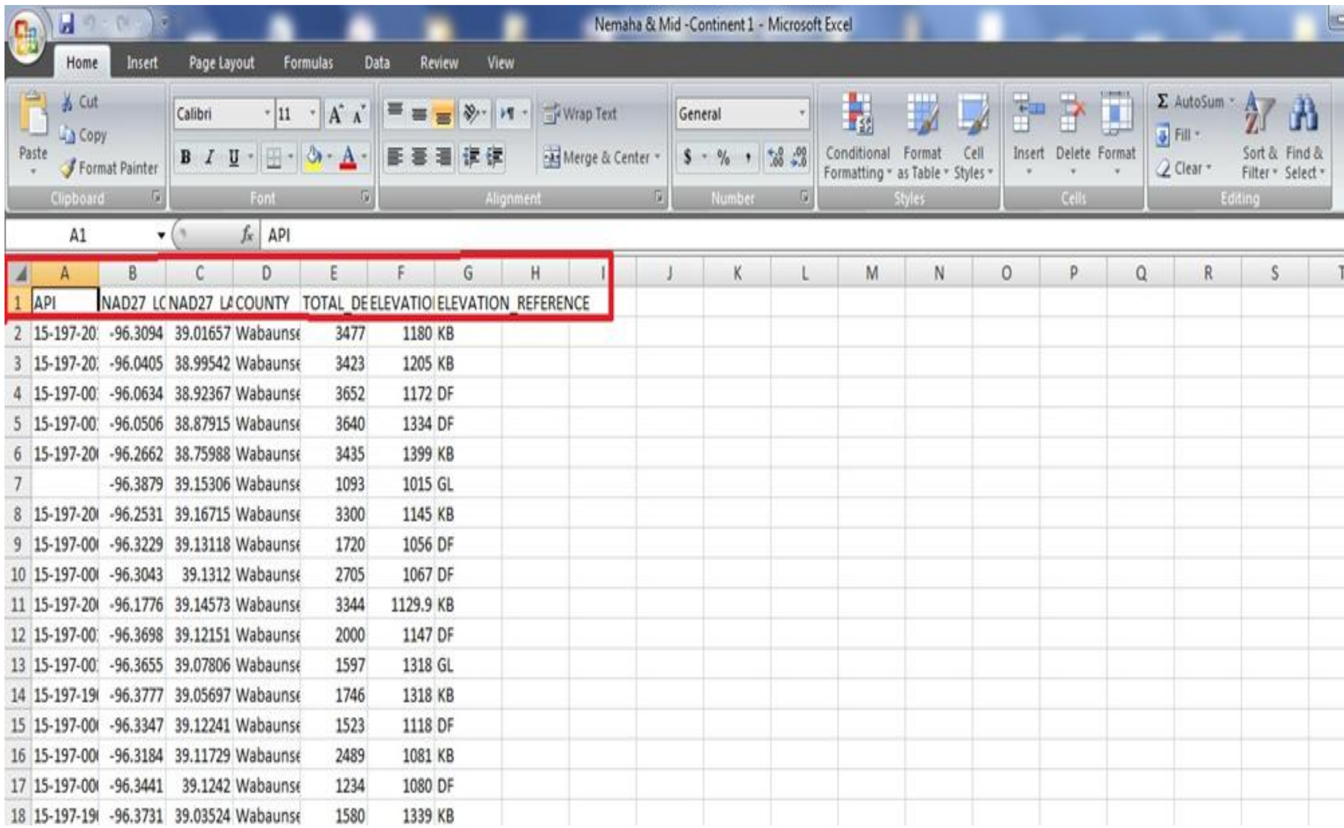



**Figure 5: Region of study.**




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | API | NAD27 LC | NAD27 LA | COUNTY | TOTAL_DE | ELEVATIO | ELEVATION_REFERENCE |
| 2 | 15-197-20 | -96.3094 | 39.01657 | Wabaunse | 3477 | 1180 | KB |
| 3 | 15-197-20 | -96.0405 | 38.99542 | Wabaunse | 3423 | 1205 | KB |
| 4 | 15-197-00 | -96.0634 | 38.92367 | Wabaunse | 3652 | 1172 | DF |
| 5 | 15-197-00 | -96.0506 | 38.87915 | Wabaunse | 3640 | 1334 | DF |
| 6 | 15-197-20 | -96.2662 | 38.75988 | Wabaunse | 3435 | 1399 | KB |
| 7 | | -96.3879 | 39.15306 | Wabaunse | 1093 | 1015 | GL |
| 8 | 15-197-20 | -96.2531 | 39.16715 | Wabaunse | 3300 | 1145 | KB |
| 9 | 15-197-00 | -96.3229 | 39.13118 | Wabaunse | 1720 | 1056 | DF |
| 10 | 15-197-00 | -96.3043 | 39.1312 | Wabaunse | 2705 | 1067 | DF |
| 11 | 15-197-20 | -96.1776 | 39.14573 | Wabaunse | 3344 | 1129.9 | KB |
| 12 | 15-197-00 | -96.3698 | 39.12151 | Wabaunse | 2000 | 1147 | DF |
| 13 | 15-197-00 | -96.3655 | 39.07806 | Wabaunse | 1597 | 1318 | GL |
| 14 | 15-197-19 | -96.3777 | 39.05697 | Wabaunse | 1746 | 1318 | KB |
| 15 | 15-197-00 | -96.3347 | 39.12241 | Wabaunse | 1523 | 1118 | DF |
| 16 | 15-197-00 | -96.3184 | 39.11729 | Wabaunse | 2489 | 1081 | KB |
| 17 | 15-197-00 | -96.3441 | 39.1242 | Wabaunse | 1234 | 1080 | DF |
| 18 | 15-197-19 | -96.3731 | 39.03524 | Wabaunse | 1580 | 1339 | KB |

**Figure 6:In Excel, the columns needed to be used are the number of the well, latitudes, longitudes, total depth, and evolution.**

The information in the Excel file included number of well, latitudes, longitudes, total depth, and evolution that was then sorted to fit the Surfer and Geosoft formats. The grid file was then created using the data from the excel file. Geosoft was opened then the grid data command button was clicked and the excel file of the wells was opened. Then the grid data was also opened, finding X,Y, Z and putting in “X” Longitude , “Y” latitude, and “Z” total depth (**Fig.7**). The gridding method was selected as Kriging and the gridding data was created (**Fig.7)** Kriging was chosen because of its ability to give unbiased linear predictions of the intermediate values. The gridding data was then used to create the contour map using the map command in the Geosoft program (Geosoft Inc., 2007).

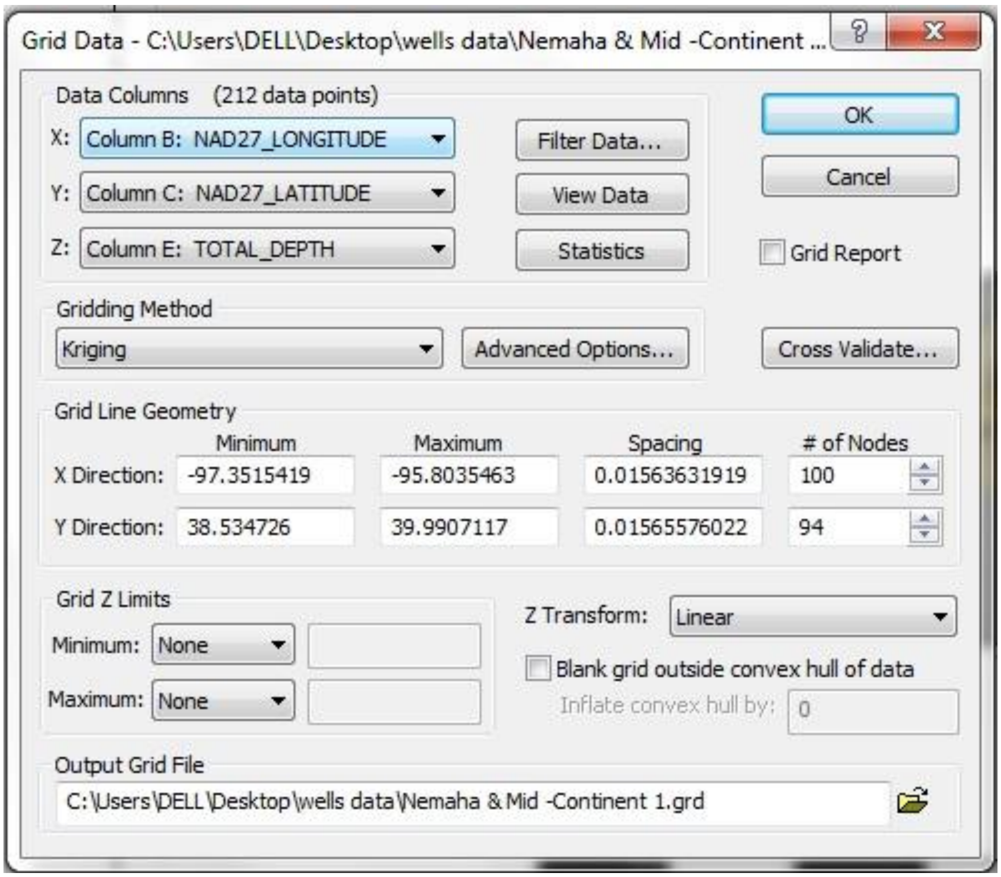



**Figure 7: Grid data X,Y, Z and Gridding Method.**

Creating the contour map was achieved through selecting the map button in the Surfer program, then “New” then “Contour map” (**Fig.8**). Followed by “Map” then “add” and “post layer”. The excel wells were then added and then opened using the “Open” command. In the object manager the “post layer” command was selected and then the property manager the “general” command followed by “worksheet columns” which contains the X and Y coordinates and putting in "X" Longitude and "Y" latitude . The contour map was then created to show the depth and the location of the various wells across the selected counties (**Fig.9**).

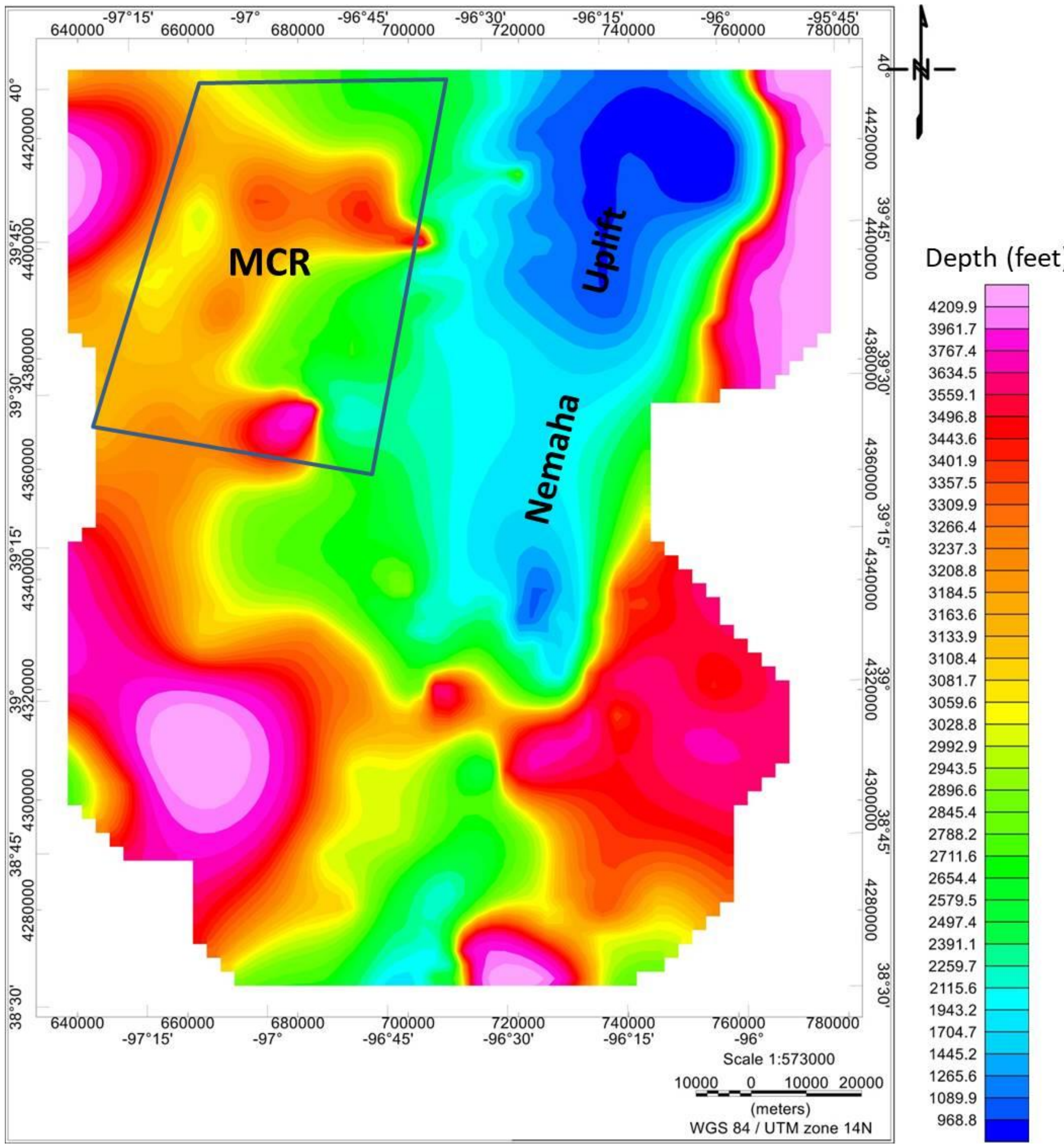



**Figure 8: The Contour Map of The Nemaha Uplift and Mid-Continent Rift.**

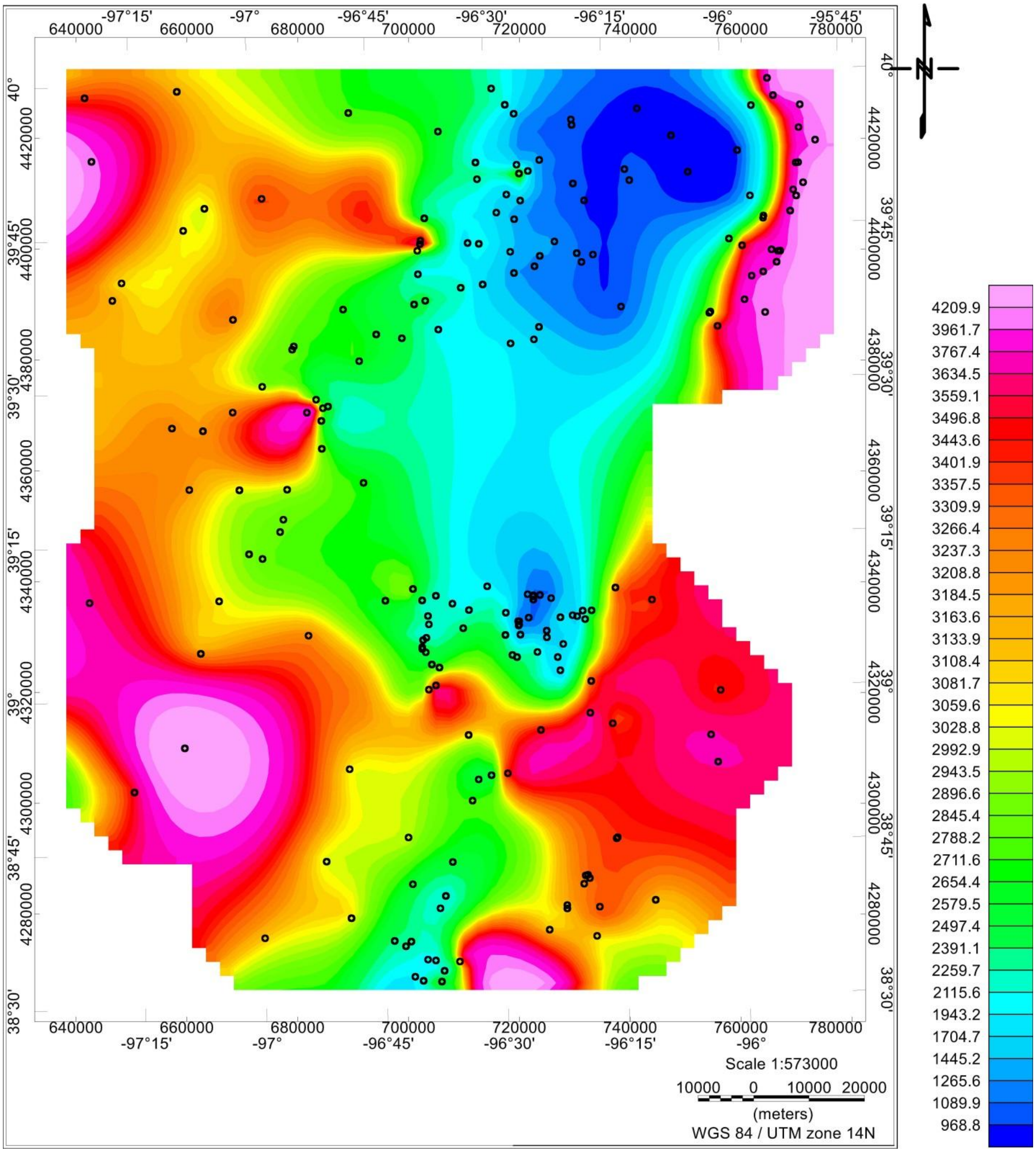



**Figure 9 : The Contour Map of Nemaha Uplift and Mid-Continent Rift and Location of wells.**

The 3D map was created by selecting the “Map” and “New” and finally the “3D Surface” command. The 3D surface map was created in order to show the Nemaha uplift and the Mid-continent relationship (**Fig.10**).

In the present study area, there was not an even distribution of the well data, therefore there is a possible limitation inherent in the 3D graphic model. The well points are concentrated in the Nemaha in contrast to the western side of the study area. This uneven distribution of the well data could be referred to the condensed well drilling programs in the Nemaha uplift area for oil exploration purposes.

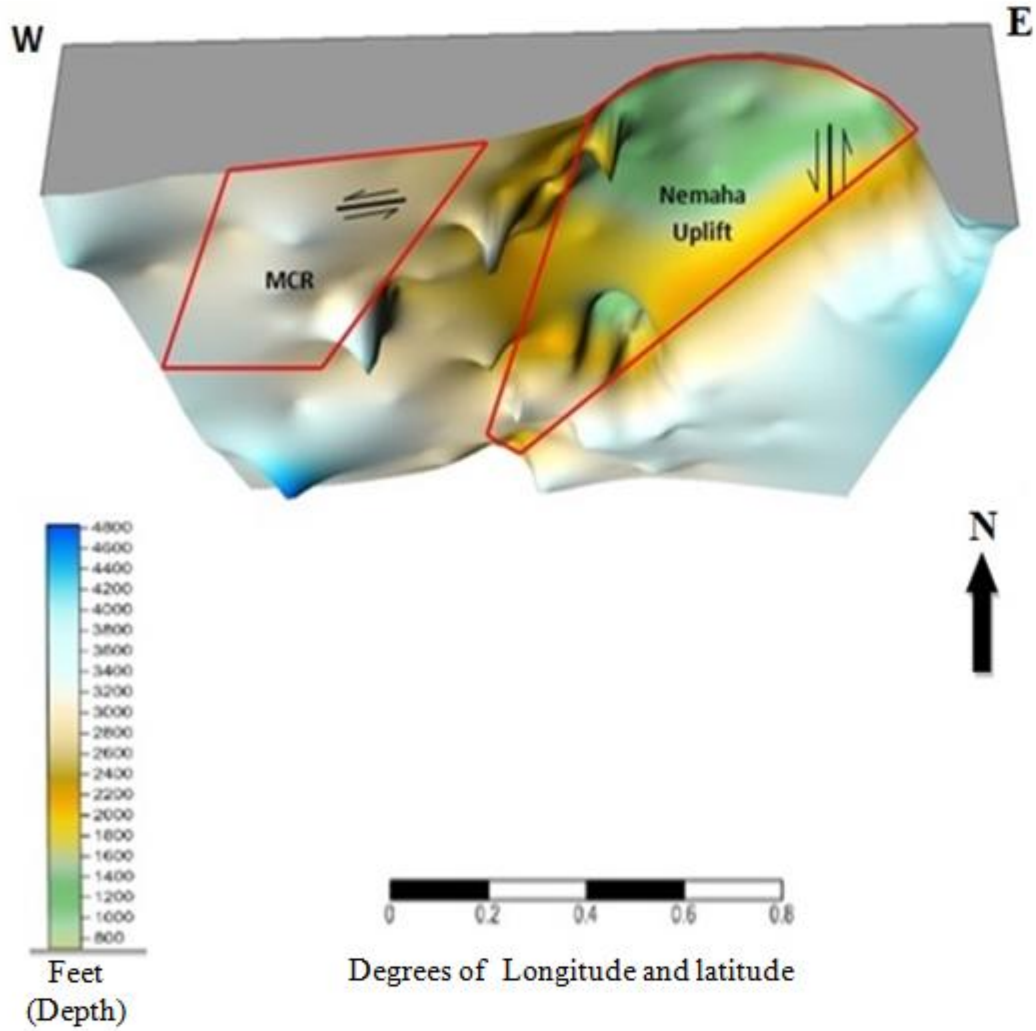



**Figure 10: Map shows the reverse faults of the Nemaha uplift and the Mid-Continent relationship.**

# CHAPTER FOUR

## 4.1. RESULTS AND DISCUSSION

### 4.1.1.THE CONTOUR MAP

The contour map is used to explain the depth of Precambrian surface for the Nemaha uplift and mid-continent **(Fig.11)**. In the study I used 213 Precambrian wells **(Fig.9)** The Nemaha Uplift in the north of study is wide roof which is more than in the south. On the map the location of Nemaha Uplift is on -96.5─ 95.94 Longitude and 39.9 Latitude. In the south it is a “tight roof” and is on location -96.8 ─ -96.64 Longitude and 38.6 latitude. The nearest depth to the ground level in Nemaha is approximately 600ft and the farthest depth is about 2200 ft.

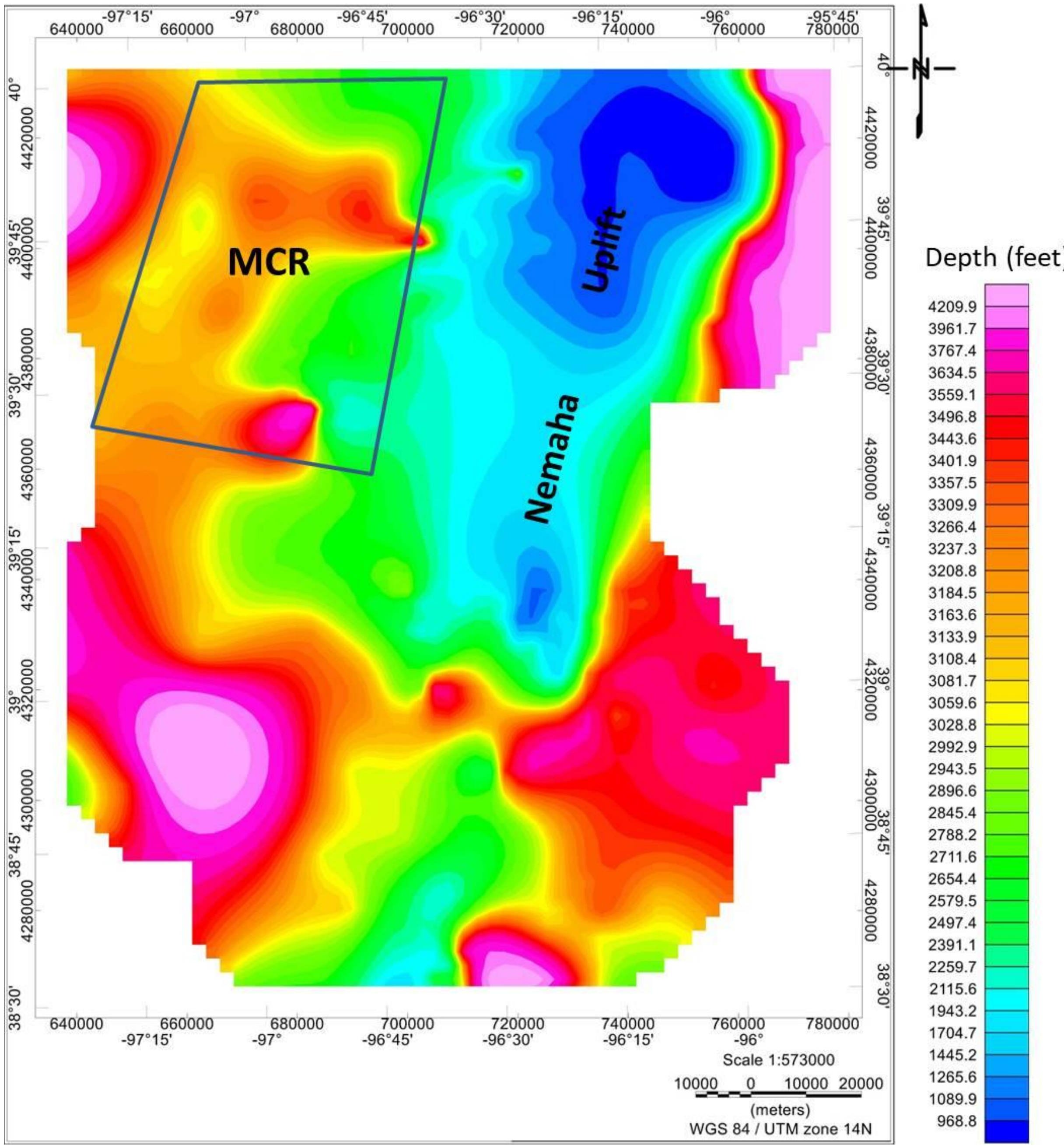



**Figure 11: The Contour Map of the Nemaha Uplift and Mid-Continent Rift.**

The Mid-continent Rift west of Nemaha is about 40 mi **(Fig. 11)**. The location of Mid-continent in the north of the study area is approximately on -96.8 – -96.16 Longitude and 39.9 latitude. In the south it is on -97 Longitude, 39.23 latitude and -97.34 , 39.43. The nearest depth to ground level in Mid-continent is about 2800ft while the farthest depth is around 3700ft.

### 4.1.2. 3D MAP

The 3D Map is used to explain the relationship between Nemaha Uplift and Mid-continent Rift (MCR) **(Fig. 12)**. The edge of Nemaha from the east is very sharp and in the west is gradual, as a platform. The Nemaha Uplift is a "wide roof" and the surface narrows as it turns south. In the east, it has a reverse fault and it is shown on the east side **(Fig.12)** located in Marshall County (Gay 1999). The reverse fault is a high angle around 90 degree (Merriam 1963) that has a hanging wall which moved up and the foot wall moved down.

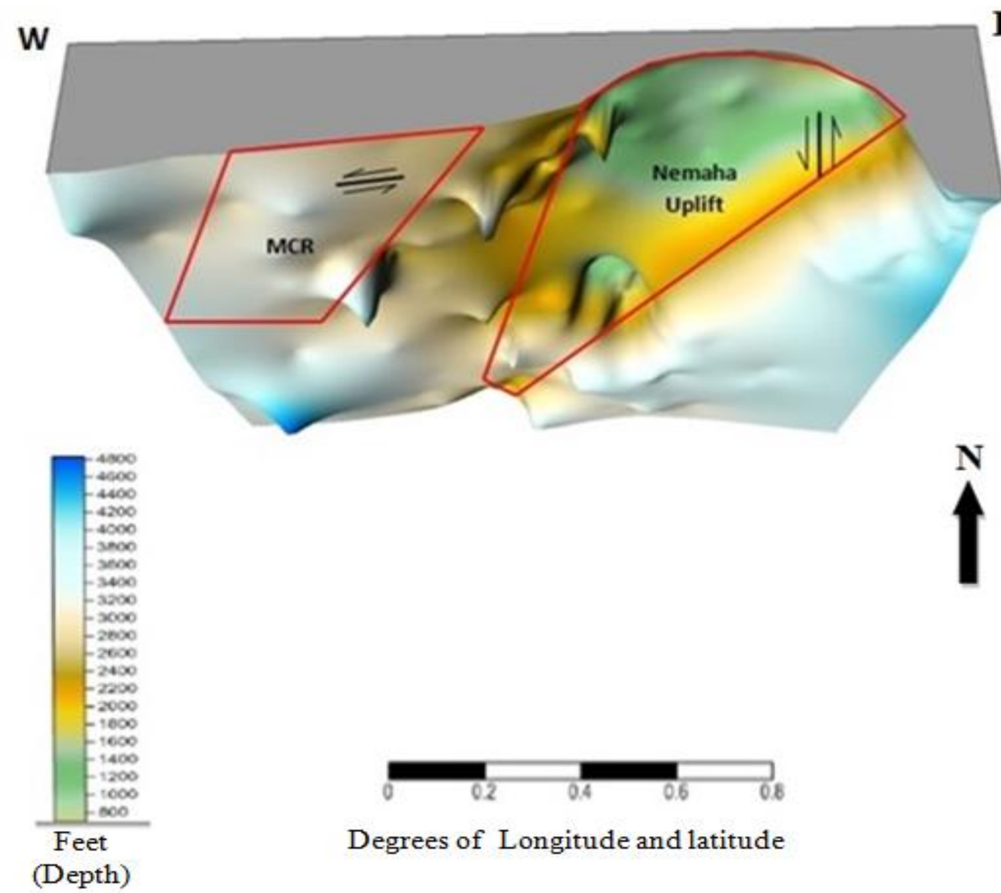



**Figure 12: 3D Map shows the reverse faults of the Nemaha Uplift and the Mid-Continent Rift relationship.**

The Mid-continent Rift (MCR) is on the west of Nemaha Uplift. The MCR has reverse (thrust) faults that are shown on the map Woelk and Hinze (1995) (Fig.9). It is located in Washington County (Berendsen et al., 1988). This has an approximately horizontal angle as is indicated by the placement on the map (Fig. 9). The hanging wall moved up going to north east and the foot wall moved down going dipping to west.

The Nemaha Uplift and Mid-Continent Rift show comparative development in the deformation processes of the Precambrian, the basement movements produced in the flat top uplifts that are bordered by verging outward constrained folds. These weak faults were reactivated by the compression forces of the Grenville Orogeny. On the Nemaha by pass faults in north east Kansas have a high angle ingredient (Merriam et al., 1958; Merriam, 1960; Merriam and Smith, 1961). There are similar faults in MCR but the difference between them is the angle. The angle of faulting in west of the MCR is very close to horizontal Woelk and Hinze (1995). The pressure processes resulting from the rifting affected some of the faults in Nemaha and turned them to reverse faults where they were normal faults. These faults are parallel to Precambrian structure in the Mid-continent. The relationship between Nemaha Uplift and Mid-Continent Rift as illustrated by the 3D map are parallel structures with the same shape as the reverse faults **(Fig.12).**

## 4.2.CONCLUSION

This research analyzed the relationship between the Nemaha Uplift and the Mid-continent Rift. This led to the establishment of the research hypothesis, that there is a structural relationship in the formation of Nemaha Uplift with relation to the Mid Continent Rift. This was to be tested by use of the 3D maps and the contour maps that were prepared using the surfer and Geosoft programs. These created maps played a key role in revealing the Precambrian surface that illustrates the tectonic movement.

The maps revealed the structural difference in the movement of the Nemaha uplift that is wide at the furthest end and narrows southwards where it ends as a platform. The study area was inclusive of the entire Nemaha region that runs from north Kansas. The

Northeast Kansas region was the preferred region for the analysis because that is where the location of Nemaha Uplift is closest to the Mid Continent Rift.

The location also was favorable because of the Precambrian surface that is accessible in both the major tectonic features and can be accessed through the geological wells drilled. The wells reveal the faulting systems in those regions. Having studied the maps created, the images reveal the presence of reverse faulting in both tectonic features. This is because of the thrusting movements that led to the uprising and platform features in the Nemaha region as well as the uprising of the mountains in the Mid-Continent rift.

As shown in the 3D map (**Fig. 13**), the Precambrian surface of Nemaha Uplift and Mid-Continent rift display the movement and the direction of the Nemaha uplift and Mid-Continent rift layers. The Nemaha layer runs upward where it formed a fault which is shown in the 3D map, where it is clearly visible in the east. The surface of Precambrian moved up characteristically where it created uplift and the movement resulted in the semi vertical angled reverse fault as that shown in the map (**Fig. 13**). The hanging wall of the reverse fault (surface of Precambrian in the 3D map) shifted up; that it made a sharp edge on the east margin (**Fig. 13**). The movement of the Mid-Continent layer differs from Nemaha in terms of movement; the movement is horizontal with regard to the direction of the Nemaha to the west. This motion created a reverse fault (thrust) as shown in (**Fig. 13**). In Fig.13 we see the Precambrian surface that represents a hanging wall towards the west at a semi-horizontal angle. This movement also had an impact on the cracks in the

Nemaha uplift; it produced compression on the faults of Nemaha. The 3D map also shows the structures of the Nemaha uplift and Mid-Continent rift and the effect of surface movement of Mid-Continent on the Nemaha. The map also displays the movement of reverse faults and their locations as well as the parallelism of the reverse faults along with the different angles of the faults (Fig. 13), which reveals the relationship between the Nemaha uplift and Mid-Continent rift. Through what has already been depicted in the 3D map, it can been seen that the relationship between the Nemaha uplift and the MCR is they have the same fault structure (reverse faulting) and there is a marked parallelism between them.

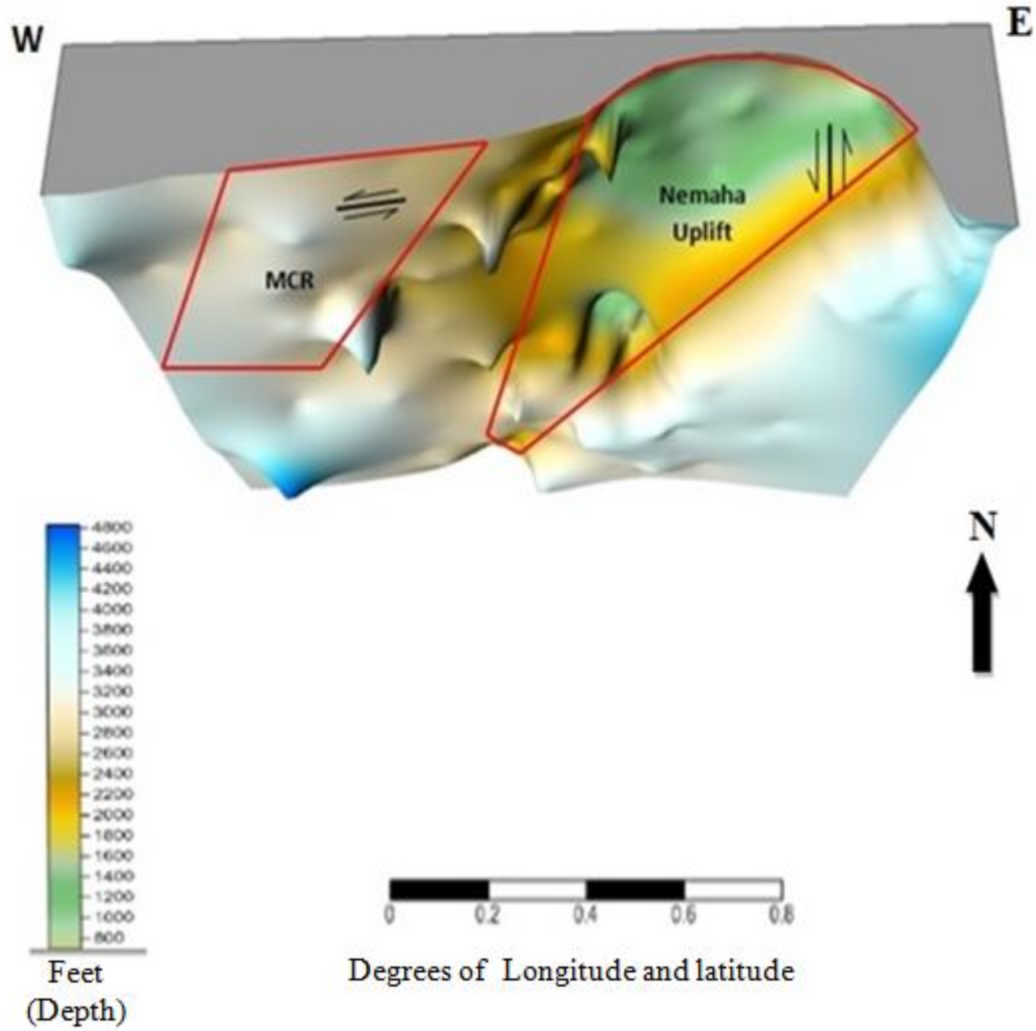



**Figure 13: 3D Map shows the reverse faults of the Nemaha Uplift and the Mid-Continent Rift relationship.**

In this study, we studied the relationship between Nemaha uplift and Mid-Continent rift using a 3D map which was created using the Surfer and Geosoft programs as illustrated in the methods section. The 3D map shows the movement of the Precambrian surface for the Nemaha and Mid-Continent, the structures of uplift and rift, and reverse faults. It also displays the location of faults where they were parallel. We created a contour map using oil and gas wells and it displays the depths of Nemaha and Mid-Continent structures. The contour map refers to the wells that were used in the study location.

The Midcontinent rift has a slight but significant influence on the formation of the Nemaha uplift because after the formation of the Midcontinent rift, there remained some weakness that the Paleozoic tectonic activities acted upon, enabling the emergence of the Nemaha Uplift. This was drawn from the observation of their location and the faults that are in the neighboring boundaries. The maps reveal the presence of parallelism with regard to faulting in both the structures. This is the identified relationship that indicates that the Mid-Continent Rift and the Nemaha Uplift are related with regard to the presence of reverse faults in their formation structures.

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