PRELIMINARY REPORT

GEOLOGY OF THE RICHFIELD ANTICLINE EASTERN NEBRASKA

By R. F. Svoboda 1962

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ABSTRACT

The Richfield anticline associated with the Nemaha range is located in western Sarpy, near the Platte River, about three miles southwest of the village of Gretna and about twenty miles southwest of the city of Omaha, Nebraska.

~~Position and structural form of~~ the Richfield anticline was ~~determined~~ by subsurface correlation of formations using cuttings and cores from well samples, drilling time logs, and electric logs. Surface exposures of bedrock along the lower Platte River valley are of Cretaceous and Pennsylvanian age, ranging from the lower Bronson group to Douglas group in the Pennsylvanian system and the unconformable Dakota group in the Cretaceous system. Pleistocene age loess and glacial drift mantles the older bedrock. Buried erosional valleys in the Dakota sandstone and Pennsylvanian limestones and shales are filled with Pleistocene glacial deposits. Pre-Pleistocene buried valleys are believed to extend in an west-east direction as a continuation of buried valleys mapped in detail by the Nebraska Geological Survey in central Nebraska.

Formations of Pleistocene, Cretaceous, Pennsylvanian, Devonian, Silurian, and Ordovician ages are represented in the sedimentary section of the Richfield anticline. Mississippian age formations are absent over the Richfield anticline but are present on the deep flank of the Nemaha range in eastern Sarpy County. Lower Ordovician sediments below the St. Peter sandstone are absent as are the Cambrian formations over the Richfield anticline but are present on the deep flank of the Nemaha range in eastern Sarpy County.

A structural map for the Hertha limestone, lower Bronson group, Pennsylvanian age indicates the general axial trend of the Nemaha range. The buried Nemaha range is a prominent subsurface feature of southeastern Nebraska that has been called an arch and ridge. The Nemaha range continues into eastern Kansas and central Oklahoma. Structural closure occurs within the Pennsylvanian age formations of about 100 feet in central Sarpy County and portions of Douglas County to the north and Cass County to the south. However the structural feature in the Pennsylvanian sediments is lost in western Sarpy County and appears only as westward dipping formations over the Richfield anticline. The Richfield anticline appears in Silurian, Ordovician and Precambrian surface strata and a structural map for the Galena (Stewartville-Prosser) dolomite formation presents the location of the anticline in western Sarpy County. Horizontal distance between the crest of the Richfield anticline and its Pennsylvanian equivalent in central Sarpy County is about twelve miles. The lateral change is accounted for by rapidly thinning Devonian age dolomites to the northwest accompanied by structural developments during Devonian time.

In the past, surface mapping of Pennsylvanian formations and shallow test drilling to key beds within the Pennsylvanian strata in eastern Nebraska and the Forest City Basin usually provided an reasonably accurate portrayal of the deeper sedimentary formations. Closure increased with depth. The Richfield anticline is a classic example of deep structures not revealed by surface or near surface formations.

Porosity and permeability of the St. Peter sandstone formation located just above the Precambrian surface on Richfield anticline is very good and displays the same lithologic features found throughout the midcontinent area. Devonian, Silurian, and Ordovician dolomites in the subsurface have good porosity and variable permeability. All of the subsurface formations contain fresh water with a dissolved mineral content of about 1,500 parts per million. Artesian flows of fresh water are common in Devonian and older porous formations with the water being used by several industrial companies in Omaha, Nebraska. Occasionally minor quantities of petroleum residue or a bituminous material is found in subsurface samples which indicates petroleum might have been in the area at one time but has been flushed by lateral movement of fresh water now found in the porous subsurface formations.

Impervious shales and shaly carbonates overlie Devonian dolomites, Galena dolomite formation and St. Peter sandstone formation which would be suitable as a caprock for natural gas storage with the St. Peter sandstone and its overlying caprock of Decorah-Platteville shale being the finest prospect.

Pennsylvanian age limestones are extensively quarried in the lower Platte Valley of Sarpy and Cass Counties for crushed rock in road construction, building and terrace stone, and for the manufacture of Portland cement. Pleistocene sand and gravels have large quantities of excellent water at a relatively shallow depth and are also used for road construction and as an element in concrete or cement products. Pleistocene loess forms the basis from which soils are developed in the upland areas.

INTRODUCTION

The Richfield anticline associated with the buried Nemaha range is located principally in Sarpy and Saunders Counties of eastern Nebraska. There is no geological surface expression of the Richfield anticline as the area is mantled with Pleistocene loess and river wash. Position and structural form of the Richfield anticline was determined by subsurface correlation of wells drilled in Sarpy, Saunders, Douglas, and Cass Counties. Outcrops of Pennsylvanian age formations along the lower Platte Valley in Sarpy and Cass Counties were used to prepare a structural map for the Pennsylvanian surface in addition to correlations of Pennsylvanian age formations from exploratory wells in the area.

The crest of the Richfield anticline is located about three miles southwest of the village of Gretna in Sarpy County and about twenty miles southwest of the city of Omaha, Nebraska. Principal surface drainage for the area is the Platte River which generally has an easterly course through central Nebraska but flows in almost a southerly direction between Sarpy and Saunders Counties and then proceeds east between Sarpy and Cass Counties. The Platte River has flood plain several miles in width but is restricted to about a mile or less in width between Cass and Sarpy Counties where its erosive processes have encountered more resistant Pennsylvanian shales and limestones. Average river gradient for the Platte River in the area is between four and five feet per mile, and would be considered in the mature or old age cycle of erosion. The Platte River enters the Missouri River just north of the city of Plattsmouth, Nebraska between Sarpy and Cass Counties.

Surface topography of the area is heavily influenced by Pleistocene glaciation. Topograhic maps were first prepared for the area in the latter part of the nineteenth century, and comparatively recent topographic maps published in 1956 by the United States Geological Survey on a scale of approximately two inches per mile are available for a large part of the area. Rolling hills of Pleistocene loess and till glacial deposits are characteristic of the upland area with elevations ranging from about 1,300 feet north of Gretna, Nebraska to about 950 feet at the mouth of the Platte River. Elevations along the Platte River and its flood plains are between 950 feet and 1,075 feet. Minor creeks and streams which flow into the Platte River or the Missouri River to the east are actively downcutting the Pleistocene loess and glacial drift deposits. Extensive soil conservation programs are in evidence in Sarpy, Douglas, and Cass Counties to prevent the erosion of Pleistocene loess and till from which the soils are principally derived.

Small grain agriculture and cattle feeding is the principal type of agriculture on the farm land. Along the lower Platte River valley extensive quarrying of limestone has been an important industry for the production of crushed rock, terrace stone, and some building stone. The Ash Grove Cement Company, located in Louisville, Nebraska, utilizes the Wyandotte limestone of Pennsylvanian age for the production of Portland cement. Gravel and sand quarries are numerous in the lower Platte River valley from Pleistocene deposits and river wash. In some places the lower part of the Dakota group sandstone was quarried for the gravel it contained that was loosely endurated. The area is served by several railroads and the recently completed Interstate Highway #80 between Omaha and Lincoln, Nebraska cuts across the eastern end of the buried Richfield anticline south of Gretna, Nebraska.

PREVIOUS WORK

The Richfield anticline is named for the small village of Richfield in central Sarpy County, although the village of Gretna is nearest to the crest of the Richfield anticline. The name of Richfield is applied because literature and geological work by members of the Nebraska Geological Survey during the first two decades of 20th century located an anticline by surface mapping of Pennsylvanian age formations along the lower Platte River valley south of the village of Richfield. A continuation of the Richfield anticline in Cass and Otoe Counties is called the Nehawka anticline. The term Nehawka is used on a map published by the United States Geological Survey, OM 198, "Map of Nebraska Showing Areal Distribution of Pre-Pennsylvanian Rocks, Anticlines, and Basins, Oil and Gas Fields, Pipelines, and Unsuccessful Test Wells" by E. C. Reed, R. F. Svoboda, G. E. Prichard, and Jeannette Fox, 1958. Oral communication with E. C. Reed, Nebraska State Geologist, states a preference for the use of Richfield anticline. The local term Richfield will therefore be used to describe the subsurface anticline in western Sarpy County and the surface and near surface expression of the anticline in central Sarpy County. Both anticlines are associated with the extensive uplift known as the Nemaha range.

The Nemaha range which has also been called the "Nemaha uplift", "Nemaha arch", and Nemaha mountains" is a buried geologic feature composed of granite and a complex of metasediments which extends from central Oklahoma through east central Kansas and southeastern Nebraska generally terminating west and southwest of Omaha, Nebraska in Douglas and Sarpy Counties. Geological studies and literature of the Nebraska, Kansas, Oklahoma, and United States Geological Surveys have identified the location and trend of the Nemaha range. Locally, along the trend of the Nemaha range the surficial expression within Pennsylvanian and Permian strata has been given several names in the three states.

In southeastern Nebraska, the Nemaha range is called the Table Rock Arch and Precambrian rocks are found at little more than 500 feet below the sedimentary section where the Nemaha range reaches its highest position with respect to sea level. East of the Table Rock arch is the Humbolt Fault which forms the east face of the buried Nemaha range in southeastern Nebraska and northeastern Kansas. The Humbolt fault trends in a north-northeast and south-southwest direction in Richardson County of Nebraska and in northeastern Kansas. Geologic surface mapping of Pennsylvanian and Permian sections by the Nebraska Geological Survey has located the trend of the Humbolt fault in southeastern Nebraska.

Displacement of the basement complex of Precambrian formations along the Humbolt fault has an interval reaching a maximum of about 1,000 feet. In a paper published by E. C. Reed, "The Possibility of a Land Bridge Across Nebraska in Mississippian Time" The Journal of Geology, Volume 56, Number 4, July 1948 a thrust fault is shown by a cross section in Richardson County and a normal fault in Nemaha County north of Richardson County, Nebraska. Faulting is believed to continue along the east face of the Nemaha range in southeastern Nebraska north into southern Otoe County where the east face of the Nemaha range is expressed in steep dip on the eastern flank. To date, there has been insufficient deep well drilling of record along the Humbolt fault to describe the fault complex and its lateral expression in the subsurface. A map published by the Nebraska Geological Survey "Contour Map of Precambrian Surface in Nebraska" by E. C. Reed and R. F. Svoboda, 1957, and revised by M. P. Carlson in 1961 indicates the Precambrian structural surface along the Nemaha range in eastern

Nebraska. Bulletin #14A of the Nebraska Geological Survey by G. E. Condra and E. C. Reed describes the Nemaha range of Nebraska and the regional terms applied along the axial trend. A series of isopach maps of the Forest City Basin published by the United States Geological Survey entitled " Structural Development of the Forest City Basin", OM 48, 1946, by Wallace Lee, etal, provides information about the sedimentary section of the Forest City basin and the Nemaha range that forms the divide between the Forest City basin and the Salina basin of central Kansas and central Nebraska. In Nebraska the Salina basin is termed the central Nebraska basin.

The development of the Nemaha range and its present structural position is the most significant subsurface in the geologic history of eastern Nebraska. Geological literature regarding the Nemaha range is cited in the bibliography. In general, the Nemaha range terminates in western Sarpy County with respect to prominence of relief on the Precambrian surface and in the sedimentary section from Devonian through Ordovician strata. Some indication that the Nemaha range continues north-northeast from Sarpy County through central Douglas County west of Omaha, Nebraska is shown by Pennsylvanian age rocks.

In southern Cass County and northern Otoe County of eastern Nebraska the Nemaha range is intersected by a structural feature now called the Union Flexure and is described in a paper by E. C. Reed published by the Nebraska Geological Survey, "The Redfield Anticline of Nebraska and Iowa", Paper Number 12, December 1938. The Redfield anticline is named for surface exposures of the Des Moines series, Pennsylvanian system near Redfield in central Iowa. The Union flexure has been mapped in the vicinity of Union, Nebraska and trends northeastward across the Missouri River through central Iowa. The structural dip on the south flank is pronounced and some authors have described the dip as a fault, in Iowa called the Thurman-Wilson fault, with the north flank of the Union flexure having a low dip.

A paper by G. E. Condra and O. J. Sherer entitled "Upper Carboniferous Formations in the lower Platte Valley" Nebraska Geological Survey Paper 16, September 1939 describes the Pennsylvanian section in the lower Platte River valley and corrects some of the errors made in Pennsylvanian correlation previously made. The paper also describes a fault in the Pennsylvanian section known as the La Platte fault which is located about three miles west of the village of La Platte in Sarpy County. A displacement of about 50 feet is mapped in a short horizontal distance which could be also explained by steep dip. The Nebraska Geological Survey has a geological areal map of southern Sarpy and Cass Counties as yet not formally published which was very useful in study and orientation of Pennsylvanian formations in the lower Platte River valley.

EXPLORATORY DRILLING

The anticlinal development of sedimentary formations associated with the Nemaha range in eastern Nebraska as determined by outcrops of Pennsylvanian and Permian age formations has been a focal point for exploratory drilling in an attempt to locate petroleum. Anticlines associated with the Nemaha range in Kansas and Oklahoma have produced prolific oil production in many areas and it was natural for petroleum operators to exploit anticlinal development along the Nemaha range in Nebraska. A well drilled by Amerada Petroleum Corporation in 1924 located in section 26, township 11 north, range 12 east of Cass County, Nebraska was particularly significant since the entire sedimentary section and about 260 feet of Precambrian section ~~was~~ were cored with almost complete recovery. The core was analyzed in detail and the Nebraska Geological Survey published a correlation of the well entitled "Correlation of the Amerada Petroleum Company, Drilled Near Nehawka, Nebraska" by G. E. Condra, Paper Number 14, February, 1939. A record of nearly every well drilled along the crest or flank of the Nemaha range in Cass, Sarpy, Douglas, and Saunders Counties is on file with the Nebraska Geological Survey in Lincoln, Nebraska and the records were examined by the author and the samples run on the important wells. Most of the wells drilled prior to 1950 were drilled with cable tools and since that time most of the wells have been drilled with rotary tools.

Northern Natural Gas Company of Omaha, Nebraska began an exploratory drilling program in southern Cass County during 1952 in an attempt to find a suitable anticlinal structure for the storage of natural gas. The exploration was conducted under the supervision of A. R. Erickson, Chief Geologist, and the author was project geologist for the exploration program when he joined the staff of Northern Natural Gas Company. A series of 11 test wells were drilled in southern Cass County during 1952 and later in the year of 1952 and of 1953 a drilling program consisting of 25 wells was drilled in Sarpy, Cass, Saunders, and Douglas Counties. M. E. Kirby, drilling contractor and geologist, provided the rotary tools and members of his company performed geologic surface studies in southern Cass County.

Surface mapping and shallow test drilling into Pennsylvanian strata in southern Cass County indicated a low lying Pennsylvanian structure west of the principal axis of the Nemaha range and generally astride the extension of the Union flexure or Redfield anticline west of the apex of the Nemaha range. A deep test well by Northern Natural Gas Company to the Precambrian surface indicated that the Devonian and Ordovician formations were structurally much lower than similar formations on the crest of the Nemaha range to the east. The St. Peter sandstone formation and the overlying Decorah-Platteville shales of Ordovician age were found to be suitable as a reservoir and caprock for potential natural gas storage. Because of unsuitable structural implications, the area was abandoned as a potential site for natural gas storage.

E. C. Reed, Nebraska State Geologist, was consulted concerning other areas along the axis of the Nemaha range that might develop structural closure and would provide a suitable reservoir and caprock by the author. Southeastern Nebraska was not considered since the faulting along the east flank of the Nemaha range might include the Decorah-Platteville formation and therefore provide an escape for high pressure natural gas. The St. Peter sandstone formation was considered to have excellent qualities of porosity and permeability since several deep wells in the Omaha, Nebraska area utilize the fresh water from the St. Peter sandstone as a source of water supply for a number of industrial companies. Some of the wells originally had artesian flows in excess of 250 gallons per minute, the water originating not only from the St. Peter sandstone but from porous dolomites in the Ordovician, Silurian, and Devonian sections. The water has a dissolved mineral content of about 1,500 parts per million with sodium chloride extremely low. Dissolved sulfates make up the bulk of dissolved solids in the deep wells and dissolved carbonates are relatively low. The temperature of the water is about 70 degrees fahrenheit.

After studies of well records, sample analysis, and geological surface data together with a recommendation from E. C. Reed the central area of Sarpy near Springfield, Nebraska was deemed worthy of an exploratory drilling program. The first well was located in section 23, township 13 north, range 11 east, about two miles southwest of Springfield. The well was drilled with rotary tools to a total depth of 1,218 feet drilling a few feet into the Precambrian surface which was a granitic type of rock. St. Peter sandstone was cored with about 85 per cent recovery and a portion of the overlying Decorah-Platteville was cored. The top of the St. Peter sandstone was at a depth of 1,167 feet and the base was at 1,215 feet for a total thickness of 48 feet. A standard type electric log and microlog was run in the well which confirmed the excellent permeabilities noted in the sandstone. A plug type core analysis was made on the sandstone which showed that the St. Peter sandstone had porosities as high as 31.9 per cent and vertical permeabilities as high as 2,410 millidarcies. The unrecovered core in the St. Peter sandstone probably had extremely high porosity and permeability as the sandstone is very loosely cemented for a large part of the interval. Average porosity for the 48 feet of St. Peter sandstone would be between 20 and 25 per cent and permeabilities averaging several hundred millidarcies. Fluid content of the St. Peter sandstone was fresh water. A detailed lithologic description of the St. Peter sandstone is provided in the section on stratigraphy. Overlying caprock of the St. Peter sandstone consisted of dense, impermeable green shales, with three zones of dense shaly limestones. Total thickness of the Decorah-Platteville shales and limestone which overly the St. Peter sandstone was 115 feet in the first test well by Northern Natural Gas Company of which about 85 feet was nearly pure shale and the balance in three zones shaly limestone totaled about 30 feet. Studies of the cores taken from the Decorah-Platteville section, sample analysis, and microlog proved a section of about 115 would be classed as impermeable to vertical migration of natural gas or fluids. A detailed description of the Decorah-Platteville formations is provided in the section on stratigraphy and the columnar section chart graphically portrays the St. Peter sandstone and overlying Decorah-Platteville caprock. In summary the reservoir conditions and caprock in the first test well and in succeeding test wells ~~was~~ were excellent with no important change either in thickness or in lithology.

Structurally the first test well by Northern Natural Gas Company was higher than the other wells in the area which had penetrated the entire sedimentary section and drilled into Precambrian rock. A cable tool wildcat oil test on the Seibold farm in section 3, township 12 north, range 11 east, in 1942 by independent operators, and about three miles south and west of the Northern well was about 20 feet lower at the top of the St. Peter sandstone and about 43 feet lower at the base of the Hertha limestone, Pennsylvanian age. The #1 Urhammer wildcat oil test drilled in 1929 with cable tools located about six miles due east of the Northern well was 125 feet lower structurally on the top of the St. Peter sandstone and is located in section 23, township 13 north, range 12 east. A wildcat oil test drilled on the Rahn farm, section 23, township 14 north, range 12 east about 9 miles northeast of the Northern well was about 375 feet structurally lower on top of the St. Peter sandstone. With the satisfactory structural information, reservoir, and caprock a shallow drilling program that penetrated the entire Pennsylvanian section and a portion of the Devonian dolomite proceeded around the first Northern well. Surface geological information indicated the Pennsylvanian beds dipped to the west, and believing that a test well program using the Hertha limestone and Devonian dolomite top as datum mapping points would confirm in detail the location of a geological structure, a program of nine additional wells were drilled. Structural closure was developed on the Hertha limestone but the Devonian dolomite top was not conclusive. Test well #11 by Northern Natural Gas Company was located about 2 miles northwest of the first well and was drilled to the Precambrian surface. The well was located in section 20, township 13 north, range 11 east. Structurally at the top of the Pennsylvanian formations and base of the Hertha limestone, the #11 well was 52 feet lower than the #1 well but 42 feet higher on the top of the Maquoketa shale, Ordovician age, and about 34 feet higher on the top of the St. Peter sandstone. In other words the #11 well was lower on the shallow Pennsylvanian beds and higher on the Ordovician formations. The idea that the Pennsylvanian beds reflected the older formations in regard to structure was completely overruled in the #11 well. Fourteen successive wells were drilled by Northern Natural Gas Company in western Sarpy County and eastern Saunders County which finally produced the Richfield anticline as shown on the structural map contained in this report for the Galena (Stewartville-Prosser) dolomite. Two of the fourteen wells were drilled to the St. Peter sandstone to confirm that the structure as shown on the Galena dolomite map would be substantially the same for the top of the Decorah-Platteville, top of the St. Peter, and top of the Precambrian surface. Because the Richfield anticline adopted an arcuate or curved axial shape a number of wells was needed to precisely locate the feature. Structural closure was established of about 50 feet within an area of about 8 square miles with the total amount of closure on the order of 300 feet extending over a wide area in western Sarpy County, Saunders County, and Cass County. The #16 well located in section 15, township 13 north, range 10 east of Sarpy County was the highest well structurally on the top of the Silurian, top of the Maquoketa and top of the Galena dolomite. Since the #16 well was high it was the intention of Northern to take the well down to the Precambrian surface; however, the rotary tools were stuck in the hole and efforts to removed the tools by the drilling contractor failed. The drill pipe was shot off above the drill collars and an electric log was made on the well to confirm sample analysis.

Electric logs were run on all the Northern wells using a truck mounted single point resistivity electrode and self potential electrode which aided in correlation of samples taken at five foot intervals and a one foot drilling time log. The Precambrian wells drilled by Northern were logged with a Schlumberger electric and microlog. Cores of the St. Peter sandstone and the overlying caprock were taken from the #11, #13, and #21 wells which confirm the presence of the St. Peter sandstone, the lithologic similarity to the #1 well as to potential reservoir and caprock, and the overall structure as presented on the structural map for the Galena dolomite. Elevations at the well sites were made by spirit leveling from bench marks by the engineering department of the Northern Natural Gas Company. Three drill stem tests were run on test well #11 in the St. Peter sandstone and Galena dolomite. In the St. Peter sandstone 845 feet of fresh water was recovered with a recorded bottom hole hydrostatic pressure of 380 pounds per square inch. The tool became plugged during the test and it is apparent the total amount of water would have been about 1,100 feet and a higher bottom hole pressure. Cable tool wells drilled in the area usually filled with water when drilling into the St. Peter formation. The lower Galena drill stem test from 794 feet to 1,045 feet recovered 595 feet of fresh water with a bottom hole recorded pressure of 280 pounds per square inch. A test on the upper Galena dolomite from 723 feet to 797 feet recovered 550 feet of fresh water with a bottom hole recorded hydrostatic pressure of 250 pounds per square inch. The tool was not left open sufficiently long in the last two Galena formation tests for the static water level to reach its maximum level.

The Northern Natural Gas Company exploratory program was completed in 1953 with a total of 25 exploratory wells. No other wells have been drilled on on the crest of the Richfield anticline since 1953. A few wells drilled by petroleum operators in central Saunders County and a water well on the Offutt Field Air Force Base in eastern Sarpy County have substantially confirmed the presence of the Richfield anticline as developed by the Northern wells. The Richfield anticline is the apex or structural high for the entire area.

STRATIGRAPHY

The stratigraphy of the Richfield anticline and its association with the Nemaha range is presented in detail with a correlation of formations to other areas such as Forest City Basin, Salina Basin, and general correlation to the Redfield Natural Gas Storage anticline in central Iowa plus the type section found in the upper Mississippi Valley of Iowa. The oldest Pennsylvanian age outcrops of the lower Bronson group are found in the lower Platte River valley.

RECENT

The geologic period of time included within the Recent classification is the interval of time since the close of the Pleistocene period. The end of the Pleistocene period is marked by the last advance and retreat of a continental glacier which covered north central United States. Only a few thousand years of time are involved in the Recent time period. Morphology and genesis of present day soils, topographic conditions, plant and animal ecology, and climate are the principal factors involved in the geological environment of the last few thousand years. When considered in geologic time which deals with hundreds of thousands or millions of years primarily, the Recent period could not be expected to change much either in flora and fauna or in physiographic appearance. The principal changes in the area deal with soil erosion and changes in stream channels by natural geologic forces. One example of a geologic force which produces continuing changes is seen in the erosion of the Missouri River which was the original political boundary established between Iowa and Nebraska during the middle of the 19th century and within the 100 year period has changed its course to put Nebraska territory on the Iowa side and Iowa territory on the Nebraska side.

Soils in the Richfield anticlinal area have been studied and mapped by the United States Department of Agriculture in cooperation with the Nebraska State Soil Survey and bulletins by county have been published.

Several types of soils are present in the area which are related in their genesis to present topographic conditions. Upland or high terrace soils are derived principally from Peorian age loess which blanketed the area during the last Pleistocene stage. Peorian loess is a light yellow or brown material consisting of silt, clay, and very fine sand deposited by wind. Marshall type silty clay loam soil with its smooth phase and slope phase covers over fifty per cent of the area. Marshall soil contains an abundance of decayed organic material and is granular in texture. The soil is normally from 8 to 16 inches thick depending on the degree of slope and is dark grayish-brown color when dry to almost black when wet. The subsoil is also a dark grayish-brown in the upper portion where stained by organic solutions from the surface soil. Marshall subsoil grades into the Peorian loess within a maximum of 7 feet in depth. Neither the surface soil or the subsoil contains sufficient lime to effervesce with dilute hydrochloric acid but is not considered deficient in lime for agricultural purposes. The smooth phase of Marshall soil is that area which contains less than 4 degrees of slope. The slope phase of Marshall soil is the area in which a slope from 7 to 15 degrees is present and the balance with a slope between 4 and 7 degrees is simply classified as Marshall silty clay loam. On slopes the soil cover can be easily removed by water erosion and the underlying Peorian loess is exposed when improperly cultivated. Marshall soils have an excellent capacity for growth of small grains, legumes, other plants, and trees.

Knox silty clay loam soils are also derived from Peorian loess and are similar to the Marshall soils but do not exceed 6 inches in thickness. Knox soils account for about 15 per cent of the total of all soil types. They occupy the steep hilly slopes near the bluffs along the Platte River and the Missouri River with slopes in excess of 15 degrees. The soil is satisfactory for agricultural purposes but strict attention must be paid to soil conservation techniques or water erosion develops deep gullies. Much of the natural wooded areas is included with Knox soils on the steep ravines.

The bottom land of most creeks and the flat land nearest the bluff of the Platte River and Missouri River contain Wabash silty clay loam and fine sandy loam. Wabash soils are rich in the abundance of organic material and is nearly black in color. Thickness of the surface soil ranges from 8 to 15 inches and the subsoil is usually dark in color to several feet in depth. The soil, although nearly flat, is well drained. Dilute hydrochloric acid tests with Wabash soil are negative, but the soil is not deficient in lime for crop production. Wabash soil is derived from sheet wash of Marshall and Knox soils, and probably is the most productive and desirable land for almost any crop grown in the midcontinent region. About 17 per cent of the area is covered by Wabash soils. Lamoure silty clay loam is similar to the Wabash soil except that it contains more lime, and occupies only about 1 per cent of the area.

Carrington silty clay loam is mapped wherever erosion has removed the loess mantle and exposed the underlying glacial drift and only a very small area on a tributary of Papio Creek is classed as Carrington soil.

The bottom land along the Platte River next to the Wabash soil is classified as Cass fine sandy loam, silty clay loam, and silt loam. About 10 per cent of the area is included as Cass soils. Cass soils have an abundance of organic material to a depth of over two feet and are free of lime. Much of the Cass soil area is poorly drained and is subjected to flooding when the river is extremely high over its banks. Cass soil is very suitable for most crop production including truck farming. Where a high amount of clay is present the soil becomes plastic when wet and may form hard clods when dry after plowing.

Sarpy loamy fine sand and river wash occupy a small area immediately adjacent to the Platte River and Elkhorn River. The area is inundated by flooding during periods of high water and is not used for cultivated crops. These soils are used for grazing land and woodland growth. The water table is near to the surface in the Sarpy and river wash area. Sarpy soils and river wash occupy about 4 per cent of the area.

Climate in the Richfield anticlinal area is temperate and continental with wide variations in seasonal rainfall and temperature. Prevailing wind direction is from the west during most of the year being southerly during the summer months. Mean annual temperature for the year is about 51 degrees fahrenheit varying from the maximum of about 112 degrees in the summer to a minus 33 degrees in the winter. The average mean seasonal temperatures are about 25 degrees for winter, 51 degrees for spring, 75 degrees for summer, and 54 degrees for fall. Average annual rainfall for the area is about 27 inches of moisture in the form of rain and snow. During the driest year recorded only 14 inches of rainfall occurred while the wettest year recorded 43 inches of moisture. Relative humidity for the area is about 70 per cent throughout the year. Average wind velocity near Omaha is recorded as 9 miles per hour with winds of 30 to 50 miles per hour not uncommon. Average date for the first killing frost in the fall is October 11th while the last frost of the spring occurs about April 26th. Number of clear days during the year averages between 120 and 160.

The Richfield anticlinal area is within the glacial drift area of Nebraska and topographic conditions as they are now are the result of glaciation and subsequent erosion. The principal drainage for the area is the Platte River which flows in a generally east direction except for a southerly course between Saunders and Sarpy Counties. Principal drainages which enter the Platte River in the area are the Elkhorn River west of Gretna, Nebraska and Salt Creek which enters the Platte River north of Ashland, Nebraska. Another drainage for the area of Sarpy and Douglas Counties is the Papio Creek which flows southeasterly into the Missouri River just north of where the Platte River enters the Missouri River. Average elevation above mean sea level for the upland rolling hill area is about 1,150 feet.

Settlement of the area by Caucasians began in 1810 near the town of Bellevue, Nebraska. Prior to this time the area was inhabited exclusively by Indians in roving bands or in settled areas with primitive agricultural methods. Most of the area prior to settlement and cultivation by the white man contained a rich abundance of native grasses consisting of bluestem, needlegrass, dropseed, and a few other types. Natural forest growth was confined to nonarable areas such as the bluff lands and areas of recently deposited sediments along the rivers and creeks. Several types of oak trees, ironwood, linden, honeylocust, and cedar trees grew in the bluffs or steep slope areas. Along the flood plains and creeks elm, ash, walnut, hackberry, boxelder, cottonwood, and willow trees grew in abundance. Small game and wildfowl was abundant. Larger animals such as the deer, coyote, and buffalo were present. Wild horses did not appear until they were brought to the Mexican area by the Spanish and French although species of horse were abundant prior to the glacial period during Tertiary time.

PLEISTOCENE SYSTEM

The Pleistocene period of time began about 1 million years ago and is noted for the advance and retreat of several glacial stages and interstages in the northern and southern hemispheres. The maximum extent of the glaciers covered about one-third of the land surface of the earth and in the United States moved as far south as the Ohio and Missouri Rivers where they enter the Mississippi River. Eastern Nebraska was covered by several hundreds of feet of ice during the first two stages of the Pleistocene period. Precise dating in the modern concept of man of major geological events and periods of time is not presumed. Even with the use of radioactive elements as a geologic dating device a specific year or even hundreds to thousands must be used in dating fossil flora and fauna or rocks. Radioactive carbon dating can be applied to fossil plants and animals within the last 30,000 years. This method is based on the concept that atmospheric nitrogen changes to carbon 14, a radioactive isotope of the element carbon. Plants incorporate carbon 14 along with regular non-radioactive carbon 12 into their systems as carbon dioxide. Because some animals feed on plants they incorporate carbon 12 and carbon 14 in their animal tissue. In the live tissue of a plant or animal the ratio of carbon 12 to carbon 14 remains constant until death. During the decay of plant or animal tissue the carbon 14 is slowly changed back to nitrogen. This process involves some 30,000 years and therefore an accurate dating of fossil plant and animal life plus the sediments into which they are incorporated is possible. Beyond 30,000 years other radioactive elements are used to date sediments and fossil flora or fauna. The process of radioactive dating is relatively new procedure for dating fossils and rocks. In general, the times periods and boundaries established by geological research using evolution of plant and animal ecology conforms with radioactive dates.

The cause of wide distribution of continental glaciers during the Pleistocene period over what are now temperate climate areas is not exactly known. Glaciation of the type during the Pleistocene time is known in other older time periods. Glaciers are built from snowfall, compaction of the snow into ice, and subsequent lateral movement by plastic flow when sufficient depth of ice is incurred. Ice becomes plastic when sufficient pressure is produced by the weight of several thousands of feet of ice and may move at a rate of from a few inches per day to several feet depending on the climate, gradiant of the earth's surface, and rate of build up of the ice sheet from precipitation in the form of snow. Major climatic changes occurred during the Pleistocene period with a general cooling during glacial stages and warming during the interstages. Increased rainfall in the form of snow is presumed with the continental glaciers causing a reduction in mean sea level as a result of ice coverage on the continents. Atmospheric conditions probably were different during glacial periods and some geologists and astronomers have speculated the the possibility that the earth's position with respect to the sun was altered to produce lower temperatures.

Plant and animal life which existed on the earth and within the area of eastern Nebraska changed with the advance and retreat of the Pleistocene glaciers. Some plant and animal life could not adapt to the climatic changes and were destroyed forever. Some animal life that was ambulatory moved to warmer regions in the tropics and continued their evolutionary cycle. Retreat of the four major cycles of glaciation during the Pleistocene period accounts for the wide variety of flora and fauna found embedded in Pleistocene strata.

Pleistocene stratigraphy is presented from the beginning of the period until the last continental glacier retreated. The lithology of the Pleistocene system in eastern Nebraska is complex as is the flora and fauna. "Pleistocene Geology of Nebraska" Nebraska Geological Survey Bulletin 10, second series, 1935, by A. L. Lugn was the first attempt at correlation of Pleistocene formations in Nebraska. Pleistocene deposits have been intensively studied by the Nebraska Geological Survey through a cooperative drilling program with the U. S. Geological Survey since 1931 in which several thousand test holes were drilled primarily in central Nebraska. Records of the wells drilled in a regular profile are preserved with the Nebraska Geological Survey in Lincoln, Nebraska and many unpublished maps are available for inspection at the Survey's offices. A test drilling program for 1962 includes drilling in Sarpy and Douglas Counties which will add to the knowledge of Pleistocene stratigraphy in the Richfield anticlinal area. The economic results of the test drilling program by the Nebraska Geological Survey serves to locate sand and gravel beds in the Pleistocene system which can provide a fine quality and large source of water for human and industrial consumption. "Correlation of the Pleistocene Deposits of Nebraska", Nebraska Geological Survey Bulletin 15A, March 1950, by G. E. Condra and E. C. Reed presents the information known about the Pleistocene of Nebraska until 1950. Subsequent reports of the test drilling program by the Nebraska Geological Survey are published primarily in the form of test well records by county and maps are available for inspection in Lincoln, Nebraska. A detailed areal Pre-Pleistocene map of Nebraska is now in process of being produced for publication by the Nebraska Geological Survey.

The topographic surface of eastern Nebraska at the beginning of Pleistocene time was essentially the same as during the present time. Deep pre-Pleistocene valleys trending in an east-west direction were developed before the advance of the first continental ice glacier. In the northern part of what is now the Missouri River Basin the drainage was toward the Hudson Bay area and in the south the drainage was into the Gulf of Mexico. The exact location of the pre-Pleistocene valleys in the Richfield anticlinal area are not known but are believed to be extensions of buried valleys mapped in central Nebraska by the Nebraska Geological Survey. Test wells drilled by Northern Natural Gas Company and other deep wells in the area did not record the Pleistocene section or save the samples. A few test wells in area by the Nebraska Geological Survey which studied the Pleistocene and a few water well records are the only records of the Pleistocene in the Richfield anticline area. Pleistocene loess outcrops in many road cuts, stream and gulley banks, but outcrops of glacial drift are scarce. The Pleistocene mantles the entire area except where outcrops of Dakota group sandstone and Pennsylvanian limestones and shales crop out along the lower Platte River valley.

The first glacial stage of the Pleistocene period is called the Nebraskan stage. The continental glacier advanced from the north and ice several hundreds of feet thick filled the valleys with gravel, sand, and glacial till, the latter being unconsolidated and unstratified mixtures of clay, silt, sand, pebbles, and boulders. Maximum thickness of Nebraskan age deposits was in excess of one hundred feet in the valleys. Subsequent erosion during the Aftonian interstage when the glacier retreated to the polar region removed a part or all of the Nebraskan stage deposition in many areas. The Aftonian interstage produced a soil horizon on the glacial till called gumbotil as a restoration of more temperate climate brought a redevelopment of plant life. The Aftonian interstage has a maximum development of sediments of about 25 feet in thickness. Nebraskan till usually has a grayish color and the Aftonian soil development has darkened the surface of the Nebraskan till where preserved. West of the glacial drift area in Nebraska the easterly flowing streams were blocked by the glacier and deposits of gravel and sand mantled the surface as the streams were aggraded. Maximum thickness of the Holdrege sand and gravels, developed during the Nebraskan stage, is over 100 feet is an important source of ground water in central Nebraska. During the interglacial stage of Aftonian time, the driftless area in central Nebraska produced the Fullerton clay and silt deposited by erosion activity of streams and wind born deposits.

A second continental glacier invaded eastern Nebraska during the stage called the Kansan glacial stage which covered abou the same area as the Nebraskan glacier and extended beyond the edge of the Nebraskan glacial drift deposits. Again the valleys were filled with gravel, sand, and till with the upland areas being covered primarily with till. West of the glacier the streams were again aggraded by the deposition of sand and gravel called the Grand Island sand and gravel. Grand Island sand and gravel is also an important aquifer in central Nebraska. The retreat of the Kansan ice glacier from Nebraska to the polar region brought about another temperate cycle termed the Yarmouth interglacial stage. Kansan till was reworked and eroded with a soil horizon of what is now called gumbotil again developing as plant life returned to the area. Loess deposits accumulated and the erosive cycle west of the Kansan glacial drift area produced the Sappa formation. Within the

Sappa formation is lenticle of volcanic ash which was probably derived from the Rocky Mountain area and blown by wind to the area. This volcanic ash layer called Pearlette is an important horizon marker.

A third continental glacier invaded the upper Mississippi Valley that did not extend as far south as the Nebraskan and Kansan glaciers. Only a small portion of northeastern Nebraska was covered by the Illinoian glacier. Deposits of sediments in eastern Nebraska were primarily Loveland loess during the Illinoian time with some aggrading of streams in eastern Nebraska in the form of Crete sand and gravels. Loveland loess mantled the entire area of eastern and central Nebraska blown in from the western high plains region. Loveland loess has a characteristic reddish color which would indicate an arid climate after the retreat of the Illinoian glacier during the interglacial stage termed Sangamon. Loveland loess accumulated to a thickness of about 30 feet but appears to be thin in the Richfield anticlinal area.

During the fourth major glacial advance in the upper Mississippi Valley termed the Wisconsin glacial stage four separate glacial advances and retreats are recorded in northern Iowa with only a very small area of northeastern Nebraska being covered by ice. The four glacial substages from youngest to oldest are the Mankato, Carey, Tazewell, and Iowa with the entire period of time of four glacial advances and retreats occurring during 30,000 years or the time classified for the entire Wisconsin glacial stage. In eastern Nebraska and central Nebraska sedimentary deposits of loess called Peorian mantled the area in excess of 50 feet. Major stream drainages of eastern Nebraska had developed their present systems prior to Wisconsin time since Peorian loess blown in from the west mantled the upland and high terrace areas. Peorian deposits crop out extensively in the Richfield anticlinal area and are promient in road cuts on the new Interstate Highway #80 between Omaha and Lincoln, Nebraska. Peorian loess consists of clay, silt, and very fine sand and has a light yellow to light brown appearance. The material is very soft. The clay is a complex of hydrous potassium aluminum silicate and the very fine sand and silt evolved from silicon dioxide or quartz. With respect to a loess or till deposit those individual particles which are less and 1/256 millimeter in diameter are properly termed clay with a mineral content of a complex hydrous potassium, calcium, sodium, calcium silicate evolved from feldspars. Particle sizes between 1/256 and 1/16 millimeter in diameter are described as silt with a mineral content of silicon dioxide or the complex clay silicate. Diametric sizes between 1/16 and 2 millimeters is sand and is composed of silicon dioxide or quartz. Present soils in the Richfield anticlinal area are evolved primarily from Peorian loess with the addition of decayed plant material. Peorian loess will sustain plant life at the present time but is easily subjected to water erosion where the terrain slopes.

Economically, the Pleistocene sedimentary deposits are the basic soil formers for present day agriculture and the value of the land depends to a great degree on the thickness of the soil developed and the degree of slope. Pleistocene sand and gravels are an important source of fine quality water for human and industrial use. Artesian flows and pump irrigation in central Nebraska for crop production produces large quantities of water from Pleistocene sands and gravels. Irrigation has stabilized the productivity and increased the productivity of agricultural products in central Nebraska since the farmer is not now completely dependent on the annual rainfall to provide moisture for his crops. The annual rainfall, although about 27 inches in eastern Nebraska, has had extremely dry periods sometimes lasting several years. The dry period during the 1930s were accompanied by dust storms and erosion of soil which decreased the fertility. Pleistocene sands and gravels are utilized in many areas for building and highway construction.

In Pleistocene time plant and animal life flourished during the interglacial stages. Many animals developed a tougher skin and thicker hair to cope with the cooler temperatures associated with glacial activity. Many species of animal life became extinct during the Pleistocene period probably because of inability to adapt to climatic changes. Fossil preservation of plant and animal from the Pleistocene is generally scarce considering the numbers of flora and fauna that existed. To be preserved a fossil has to be quickly covered with sediments and located where erosive processes will not destroy the skeleton. Plant preservation is usually in the form of pollen and seeds that are highly resistant to decomposition. Occasionally, some plant and animal life has been found perfectly preserved in glaciers of the far north. Animals that flourished during the Pleistocene in Nebraska were the sabre-tooth tiger, mastodonts, mammoths, camels, and caribou but are now absent. Animals that flourished during the Pleistocene period which are still present are rabbits, squirrels, mice, raccoons, deer, and buffalo.

TERTIARY SYSTEM

Tertiary system formations are absent in the subsurface of the Richfield anticlinal area and in eastern Nebraska. The Tertiary period represents about 59 million years of time preceding the Pleistocene period. In western and central Nebraska continental deposits of the Tertiary system containing sand, sandstone, and clay reach a thickness of over 2,100 feet. Correlation of the western Nebraska Tertiary period includes the Pliocene, Miocene, and Oligocene epochs. Sands and clays of the Tertiary period in Nebraska were derived from the Rocky Mountains of Colorado and Wyoming being borne by terrestrial rivers and winds to their present position. Tertiary system formations along the borders of the North American continent were marine in nature and notably in the Gulf Coat an excess of 40,000 feet of sediments were deposited with these sediments being the most important petroleum producing formations in Texas and along the Gulf Coast.

The Tertiary period in eastern Nebraska is marked by west-east trending valleys cutting into pre-existing formations of Cretaceous, Pennsylvanian, and Permian age.

CRETACEOUS SYSTEM

Cretaceous system formations are represented in the subsurface and near surface of the Richfield anticlinal area by Dakota group sandstones. The period of time covered by the Cretaceous age is about 70 million years. Widespread invasion of seas covered the Great Plains and what is now the Rocky Mountains. The Rocky Mountains were formed at the close of the Cretaceous period and during the first part of the Tertiary period. Four to five thousand feet of sediments were deposited in western Nebraska, principally shales, sandstones, and some limestones. Western Nebraska oil fields are from sands in the Cretaceous system. In eastern Nebraska the Cretaceous system formations are less than 400 feet thick and consist primarily of sandstone in large part of continental origin. In the Richfield anticlinal area the maximum thickness of about 200 feet of Dakota group sandstone was found in a well just east of Gretna, Nebraska. Erosion subsequent to deposition has reduced the thickness of the Dakota group sandstones to less than 100 feet in most of the Richfield anticlinal area. In the lower Platte River Valley, Dakota group sandstone is entirely absent except in outcrops overlying the Pennsylvanian formations in the bluffs along the river.

Dakota group sandstones are also absent in the Missouri River valley except in the high bluffs. In a few test wells in the upland area Pleistocene deposits lie directly on the Pennsylvanian formations with the Dakota group sandstones being absent by channel erosion or very thin.

Sample records from wells of Dakota group sandstones in the Richfield area indicate the sandstone probably belongs to the Lakota formation, but samples were not preserved in most of the wells. Outcrops of Lakota sandstone occur in the bluffs along the lower Platte River valley and a good outcrop of Lakota sandstone was exposed by road construction just east of Papio Creek on west Dodge Street near Omaha.

Lakota sandstone is fine to medium grained in its upper and middle part and is for the most part friable and soft. The color varies from light gray to brown. Zones of dark brown ironstone like sandstone are present that are very hard. The Lakota sandstone on its weathered outcrop presents a rusty colored appearance. Siderite concretions are present in the formation as is the mineral mica.

The Lakota sandstone of the Dakota group is a good subsurface aquifer in eastern Nebraska but the water will normally have a yellowish appearance from the iron rust and a rusty material will settle out when the water is allowed to stand. The water is not considered good for human consumption because of the iron but has been used where other sources of water are not present.

The base of the Lakota sandstone is marked by loosely endurated gravel like sandstone with some of the gravel attaining pebble size. Lakota gravel has been quarried for road construction in many localities where it is loosely cemented.

There is little or no fossil record in the Cretaceous system of eastern Nebraska although the Cretaceous period is famous for being the "Age of Dinosaurs" when many species of the huge reptiles reached their maximum size. Dinosaurs became extinct at the close of the Cretaceous period.

JURASSIC, TRIASSIC AND PERMIAN SYSTEMS

The Jurassic, Triassic, and Permian periods of time are not represented by any formations in the geologic column fo the Richfield anticline. Combined, these major periods of time account for about 70 million years or a long hiatus between the Cretaceous system and the Pennsylvanian systems which do occur in the geologic column of the Richfield anticline. Jurassic formations are present in western Nebraska with a maximum thickness in the panhandle area of about 550 feet and are found only in the subsurface. About 25 million years of time is assigned to the Jurassic period.

The Triassic period accounts for about 30 million years of geologic time and formations of the Triassic system are present in the subsurface of the panhandle area of Nebraska. Total thickness of the Triassic formations which consist primarily of the Spearfish formation is about 150 feet.

Triassic, Jurassic and Cretaceous systems combined total about 125 million years and are collectively known as the Mesozoic era. The Mesozoic era was the "Age of the Reptiles" and the beginning of modern type mammals, birds, and plants. Plant life of the Mesozoic era included cycads, ferns, and conifers with angiosperms becoming dominant during the Cretaceous period. Invertebrate marine fossils continued their development in Mesozoic seas.

Permian system formations are also absent in the subsurface of the Richfield anticline area but are present on the surface and subsurface in southeastern Nebraska and in the subsurface of central and western Nebraska. Permian sediments probably did cover the Richfield anticlinal area but have been entirely removed by erosion. A composite section for the entire Permian system of Nebraska would involve over 2,000 feet of sedimentary rocks. Permian time was one of shallow seas and intervening aridity. Sediments are predominantly shales with red coloring and gray. Limestones are generally thin and sandstones are present usually as channel fills. Evaporites which form under desert like conditions that contain salt and gypsum are common in the Permian system in some areas. The Permian system includes about 25 million years of time and concludes the Paleozoic era.

The Richfield anticlinal area was a low-lying plain area during most of Permian, Triassic, and Jurassic time with little or no sediments being deposited either continental or marine.

PENNSYLVANIAN SYSTEM

Strata of the Pennsylvanian period are represented on the surface and subsurface in the Richfield anticlinal area. They lie unconformably under Dakota group sandstone over most of the area and unconformably under Pleistocene sediments in the lower Platte River valley and Missouri River valley. The Pennsylvanian period represents about 25 million years of time preceding the Permian period.

Pennsylvanian system formations are subdivided into three main series of formations separated by unconformities. The series are further subdivided into groups separated by minor unconformities. Pennsylvanian groups are then divided into formations and in some cases members of a particular formation. The unconformities between Pennsylvanian groups and series represent a time lapse in uniform sedimentation where previous beds have been eroded before a new cycle of sedimentation. The sedimentation in the Pennsylvanian period was different from preceding periods in that the widespread marine seas which invaded the midcontinent and eastern United States were very shallow with lagoons and marshes predominating. Some thin limestones such as the Hertha limestone formation can be continuously mapped for hundreds of square miles on the surface or subsurface with little change in thickness or lithology. The Pennsylvanian sea during Hertha time was very shallow and the bottom of the sea was almost a complete flat surface in order to produce a limestone of uniform thickness throughout a wide area. Pennsylvanian shales were formed under even shallower sea conditions than the limestones with coals developing in lagoonal and swamp areas from decayed plant vegetation. There is little or no sandstone in the Pennsylvanian section of the Richfield anticlinal area. The sandstones that do occur are erratic channels marking unconformities. The depositional environment of the Pennsylvanian formations in the Richfield area consists of a cyclic series of shales and limestones in variable shallow seas. Coal in commerical quantities does not occur in the area.

Correlation of individual Pennsylvanian formations in the Richfield anticlinal area closely parallels a correlation found in the Nebraska Geological Survey Bulletin #14A by G. E. Condra and E. C. Reed, July 1959, entitled " The Geological Section of Nebraska". Many publications concerning the Pennsylvanian outcrops in Nebraska have been published by the Nebraska Geological Survey when the detailed studies began early in the 20th century. Because of the complexity of the Pennsylvanian section many miscorrelations were made during early studies in an attempt to correlate the formations with similar beds in surrounding states. In the correlation of Pennsylvanian formations from rotary well samples to other wells and the exposed outcrops drilling time logs with a one foot interval are very helpful in divided the shales from the cemented limestones. Using a series of several formations of limestones and shales, a drilling time log comparison of several wells penetrating the same formations is itself very distinctive. Because of carryover of samples in the rotary drilling process, particular attention must be paid to new lithology encountered and not so much to quantity of various lithologies encountered. The occurrence of red shales, green shales, and black shales aids in locating the position of the well in the subsurface section. Distinctive oolite limestones, crystalline limestones and their thickness is important in arriving at the correct correlation. Chert bearing zones in a few limestones are key horizon markers. Individual fossils are broken during the drilling process and are secondary in their importance for subsurface correlation. The same fauna appear in many limestones and shales and therefore their correlation for individual beds are not as helpful in a local situation as they are for regional correlation. Details of the series, groups, formations, and members are presented with emphasis on those formations that are more easily recognized in subsurface samples. After a well was completed in the series drilled by Northern Natural Gas Company an electric log with a single point resistivity curve was run in every well except those finished in the Precambrian surface where a regular Schlumberger type electric log and microlog was made. The single point resistivity log was better than the Schlumberger logs for correlation in the Pennsylvanian section since a single point electrode will precisely determine formational changes as thin as three feet in thickness. The standard Schlumberger electric log has electrodes with spacings of 16 inches, 64 inches, and 16 feet which cannot precisely mark individual differences in shale and limestone changes when the bed thickness approaches the spacing interval. The electric logs also served as a depth check to various formations with the depth measurements kept by the drilling contractor.

VIRGIL SERIES

The Virgil series is the upper Pennsylvanian subdivision which is further subdivided into the Wabaunsee, Shawnee, and Douglas groups. Only a portion of the Douglas group is present in the Richfield anticlinal area with the younger groups having been removed by erosion. Wabaunsee and Shawnee group formations are found on the surface and subsurface of southeastern Nebraska with a combined thickness of about 600 feet and consisting of thick shales, thin limestones, and some sandstones. The Shawnee group is present on the surface in many part of central and southern Cass County. The Virgil series thickens southeasterly toward the central part of the Forest City Basin in southeastern Nebraska. A portion of the lower Shawnee group is exposed in the vicinity of Ashland, Nebraska where the limestones are quarried but the group is entirely absent in Sarpy County to the north and within the environs of the Richfield anticline.

SHAWNEE GROUP

About 47 feet of the lower Shawnee group is present on the surface and subsurface in the vicinity of Ashland, Nebraska and is highly eroded in the area. Only the Oread formation is represented in the area.

Oread Formation

A composite section of the Oread formation totals about 47 feet which lies unconformably beneath Dakota group sandstone or Pleistocene mantle.

Seven members of the Oread formation consist of alternating shales and limestones which are briefly described from the area of outcrop.

Kereford Limestone

Limestone, dark gray, massive, dense, and locally oolitic having a thickness of about 3 feet.

Heumader Shale

Shale, gray to dark gray, brachiapods, Chonetes, Composita and Neospirifer, and bryozoa, total interval about 3 feet.

Plattsmouth Limestone

Limestone with two shale intervals each about 1 foot thick, overall thickness of entire bed is about 15 feet. The upper limestone layer is dark gray and is about 2 feet thick. Next in sequence is a gray shale layer about 1 foot thick. The third bed is limestone, light gray with a chalky appearance, blocky, and contains many protozoa, Fusulinids. Fourth layer in sequence is shale about one foot, gray to dark gray, contains brachiapods, Neospirifer triplicatus . The lowest layer is limestone about 8 feet, dark gray, with free calcite, two chert zones in the upper portion, faunal assemblage includes protozoa, Fuslinids, horncorals, brachiapods, Enteletes hemiplicatus common.

Plattsmouth limestone is a highly important quarry rock for building, terrace, and crushed rock, which is extensively quarried where located near the surface.

Heebner Shale

Shale, gray, black and fissile below, and has a combined thickness of about five feet. The black fissile shale is an important key horizon for correlation.

Leavenworth Limestone

Limestone, bluish gray, forms rectangular blocks, and is about one and one half feet thick.

Snyderville Shale

Shale, mostly red with gray at top and bottom which has a total interval of about 12 feet.

Weepingwater Limestone

Limestone, gray, massive to shaly, contains brachiapods, bryozoa, and echinoderm fragments, Crinoids, with a thickness from 8 to 9 feet.

DOUGLAS GROUP

The Douglas group is present on the surface and subsurface in the lower Platte River valley between Ashland and South Bend, Nebraska with a total interval of about 38 feet consisting primarily of shale. The group is unconformable at the base and has an unconformity near the middle and an uneven top. No part of the Douglas group is present on the Richfield anticline in Sarpy County. Two formations represent the group in northern Cass County.

Lawrence Formation

The Lawrence formation has a total thickness of about 19 feet and consists of red and gray shales which are sandy in part, unconformable at base.

Stranger Formation

The Stranger formation is primarily limestone with shale at the top and base. The top shale is gray, contains mollusks, Pelecypods, and is pebbly at the top, about 2 feet. The lower shale is gray and about 1 foot with pebbles and erosion evident on the outcrop. Total thickness of the Stranger formation is about 18 feet containing one member in this area.

Cass Limestone

Limestone with two shale beds near the top and base which are about one foot in thickness each. The upper shale is gray and calcareous, and the lower shale is bluish with some black fissile shale and contains many fossils, proterozoa, Fusulinids, brachiapods, Neospirifer and Chonetes, bryozoa, Rhombopora and Polypora. The middle limestone bed is about 10 feet thick and fossiliferous, with free calcite, and gray in color.

MISSOURI SERIES

The Missouri series is subdivided in to the Pedee, Lansing, Kansas City, and Bronson groups with a combined total thickness of about 240 feet in the Richfield anticlinal area. Formations of the groups crop out in the lower Platte River valley from the Ashland, Nebraska area to a point in the bluffs west of the village of La Platte. Beds from youngest to oldest appear along the Platte River and on creeks entering the Platte River proceeding downriver from Ashland. The beds have a gentle dip to the west. Channel erosion and truncation have removed portions of the series overlying the Richfield anticline in western Sarpy County and in central Sarpy County east of Springfield, Nebraska the entire section including the Hertha limestone is absent by truncation.

PEDEE GROUP

The Pedee group crops out near South Bend, Nebraska in the Platte River valley and has a maximum thickness of about 13 feet. This group is entirely absent in Sarpy County and Saunders County on the Richfield anticline.

Weston Formation

Weston shale is purple-red in color with gray shale at the top and base. A total thickness of about 13 feet is present on the outcrop with the coloring diagnostic for correlation. The formation contains bryozoa, Rhombopora lepidodendroides at the base. Weston shale could be used in brick manufacturing because of its coloring provided a suitable areal extent existed without being absent because of erosion.

LANSING GROUP

The Lansing group averages very close to 52 feet in thickness over a wide area in the lower Platte Valley where exposed and in the subsurface on the Richfield anticline. The group is absent in most of the wells drilled by Northern Natural Gas Company by channel erosion and truncation.

Stanton Formation

The Stanton formation and its five members crop out in the lower Platte River valley with a total thickness of about 35 feet. Two limestone members are prominent as key correlation beds with an intervening red shale. Sample, drilling time, and electric log correlation of this formation in the subsurface is precise.

South Bend Limestone

Limestone, massive, with two thin shale seams with the upper limestone layer containing chert that is diagnostic in well samples, central and lower limestone beds are gray and oolitic. Faunal assemblage includes protozoa, Fusulinids, bryozoa, Rhombopora, and brachiapods, Ambocoelia, Spirifer, and Rhipodomella. The total thickness of the South Bend member is about 9 feet and the limestone is quarried for crushed rock.

Rock Lake Shale

Shale, maroon, calcareous, with a one foot gray layer at top and a total interval of about 6 feet. The Rock Lake shale is easily identified in well samples by color and drilling time with low resistivity on the electric log.

Stoner Limestone

Limestone, gray to light gray in upper 11 feet, dense, contains free calcite, faunal assemblage includes protozoa, Fusulinids, (Triticites) and brachiapods, Composita and Marginifer. A two foot layer of shale beneath the limestone is gray and calcareous containing, protozoa, Fusulinids (Triticites), brachiapods, Chonetes, Spirifera, and Productus, coelenterates, Lophophyllidiom, and echinoderm fragments, Crinoids. The lower zone of the Stoner member contains two thin limestones separated by a 3 foot shale bed. The limestones are gray, fossiliferous, and the shale is gray, calcareous, and fossiliferous. Total thickness of the Stoner member is between 15 and 16 feet. Stoner limestone is quarried where found near the surface, and is easily recognized in well samples, drilling time, and on the electric log.

Eudora Shale

Shale, gray with lower six inches dark and coal-like with a total thickness of about 2 feet. The coal-like layer is sometimes a good marker in well sample study.

Capitan Creek Limestone

Limestone, gray, containing brachiapods and echinoderm fragments, Crinoids, with a total interval of about one and one half feet.

Vilas Formation

Shale, gray, with a total of about 6 feet in thickness. Two limestone seams are present which are earthy and very thin. The base of the Vilas shale has some reddish material and the top of the shale is almost black.

Plattsburg Formation

The Plattsburg formation consists of two member limestones separated by a shale for a total of about 10 feet.

Springhill Limestone

Limestone, gray, weathers buff, varies between 3 to 4 feet.

Hickory Creek Shale

Shale, gray, between 1 and 3 feet thick.

Meadow Limestone

Limestone, massive, gray, very fossiliferous with bryozoa, Polypora, and is between 2 to 3 feet in thickness.

KANSAS CITY GROUP

The Kansas City group is well exposed in the lower Platte Valley and is present at least in part in most of the wells drilled on the Richfield anticline. Like the Lansing it has been eroded in many places and averages about 100 feet in thickness on the outcrop. Thickness is somewhat greater in the Northern Natural Gas Company wells drilled in Saunders County on the west side of the Richfield anticline where the total Kansas City section approaches 119 feet.

Bonner Springs Formation

Shale, gray, some reddish zones in the upper part and thin seams of fossiliferous limestone containing brachiapods, Derbya, bryozoa, Rhombopora and Septopora. The total interval varies between 6 and 8 feet.

Wyandotte Formation

The Wyandotte formation contains two limestone members and two shale members for a total interval of about 30 feet. The Ash Grove Cement Company of Louisville manufactures Portland cement from the Wyandotte formation and has a large plant located near the outcrop area.

Farley Limestone

Limestone, gray, massive, weathers yellow on the outcrop and is between 4 and 5 feet thick.

Island Creek Shale

Shale, gray, and is between 1 and 3 feet thick.

Argentine Limestone

Limestone, gray, dense in upper portion with thin shaly seams in the lower part. Total interval is about 21 feet. Argentine is diagnostic in well samples because of its thickness related to drilling time and high resistivity on the electric log.

Quindaro Shale

Shale, dark to black, fissile, 3 to 4 inches thick on the outcrop.

Lane Formation

Shale, light green, fossiliferous, about 6 inches on the outcrop in the lower Platte River valley. In the Northern Natural Gas Company wells drilled in Saunders County the Lane shale formation was between 10 and 16 feet thick according to drilling time and the electric log and would indicate an increase in the interval on the west side of the Richfield anticline.

Iola Formation

Limestone, with a thin shale layer between two limestone beds. On the outcrop in the lower Platte River valley the interval is about 4 feet thick and in the test wells west of the Richfield anticline in Saunders County the thickness was between 10 and 12 feet. The three members of the Iola formation are described herein.

Raytown Limestone

Limestone, gray, fossiliferous, and between 6 and 8 inches thick on the outcrop. The member cannot be separately identified on electric logs.

Muncie Creek Shale

Shale, upper part blue lower part black, carbonaceous, fissile, with a total interval of about 1 to 2 feet.

Paola Limestone

Limestone, earthy, brachiapods common, Derbya, about 8 inches.

Chanute Formation

Shale and claystone, gray, calcareous, with thin limestone seam near base that contains brachiapods, Derbya. Total thickness on the outcrop in the lower Platte Valley is about 14 feet, but in test wells west of the Richfield anticline in Saunders County the interval is between 4 and 5 feet.

Drum Formation

Limestone, dense, gray, with two calcareous shale seams near base, contains brachiapods and echinoderms, Crinoid fragments. Total thickness of the formation on the outcrop is about 9 feet and in the Northern Natural Gas Company wells west of the Richfield anticline the interval is about 11 feet. The limestone is sometimes used in quarrying operations.

Quivira Formation

Shale, green, fossiliferous with a black carbonaceous shale of about 1 foot near the middle with a total interval of about 6 feet.

Westerville Formation

In the outcrop area and in a quarry south of Richfield, Nebraska 9 separate beds have been described within the Westerville formation which is principally limestone. The separate beds cannot be identified in sample analysis or on the electric log. Faunal assemblage in the Westerville formation includes protozoa, Fusulinids, brachiapods, Chonetes, fenestrated bryozoa, mollusks, Gastropods, Pelecypods, (Myalina and Pinna), and echinoderms, Crinoid fragments. Total thickness on the outcrop is 18 feet and in the Northern Natural Gas Company test wells west of the Richfield anticline the thickness averages 14 feet.

The Westerville limestone is often used for quarrying of limestone for crushed rock.

Cherryvale Formation

Shale, gray to buff, very sandy in upper part, black fissile shale in the middle about 2 feet and greenish shale at the base. On the outcrop the total thickness in the lower Platte River valley is about 13 feet but averages about 6 feet in the Northern Natural Gas Company test wells in Saunders County west of the Richfield anticline. The black shale and sandy shale are diagnostic in well samples.

BRONSON GROUP

The Bronson group is the oldest group of Pennsylvanian formations exposed in the lower Platte River valley. The basal limestone formation in the Bronson group is called the Hertha limestone formation and is the unit used in preparing a structural map for the Pennsylvanian system. Total thickness of the group in about 79 feet including the basal shale member termed the Bourbon formation. The Bourbon shale cannot be identified in this area as a separate formation and the interval is included with the Marmaton-Cherokee undivided groups. The interval between the top of the Bronson group and base of the Hertha limestone averages about 58 feet in the test wells and the group or portions of the group are found in every test well in the area except in the Northern Natural Gas Company well #9 located in section 19, township 13 north, range 12 east, the #1 Urhammer well located in section 23, township 13 north, range 12 east, and the #1 Timm well located in section 15, township 13 north, range 12 east. The Bronson group is absent in the area of these wells by truncation and possible channel erosion.

Dennis Formation

The Dennis formation is composed of three members with a total thickness of about 21 feet and is exposed in the lower Platte River valley.

Winterset Limestone

Limestone, gray, with several layers and a thin shale seam near the base, upper limestone layer is about 7 feet thick, gray, forms large blocks on the outcrop and contains brachiapods, Composita. The second limestone layer contains dark chert which is diagnostic of the member in well samples. The balance of the Winterset member is limestone which is tan colored and softer than the upper layers. Winterset limestone is easily recognized on the drilling time log, in sample analysis, and on the electric log. The member is extensively quarried where it appears on the surface or near the surface in Nebraska and western Iowa.

Stark Shale

Shale, gray, calcareous, fossiliferous, with thin limestone seam near the middle and is about 2 feet thick.

Canville Limestone

Limestone, hard, dense, dark gray, about 1 foot.

Galesburg Formation

Shale, gray, with upper part containing worm burrows on the outcrop. Two thin limestone seams are present which are dark gray and dense. Faunal assemblage includes brachiapods, Ambocoelia and Chonetes, bryozoa, Rhombopora. Black fissile shale is found in well samples. Total thickness on the outcrop is about 10 feet and averages about 5 feet in the sursurface of test wells drilled in eastern Saunders County.

Swope Formation

Principally a limestone with a total thickness on the outcrop of about 20 feet and 16 feet on the Richfield anticline. Three separate members are included with the formation.

Bethany Falls Limestone

Limestone, gray to light gray, upper portion nodular, styolitic, algal growth, fossiliferous, and contains pyrite crystals. The lower portion is fine textured, dense, and crystalline. Total thickness is about 15 feet. Bethany Falls limestone is recognized in the subsurface samples by its lithology, drilling time, and resistivity on the electric log. The member is quarried for crushed rock.

Hushpuckney Shale

Shale, dark gray, calcareous, with a thin limestone seam and a total of about 4 feet. Faunal assemblage includes brachiapods, Lingula, Wellerella, and Orbiculoidea. This member cannot be identified in the subsurface on the Richfield anticline.

Middle Creek Limestone

Limestone, dark gray, fine textured, contains pyrite crystals, fossiliferous, and algal growth with a total thickness of about one and one half feet. This member is not identified in the subsurface on the Richfield anticline.

Ladore Formation

Shale, gray to dark gray, calcareous, with light colored mica, limy concretions, and pyrite crystals. Total interval of the formation is about 5 feet.

Hertha Formation

Limestone, dark gray, brownish, reticulate, styolitic, fossiliferous and with a thin shale near the middle. Lower portion of the limestone is semi-crystalline, contains pyrite and fine mica. Faunal assemblage includes brachiapods, Orbiculoidea, Composita, Ambocoelia, and fragments, protozoa, Fusulinids, echinoderms, Crinoid fragments. Hertha limestone was exposed in a quarrying operation in the lower Platte River valley several years ago but was later covered by water. The limestone is easily recognized on the electric log and in sample analysis.

DES MOINES SERIES

The Des Moines series of formations is present in the subsurface only of eastern Nebraska and over the Richfield anticlinal area. In southeastern

Nebraska, the Des Moines series attains a total thickness of about 900 feet in the central part of the Forest City basin. The lower group, Cherokee, reaches a thickness of about 700 feet in Richardson County, Nebraska and consists primarily of sandstones, gray and dark shales, some thin coals, and very little limestone. The Cherokee sandstone has produced minor quantities of oil near Tarkio, Missouri and has produced oil and gas in the southern part of the Forest City basin in Kansas. The Marmaton group overlies the Cherokee group within the Des Moines series and averages about 160 feet in thickness in Richardson County, Nebraska. Correlation of the subsurface formations in the Marmaton group has been made with the outcrop area in Iowa and Missouri. The Marmaton group in southeastern Nebraska consists of one thick limestone formation, the Altamont, several thin limestones, red shale, gray to dark gray shales, and minor amounts of coal.

In the subsurface of the Richfield anticline no subdivisions of group boundaries for the Des Moines series is recognized either in samples, drilling time, or electric log. The resistivity log for the section has low resistivities characteristic of shale. In many wells the resistivity increases at irregular points in the section which probably indicates local facies changes to sand or sandstone. Sample analysis of the Des Moines section had only minor quantities of limestone, minor amounts of sandstone which varied from well to well, and large quantities of red shale and gray shale. Fossil fragments are rare and in order to properly correlate this section with the outcrop area or southeastern Nebraska a core would have to be taken. The Des Moines series with undivided Marmaton and Cherokee groups represents the time interval for the lower part of the Pennsylvanian system in the area. Thickness of the Marmaton-Cherokee group from the base of the Hertha limestone to the top of the Devonian dolomite, Mississippian being absent, varies from 126 feet in the Northern Natural Gas Company well #12 located in section 24, township 13 north, range 10 east to 162 feet in the Northern Natural Gas Company well #6 located in section 9, township 12 north, range 12 east of Cass County. On the flanks of the Richfield structure the Marmaton-Cherokee interval thickens with 265 feet of section in the #1 Rahn well located in section 23, township 14 north, range 12 east of Sarpy County and 205 feet in the well on the Offutt Air Force Base in eastern Sarpy County. North of the Richfield structure in Douglas County the Marmaton-Cherokee interval increase to 215 feet in the Northern Natural Gas Company well #8 located in section 9, township 14 north, range 11 east.

Marmaton-Cherokee shales of the Des Moines series lie unconformable over the Devonian dolomite throughout the higher parts of the Richfield anticlinal area except on the deeper flank in eastern Sarpy County, Douglas County, and Cass County where Mississippian formations are present. There is no economic significance for the Marmaton-Cherokee shale section. The depth to the Marmaton-Cherokee in the vicinity of the #1 Urhammer well is only about 70 feet. In central Iowa near Redfield where the Marmaton crops out the shale is used for brick and tile manufacture. The shale might be useful for underground storage of butane and propane.

MISSISSIPPIAN SYSTEM

The Mississippian system of rocks is not present over the Richfield anticlinal area except in the eastern portion of Sarpy, Douglas, and Cass Counties. The Offutt Air Force Base well, located in section 11, township 13 north, range 13 east, contains a Mississippian carbonate section of about 217 feet and several deep wells in the Omaha area contain about 150 feet of Mississippian carbonates. The Mississippian section thins by truncation westward over the Richfield anticline on the east side and is not present in the #1 Urhammer well which is located about 7 miles west of the Offutt Field well.

The cross section present in this report with a general west-to-east profile shows wedging of Mississippian period carbonates against the east front of the Nemaha range. Mississippian carbonates are found in central Nebraska on the west flank of the Nemaha range and north of the Nemaha range. About 30 million years of time is assigned to the Mississippian period and during widespread invasion of marine seas throughout the midcontinental area, the Richfield anticline and the Nemaha range were covered by the sea but the limestones and dolomites were removed by erosion following orogenic uplift. Faunal life was principally invertebrate marine with crinoids, blastoids, and cystoids of the echinodermata phylum very prominent. Bryozoans were common and foraminifera of the protozoan phylum were very prominent. Foraminifera occur as a principal agent for the construction of many Mississippian formations.

A brief description of the Mississippian section found in the Offutt Field well is presented. Two deep wells to the Precambrian surface have been drilled near the headquarters building of the Offutt Air Force Base, the location of the Strategic Air Command. The first well was completed in 1956 and is used as a source of water. The second well was completed in 1961 was cored throughout most of the subsurface section but the geologic information and cores have not as yet been released. The purpose of the wells was to study the deep subsurface in some detail in the air an provide a source of water that would be uncontaminated by radioactive elements in the event of nuclear bombing on or near the base.

IOWA SERIES

Total carbonate section thickness of about 217 feet in the subsurface with the series being subdivided into the Meramec, Osage, and Kinderhook groups.

MERAMEC-OSAGE GROUP

In combination the Meramec-Osage group contains about 155 feet of limestone and dolomite with the division into formations as follows:

Warsaw Formation

Limestone, light gray to white, coarsely crystalline, contains vugs with chert and calcite, sandy in part, upper margin unconformable with overlying Pennsylvanian shale. Crinoid fossil fragments are common. A total of about 30 feet if Warsaw limestone is present in the Offutt Field well.

Keokuk-Burlington Formation

The Keokuk and Burlington formations are not subdivided at the present time and contain a total thickness of about 125 feet. The formation consists principally of dolomite with limestone in minor quantities with the latter appearing in the lower part of the formation. In central Iowa the Keokuk formation is about 90 feet thick in itself and probably thins westward. The upper part of the Keokuk formation in central Iowa is a dark brown dolomitic limestone which does not appear in the Offutt Field well. The lower part of the Keokuk in the Offutt Field wells compares favorably with central Iowa in that the formation is primarily dolomite, gray, crystalline, spicular, vuggy, and contains gray-brown chert. Some selenite gypsum is present. The lower portion of the Keokuk-Burlington formation in the Offutt Field well is primarily limestone, gay to light brown, crystalline, common chert light gray-brown and white, some traces of glauconite. The glauconite is the boundary between the Keokuk and Burlington formations in central Iowa. A study of the cores in the second Offutt Field well should correlate this section in more detail with the subsurface in central Iowa and the type section in the upper Mississippi Valley.

KINDERHOOK GROUP

In the Offutt Field well about 62 feet of Kinderhook group limestone is present and is called the Chouteau formation in Nebraska.

Chouteau Formation

The Chouteau formation correlates with the Gilmore City and Hampton formations in the subsurface of central Iowa where they have a combined thickness of about 140 feet. In central Iowa the Gilmore City limestone is notably an oolitic limestone as is the upper portion of the Chouteau formation in the Offutt Field well. The Hampton dolomite formation in central Iowa contains limestone in the upper portion, is generally very dense, crystalline, contains chert, and is oolitic at the base. The Hampton formation in central Iowa is about 102 feet thick. The combined interval of the Gilmore City and Hampton formations is about 140 feet and this interval termed the Chouteau in Nebraska is about 62 feet in the Offutt Field well.

MISSISSIPPIAN-DEVONIAN BOUNDARY PROBLEM

The Mississippian-Devonian boundary in the central states region of the United States has been the subject of much controversy between geologists who have studied the section. The shale which lies between the Mississippian carbonates and the Devonian carbonates is easily recognizable in well samples, on the outcrop, and on the electric log. Some authors have placed the entire shale section within the Devonian age and others have place the upper portion of the shale in Mississippian age with the remainder Devonian. Recent studies by K. J. Mueller published in 1956 using conodonts for correlation has placed the entire section with the Devonian age. In the eastern Nebraska area the shale below the Mississippian Chouteau formation which varies from 20 to 48 feet in thickness is part of the Mississippian Kinderhook group and is called the Hannibal shale. The Hannibal is normally sandy at the top, a greenish-gray shale, micaeous, and contains some impure dolomite. The Hannibal would correlate with the Maple Mill shale formation in central Iowa where the interval is 40 feet and has about the same lithology as in the Offutt Field well where the shale is about 78 feet thick. For regional correlation the shale section between the Mississippian carbonates and the Devonian carbonates has been called the Chattanooga shale and this term has widespread usage. The base of the Hannibal shale and top of the Sheffield shale, the latter being Devonian, is marked by a reddish oolitic layer of hematite which in eastern Nebraska is the boundary between the Mississippian and Devonian periods.

DEVONIAN SYSTEM

The Devonian period of time is represented in the subsurface throughout the Richfield anticlinal area by deposition of principally dolomite strata. Approximately 55 million years of Devonian time is recorded which as during the Mississippian period the midcontinental area was invaded by marine seas and deposited hundreds of feet of limestone and dolomite before withdrawal.

The upper part of the Devonian system is termed Chattanooga shale and is widely used in the petroleum industry to identify the shale overlying the Devonian carbonates. In Nebraska, the Devonian shale is called the Sheffield-Lime Creek formation and includes an interval approaching 250 feet in the deeper part of the Forest City basin. In central Iowa the Lime Creek portion is a limestone underlying the Maple Mill shale and the type section of the upper Mississippi Valley for the Lime Creek formation is shale and limestone.

Devonian shale is absent in the Richfield anticlinal area where the section is represented by dolomites. Devonian fossil life is marine with the period sometimes called the "Age of Fishes" when vertebrates first became prominent. Preservation of entire fossil fish skeletons is not common but their teeth, called conodents, are an important index fossil. Crinoids, blastoids, and cystoids of the echinoderm phylum are common fossils in Devonian rocks. Coelenterates, (corals), porifera, (sponges) and brachiapods were also common invertebrate animals in the Devonian period. Preserved in formations of Devonian age in eastern United States is the first evidence of large trees.

Devonian dolomite thins rapidly in a general northwestward direction over the Richfield anticline and the isopach for the Devonian-Silurian interval prepared for this report is almost exclusively truncation of Devonian dolomite. A discussion of the structural implications of the isopach map is presented in the section dealing with structural history. The west-east cross section prepared for this paper also shows the Devonian section thinning.

Lithologically, the Devonian carbonates are brown and tan dolomite with tan and pink chert. Some thin greenish shale layers are present to a minor degree and white tripolitic chert. The Devonian section reaches its thinnest interval in the Northern Natural Gas Company well #21, located in section 6, township 13 north, range 10 east, of Saunders County of about 36 feet. The highest structural well in the area, Northern Natural Gas Company well #16, located in section 15, township 13 north, range 10 east of Sarpy County has about 84 feet of Devonian dolomite. To the east, as shown in the cross section, the Northern Natural Gas Company well #1, located in section 23, township 13 north, range 11 east of Sarpy County contains 280 feet of Devonian dolomite. East along the cross section the #1 Urhammer well, located in section 23, township 13 north, range 12 east contains 415 feet of Devonian section. The last well in the cross section located on Offutt Field, section 11, township 13 north, range 13 east of Sarpy County contains 470 feet of Devonian dolomite. The upper section of the Devonian section is lost by truncation. In Butler and Polk Counties west of Saunders County the Devonian section becomes thicker than on the Richfield anticline.

The Devonian section in eastern Sarpy County and eastern Douglas County attains a maximum thickness of over 500 feet for the carbonate section alone. This thickness is similar to the Devonian carbonate section on the flanks of the Redfield Natural Gas Storage anticline near Redfield in central Iowa. A well drilled near Nebraska City in Otoe County, Nebraska just south of Cass County and east of the Nemaha range contains about 463 feet of Devonian dolomite and limestone. The type section where the Devonian outcrops in the upper Mississippi Valley of northeastern Iowa contains over 500 feet of carbonates and minor quantities of shale below the Sheffield shale. The Devonian carbonates in northeastern Iowa, central Iowa, and eastern Nebraska are thicker than are found in the central part of the Forest City basin where in Richardson County of southeastern Nebraska the Devonian carbonate section is about 200 feet thick.

In attempting to correlate the Devonian dolomite over the Richfield anticline where it thins rapidly west, it is believed that the lowest formation, termed the Wapsipinicon, persists being reduced to about 40 feet in eastern Saunders County. The Wapsipinicon dolomite has a thickness of about 125 feet in the central Forest City basin of Nebraska and thickens to 193 feet at Nebraska City in Otoe County, Nebraska. In the Offutt Field well of eastern Sarpy County and wells drilled in Omaha, Nebraska the Wapsipinicon dolomite is about 220 feet thick. In central Iowa on the flanks of the Redfield Natural Gas Storage anticline, the Wapsipinicon is about 80 feet thick and in the type section area where the Wapsipinicon outcrops of northeastern Iowa the formation is between 95 and 140 feet in thickness. The Wapsipinicon dolomite, which is at the base of the Devonian, normally is sand embedded or contains a thin fine sandstone section at the base. This sandy zone is the principal lithologic feature which separates the Devonian dolomite from the underlying Silurian dolomite, and was found in most of the Northern Natural Gas Company wells and other deep wells in the Richfield anticlinal area. The color of the Wapsipinicon varies from light brown to brown with some gray, contains white tripolitic chert, is crystalline, vuggy, and has fair porosity and permeability.

Above the Wapsipinicon formation is normally found the Independence shale which is not easily identified in the subsurface and is only a few feet thick. In Richardson County, Nebraska the shale is dolomitic and about 10 feet thick. At Nebraska City, in Otoe County, Nebraska, the Independence shale is about 30 feet thick with a 10 foot layer of dolomite separating two shale beds. The shale is a greenish-gray color. Independence shale is not found in the Offutt Field well but may be located in the cores taken from the second well drilled in 1961. No shale correlating with the Independence shale was recorded in the section at the Redfield Natural Gas Storage anticline in central Iowa. In the type section on the outcrop of northeastern Iowa, the Independence shale is from 7 to 20 feet thick.

Next above the Independence shale interval is the Cedar Valley formation which is entirely absent over the high parts of the Richfield anticline. In central Iowa on the deep flanks of the Redfield Natural Gas Storage anticline, the Cedar Valley formation is about 426 feet thick and thins to about 300 feet on top of the Redfield structure. In the type section on the outcrop of northeastern Iowa, the Cedar Valley formation is from 90 to 150 feet thick. At Offutt Field, the Shellrock-Cedar Valley interval combined is about 240 feet thick and at Nebraska City, the Shellrock-Cedar Valley interval is also about 240 feet thick. The Shellrock-Cedar Valley interval thins to about 70 feet in Richardson County in the Forest City basin. At Omaha, Nebraska the Shellrock-Cedar Valley section contains about 240 feet. The Shellrock formation in the outcrop area of northeastern Iowa varies from 4 to 66 feet and is not subdivided as a separate formation in Nebraska. Shellrock-Cedar Valley formation in Nebraska is primarily dolomite, brown to gray, dense, crystalline, and contains minor quantities of chert. In the upper part the formation is limestone, light to medium gray, crystalline, lithographic in part, and contains crinoid fragments.

In the interval above the Shellrock-Cedar Velley formation of Nebraska, the Lime Creek formation is combined with the Sheffield formation and is almost completely shale. This interval is commonly called Chattanooga shale. In the Richardson County area of southeastern Nebraska the Sheffield-Lime Creek formation reaches a maximum thickness of about 250 feet with an average of about 220 feet. The Sheffield-Lime Creek formation in Nebraska is a light green to dark gray color, micaeous, and contains dolomitic and limy zones. The upper part where it is thickest in Richardson County is a reddish shale with hematitic oolites of about 10 feet and is called the Boice shale in Nebraska. According to interpretations by the Nebraska Geological Survey, the reddish shale zone with hematitic oolites is the time boundary between the Devonian and Mississippian periods.

In central Iowa, over the Redfield Natural Gas Storage anticline, the Lime Creek formation is predominantly a pure limestone consistantly about 110 feet in thickness. The limestone there is very light brown to white, dense, medium crystalline, contains styolites and chert that is gray speckled black. The Lime Creek formation on the outcrop in the type section area of northeastern Iowa varies from 165 to 190 feet in thickness and is limestone with a 30 to 45 foot shale layer in the middle.

The formation term Hunton is commonly applied by petroleum operators and geologists for the carbonate section of the Devonian system and has wide usage in Nebraska, Kansas and Oklahoma. Petroleum occurs in the (Hunton) in Richardson County of southeastern Nebraska where oil was first discovered in Nebraska in 1938. The Falls City Oil Field located near Falls City, Nebraska in Richardson County has produced nearly 5 million barrels of oil from the (Hunton) since 1938 over an area of 1,400 acres with production in 1961 totaling about 30,000 barrels. The Barada Oil Field also in Richardson County was discovered in 1941 and has produced 2,900,000 barrels of oil from 2,200 acres, with the 1961 production being about 20,000 barrels. Recovery of oil per acre from the Falls City Oil Field has been about 3,500 barrels per acre at an approximate depth to production of about 2,100 feet. Recovery of oil from the Barada Oil Field per acre has been about 1,300 barrels per acre. Porosity and permeability conditions in the Barada Oil Field are the same as in the Falls City Field. The structure has an equivalent amount of closure and about the same total thickness of oil saturation. Recovery of oil from the Barada Oil Field should have been about 7,000,000 barrels, but independent operators who developed the large part of the field used 5 acre well spacings, excessive acidizing, and overproduced the wells so that connate water in large quantities entered the wells early in the life of the wells and reduced the long run productive capacity of the field. The Dawson Oil Field in Richardson County also produces oil from the (Hunton) and from the Ordovician Galena (Viola) dolomite and St. Peter (Wilcox) sandstone. Separate production records are not available for the (Hunton) alone in the field but the total production since discovery in 1942 from 700 acres has been about 1,200,000 barrels of oil with 1961 production totaling about 130,000 barrels.

In the Richfield anticlinal area occasional minor stains of petroleum residue are found in the Devonian dolomite. Cable tool wells penetrating the Devonian dolomite on the eastern flank have encountered artesian flows of fresh water from the section. Several commercial firms in Omaha, Nebraska have deep water wells which use the Devonian dolomite as part of a source of water which has a dissolved mineral content of about 1,500 parts per million.

SILURIAN SYSTEM

The Silurian system is represented in the subsurface on the Richfield anticline by a dolomite which has been correlated with the Niagaran series. About 40 million years of time is placed within the Silurian period. The midcontinental area was invaded by deep seas which deposited several hundreds of feet of carbonates which are dolomitic in Nebraska. Richardson County in southeastern Nebraska contains the greatest interval of Silurian sediments with about 425 feet. The type section outcrop of Silurian formations in northeastern Iowa contains the Niagaran and Alexandrian series, but in Nebraska the entire Silurian section is classed as Niagaran since fossil content correlates with Niagaran age fossils in the Niagaran series of Niagara County, New York. No separation into groups or formations is made for the Niagaran in Nebraska.

In the Richfield anticlinal area the Niagaran series ranges from 130 to about 190 feet in thickness with a slight thinning trend west and north. An erosional unconformity exists between the Niagaran and the overlying Wapsipinicon formation of Devonian age expressed by a basal sand or sand embedded dolomite. From a cored well in Cass County, Nebraska by Amerada Petroleum Company coelenterates classed as coral have been identified as <u>Favosites</u> <u>niagarensis</u> and <u>Halysites</u> <u>catenulatus</u>. These fossils are broken in rotary samples taken from the wells drilled on the Richfield anticline. The Niagaran dolomite in the Richfield anticlinal area varies from gray to light brown, gray being the most predominent color. Tripolitic chert is common in the section and some pyrite crystals are embedded in the dolomite.

The Silurian section is often classed collectively with the Devonian formations below the Chattanooga shale as (Hunton) in petroleum fields by oil operators in the midcontinental area. The (Hunton) has been oil productive in Oklahoma and southern Kansas. Near Omaha, Nebraska some of the deep cable tool wells encountered fresh water in the Silurian section and water from the Silurian contributes to the total water supply in many industrial deep wells in Omaha, Nebraska. The dissolved mineral content is about the same as for the Devonian dolomite.

ORDOVICIAN SYSTEM

Over 500 feet of upper Ordovician sediments are found in the subsurface on the Richfield anticline ranging from the Maquoketa shale formation to the St. Peter sandstone formation. On the deep east flank of the Nemaha range, to the north, and in central Saunders County pre-St. Peter Ordovician formations occur. The U. S. Geological Survey map "Map of Nebraska Showing Areal Distribution of Pre-Pennsylvanian Rocks, Anticlines, and Basins, Oil and Gas Fields, Pipelines, and Unsuccessful Test Wells", OM 198, 1958, by E. C. Reed, R. F. Svoboda, G. E. Prichard, and Jeannette Fox shows the areal extent of St. Peter sandstone where it occurs overlying Precambrian rocks. About 80 million years is assigned to the Ordovician period. During Ordovician time the most widespread invasion of seas covered most of North America and deposited several thousands of feet of sediments in many areas. Faunal assemblage in the Ordovician includes a wide variety of brachiapods, coelenterates, (corals), echinoderms, (crinoids, blastoids, and asteroids), and mollusks, (pelecypods, gastropods, and cephalopods).

CINCINNATTIAN SERIES

In the Richfield anticlinal area the series is represented only by the Richmond group.

<u>RICHMOND GROUP</u>

In the Richfield anticlinal area the Richmond group contains only the Maquoketa formation.

Maquoketa Formation

The Maquoketa formation is present over the Richfield anticlinal area and throughout the midcontinental area. The type section on the outcrop is near Maquoketa, Iowa in the upper Mississippi Valley. In Oklahoma the formation is called the Sylvan shale. At many places in the subsurface of the Forest City basin the Maquoketa shale is marked by a reddish shale containing oolitic hematite. Oolitic red shale is found in the subsurface at the top of the Maquoketa formation on the Redfield Natural Gas Storage anticline in central Iowa.

In the Richfield anticlinal area the Maquoketa formation is a green shale which averages between 45 and 60 feet in thickness over the area. East of the anticlinal area the Offutt Field well contains 110 feet of shale with the upper part being interbedded dolomite and shale. West of the Richfield anticlinal area in the Northern Natural Gas Company wells #19 and #21, located in section 5, township 13 north, range 10 east, and in section 6, township 13 north, range 10 east respectively, the Maquoketa formation is about 95 feet thick. The resistivity curve on the electric log shows low resistivities normally found in shales for the Maquoketa formation and the boundaries of the Maquoketa shale formation is easily established.

MOHAWKIAN SERIES

The Mohawkian series is represented in the subsurface of the Richfield anticline by the Trenton and Black River groups with about 400 feet of section. Mohawkian series rocks outcrop in northeastern Iowa.

TRENTON GROUP

The Trenton group contains the Galena, (Stewartville-Prosser), and Decorah formations in Nebraska contains an interval averaging about 350 feet.

Galena Formation

The Galena formation is called the Stewartville-Prosser undivided formation in Nebraska and in this report the term Galena will be used. In the Richfield anticlinal area the Galena formation averages between 290 and 325 feet in total thickness except for one well in Saunders County, the Northern Natural Gas Company well #21 which contained an interval of 256 feet. In the Omaha, Nebraska area the deep wells have an average thickness of about 370 feet for the Galena formation and in central Iowa on the Redfield Natural Gas Storage anticline the Galena formation is about 210 feet thick. In Richardson County of southeastern Nebraska, the Galena formation is about 250 feet thick. The cored drilled well by Amerada Petroleum Company located in southern Cass County on the west flank of the Nemaha range contains about 233 feet of Galena dolomite.

Galena formation dolomites are normally brown to gray in color, crystalline, vuggy, porous, containing crinoid fragments, and white tripolitic chert. In the core drilled well of southern Cass County bryozoan fossils identified as <u>Escharopora</u> were present. In the Richfield anticlinal area florescence under ultra-violet light was common in the Galena section with a yellow-orange color. Some minor oil staining and petroleum residue material were found in the Galena dolomite, pyrite crystals were common, and gray and white chert was very common in the lower part. Some fresh water is produced from the Galena section for industrial use in Omaha, Nebraska. Galena dolomite exhibits good porosity and fair permeability on the Richfield anticline.

Galena dolomite, called Viola in Kansas and Oklahoma, is a prolific oil producer in Kansas and Oklahoma in many places. The only field in Nebraska that produces oil from the Galena formation is the Dawson Oil Field located in Richardson County. The Falls City Oil Field and Barada Oil Field which produced large quantities of oil from the Devonian dolomite have only minor shows of oil in the Galena, (Viola) section on top of their structures.

Decorah Formation

The Decorah formation consists of the Ion shale and Guttenberg limestone members which are classified as formations by the Nebraska Geological Survey. A total of 40 feet is contained within the Decorah formation

Ion Shale

Ion shale underlies the Galena dolomite formation and consists of about 25 feet of dark green and gray shale with a few thin dolomitic seams. Faunal assemblage includes brachiapods, Dalmanella, and arthropods, trilobites, Isotelus. Electric log resistivities for the shale are low and no permeability is shown on the microlog. A portion of the Ion shale was cored in the Northern Natural Gas Company well #1, located in section 23, township 13 north, range 11 east, and the entire section was cored in the Amerada Petroleum Company well in southern Cass County.

Guttenberg Limestone

The Guttenberg limestone is brown in color, dense, and contains shaly material throughout. No permeability is present in sample analysis and the microlog confirms the sample study. About 15 feet of limestone is present on the Richfield anticline.

BLACK RIVER GROUP

The Black River group consists of the Platteville formation which is further subdivided into 3 members. The group averages about 80 feet in thickness over the Richfield anticline.

Platteville Formation

The Platteville formation in the Richfield anticlinal area contains the Spechts Ferry shale, McGregor limestone, and Glenwood shale. About 80 feet is the average for the Platteville formation.

Spechts Ferry Shale

Spechts Ferry shale varies in thickness from 20 to 25 feet and contains a dark brownish colored dense limestone about 5 feet in thickness in the upper portion of the shale. The limestone exhibits no porosity or permeability either in the core or on the microlog as it is very shaly. The shales are dark green to gray in color having a waxy appearance. Faunal assemblage includes bryozoa, Rhinidictya, Homotrypa, Monticulopora, and brachiapods, Rhynchotrema.

McGregor-Pecatonia Limestone

McGregor-Pecatonia limestone is brownish colored, dense, fine grained, and shaly limestone with about 7 feet of thickness. The microlog shows no permeability in the limestone. Faunal assemblage includes brachiapods, Rafinesquina and Trematis.

Glenwood Shale

The Glenwood shale in the Richfield anticlinal area is about 45 feet thick and is dark gray to dark green in color having a waxy appearance. Portions of the Glenwood shale were cored in the Northern Natural Gas Company wells #1 and #13 in Sarpy County and #21 in Saunders County. Some thin shaly limestone seams are present in the shale but the electric log and microlog plus sample analysis indicates no permeability in the Glenwood shale. Fossil assemblage includes brachiapods, Rafinesquina, Dalmanella, and Pionodema subadquata.

The entire section below the Galena formation is commonly referred to as the Simpson shale in Kansas and Oklahoma. The Decorah-Platteville section on the Richfield anticline correlates with the Decorah-Platteville section on the Redfield Natural Gas Storage anticline in central Iowa where to total interval is about 60 feet compared to the 115-125 feet on the Richfield anticline. The Decorah-Platteville section forms the caprock to contain high pressure natural gas in the St. Peter sandstone for the Redfield Natural Gas Storage Field in central Iowa. The sandstone contains more than 45 billion cubic feet of natural gas.

CHAZYAN SERIES

The Chazyan series in the Richfield anticlinal area contains one group and one formation for a total of about 50 feet.

ST. PETER GROUP

Only one formation, the St. Peter sandstone, represents the group.

St. Peter Formation

The St. Peter sandstone is widespread throughout the midcontinental area and outcrops in northeastern Iowa. Normally, in the subsurface the St. Peter sandstone averages from 25 to 50 feet in Iowa, Nebraska, Missouri, Kansas, and Oklahoma and retains its basic lithologic characteristics of a fine rounded loosely cemented sandstone. In Kansas and Oklahoma, the St. Peter sandstone is called Wilcox and is oil productive. The only oil production from the St. Peter sandstone in Nebraska is in the Dawson Oil Field of Richardson County. In Omaha, Nebraska the St. Peter sandstone supplies fresh water to several industrial companies and early wells had artesian flows that exceeded 250 gallons per minute. The Union Pacific Lane Station well in section 27, township 15 north, range 11 east, of Douglas County had minor quantities of black petroleum residue in the St. Peter sandstone.

The dissolved mineral content of water from the St. Peter formation in Omaha, Nebraska is a total of about 1,800 parts per million which is similar to the dissolved mineral content found in water from the St. Peter sandstone on the Redfield Natural Gas Storage anticline. Dissolved sulfates form the bulk of mineral content in the water with carbonates and chlorides in very small quantities. Bottom hole hydrostatic pressure at Redfield, Iowa was slightly less than 1000 pounds per square inch. The hydrostatic bottom hole pressure as calculated from a drill stem test on the Northern Natural Gas Company well #11 was 380 pounds per square inch with a recovery of water totaling 845 feet. The drill stem test tool was plugged during the test and a general calculation based on cable tool wells which filled with water when drilling into the St. Peter sandstone would probably give the St. Peter hydrostatic pressure closer to 600 pounds per square inch.

In the five wells which drilled completely through the St. Peter sandstone on the Richfield anticline the thickness varied from 47 to 55 feet in thickness with 50 as an average. The lower few feet of St. Peter sandstone is reworked Precambrian material and shale denoting the unconformity over the Precambrian surface. Part or all of the St. Peter sandstone was cored in the Northern Natural Gas Company wells #1, #11, #13, and #21 in Sarpy and Saunders Counties. The top five feet of sandstone is shaly and brownish in color with a strong sulfur smell in the #11 well. From the #1 Northern Natural Gas Company well the core was submitted to a plug type permeability and porosity analysis, and the porosity values reached a maximum of about 31.9 per cent and the vertical permeabilities a maximum of 2,410 millidarcies. Average porosity for 48 feet of sand was between 20 and 25 per cent and the permeability average several hundred millidarcies. The lower St. Peter section immediately overlying the Precambrian granite has sand and conglomerate, shaly, contains brachiapods, and brachiapod fragments. Weathered hornblende, feldspar, quartz, and mica are present in the lower part of the St. Peter sandstone.

The size ranges of sandstone grains in the St. Peter sandstone are concentrated in the 1/2 to 1/8 millimeter diametric range with about 80 per cent of the sand grains in this size. St. Peter sandstone is well sorted having a coefficient of sorting averaging about 1.25 with normal sorting averaging 3.0 and poor sorting above 3.0. Studies of the coefficient of skewness and effective size plus coefficient of sorting for the St. Peter sandstone indicates that the formation not only has high capacity for water or natural gas but has excellent horizontal and vertical transmission qualities over a wide area. In the Redfield Natural Gas Storage Field, the natural gas injected into the St. Peter formation quickly disperses laterally and uniformly throughout the sand replacing the connate water and forming a horizontal gas-water contact. No lenses of water are trapped above the gas-water contact because of the uniformity of vertical permeability. Hydrate formation on withdrawal from the St. Peter formation was at first high but through successive cycles of injection and withdrawal the water has been removed from the sandstone above the gas-water contact.

Mineralogically the St. Peter sandstone has quartz by volume of 99 per cent with the balance heavy minerals. In the remaining 1 per cent pyrite is very abundant, zircon moderately abundant, tourmaline moderately abundant, and traces of garnet and magnetite. Under petrographic analysis the St. Peter quartz grains have a part which shows evidence of secondary growth rings about the primary grain. Overall sizes of grains less than 1/16 millimeter in diameter which are silt and clay account for about 5 per cent of the total sample measured. No carbonate material was found in the sandstone.

PRECAMBRIAN

Beneath the St. Peter sandstone over the Richfield anticline lies the Precambrian surface which consists of a granite type igneous rock containing quartz, feldspar, minor amounts of hornblende, mica, and a few other basic minerals. In the Northern Natural Gas Company wells #1, #11, and #21 which penetrated the Precambrian surface, granite type rock was logged in the few feet penetrated. The granite drilled extremely hard and is considered very dense and impermeable.

In the #1 Urhammer and #1 Seibold wells located in Sarpy County on the south and east flank of the Richfield anticline, a quartzite type of rock was logged as the Precambrian underlying the St. Peter sandstone. The quartzite is gray and red corresponding to what is called Sioux quartzite. The #1 Urhammer and #1 Seibold wells were both drilled with cable tools and the samples recovered were of poor quality. The Amerada Petroleum Company well in southern Cass County which cored the Precambrian for about 260 feet recovered a section which was entirely quartzite. In the #1 Rahn well located on the northeast flank of the Nemaha range in Sarpy County drilled about 40 feet of quartzite with cable tools. A rotary test well in Saunders County, the #1 Koutney, located in section 11, township 15 north, range 7 east, northwest of the Richfield anticline encountered soft Precambrian rock at 1670 feet and continued to drill to 2,700 feet without encountering either quartzite or granite. The section contained soft silt and arkosic material for about 1,000 feet. Another well drilled in Douglas County north and west of the Richfield anticline, located in section 25, township 16 north, range 9 east drilled with rotary tools to 1960 feet where Precambrian material was logged and continued on to 2,347 feet or about 400 feet without hard drilling that is normal for quartzite and granite. The material logged in the well was soft silts and arkosic material. A well at Wagner, South Dakota drilled 3,500 feet of quartzite without encountering granite or any igneous rock. On the high part of the Table Rock Arch in southeastern Nebraska, granite is drilled below a thin section of sedimentary rocks at a depth of 500 feet. Wells in the central Nebraska basin have drilled Precambrian rocks which basic intrusive type igneous rocks.

The relationships of the Precambrian rocks drilled in Nebraska and surrounding states is not fully understood but granite seems to underlie the high parts of the Nemaha range, quartzite on the flanks of the Nemaha range and basic igneous intrusives at irregular points.

On the flanks of the Nemaha range in eastern Sarpy County, eastern Douglas County, and eastern Cass County, Pre-St. Peter Ordovician and Cambrian sedimentary rocks are present which are truncated over the Nemaha range and disappear entirely on the Richfield anticline. The #1 Rahn well located in northeastern Sarpy County has 240 feet of Cambro-Ordovician dolomites and sandstones. The Offutt Field well farther east in Sarpy County has about 230 feet of Cambro-Ordovician sediments. The wedging out of the Cambo-Ordovician section against the Nemaha range is shown in the cross section prepared for this report. In Omaha, Nebraska deep wells have logged about 220 feet of Cambro-Ordovician section above the Precambrian surface and beneath the St. Peter sandstone. North of the Richfield anticline at the Union Pacific Lane Station well located in section 27, township 15 north, range 11 east about 350 feet of Cambro-Ordovician strata lie beneath the St. Peter sandstone. West of the Richfield anticline in Saunders County the #1 Koutney, located in section 11, township 15 north, range 7 east, has about 70 feet of Cambro-Ordovician sediments beneath the St. Peter formation. The #1 Johnson well located in section 33, township 13 north, range 7 east, has about 90 feet of Cambro-Ordovician strata under the St. Peter formation. Cambro-Ordovician sediments thicken westward into the central Nebraska basin where the maximum pre-St. Peter Cambro-Ordovician section totals about 500 feet. This section has been called the Arbuckle among oil operators in Nebraska, Kansas, and Oklahoma.

STRUCTURAL HISTORY

The Richfield anticline is located within an area of the North American continent known as the Central Stable Region as defined by A. J. Eardley in his book "Structural Geology of North America", 1951. The Central Stable Region generally includes the upper Mississippi, Missouri, and Ohio Valley area. Although the Central Stable Region was subjected to widespread marine invasion, uplift, and downwarping throughout known geologic time, the area was not subjected to diastrophism on the order that is found in the Rocky Mountain and Pacific coastal area or in the Appalachian Mountaina area, or along the Gulf Coast. In western United States and in eastern United States orogenic belts of structural development during geologic time involved tremendous volcanic activity, geosynclinal development accompanied by tens of tens of thousands of feet of sedimentary deposition, and geanticlinal uplift in the tens of thousands of vertical uplift. Major faulting, overthrust, overturn, and metamorphism are of much greater proportions in western United States and eastern United States than found in the Central Stable Region.

Structural geology and history of the Richfield anticline is based on the developments of the sedimentary section since Cambrin time or about the last 500 million years. Precambrian time which involves 3 to 4 billion years involves a complex section of metamorphic rock and igneous rocks in the subsurface of which little is known. The sedimentary rocks since Cambrian time, through lithologic and fossil studies, lend themselves to presenting the structural history of the Richfield anticline.

During Cambrian time, the Richfield anticline and the Nemaha range did not exist. The area along with the entire middle North American continent was inundated by marine seas that deposited sandstones, carbonates, and shales on the Precambrian surface. Less than 200 feet of upper Cambrian sediments are present in the subsurface of eastern Nebraska which indicates that during most of Cambrian time the Richfield area was a lowland plain above sea level, and was submerged for a relatively short time during the latter Cambrian period. Cambrian sediments thicken eastward and southeast into Iowa and Missouri, and thin to the west and northwest in Nebraska.

There is no marked unconformity between Cambrian sediments and overlying Ordovician strata with Nebraska continuing to be submerged during Ordovician time. During Ordovician time is when the Nemaha range first began its structural development. Prior to the deposition of St. Peter sandstone, the Nemaha range was raised above sea level several hundreds of feet and the Ordovician sediments and Cambrian sediments were eroded from the Nemaha range exposing granite and metamorphic rock. On the flanks of the Nemaha range the Pre-St. Peter formations were truncated. The principal area of uplift is shown on the U. S. Geological Survey map "Map of Nebraska Showing Areal Distribution of Pre-Pennsylvanian Rocks, Anticlines, and Basins, Oil and Gas Fields, Pipelines, and Unsuccessful Test Wells" OM 198, by E. C. Reed, R. F. Svoboda, G. E. Prichard and Jeannette Fox, 1958. The width of the area from which Pre-St. Peter sediments were removed from the Nemaha range is about 25 miles in Sarpy and Saunders Counties. This erosional area terminates in western Douglas and northeastern Saunders Counties.

Prior to or during St. Peter time the eastern Nebraska area including the Nemaha area was submerged in shallow marine seas that deposited the St. Peter sandstone over a wide area in the midcontinental region. The source area for the St. Peter sands appears to be from the north and east since the sandstone is thicker in Minnesota and northeastern Iowa, and the St. Peter sands contain a more varied suite of heavy minerals in those areas. The environment for the St. Peter sandstone deposition was one of shallow water continental shelf like area. Some question has been raised by the frosted appearance of the sand grains which might indicate continental environment in which the surface of the sand grains were pitted by wind action. The roundness of the grains and secondary growth rings supports water transportation and deposition since the growth rings of silica were soluable silica from fluid solution.

Development of the Decorah-Platteville shales and thin shaly limestones over the St. Peter sandstone indicates and period of marine shallow seas on a level sea floor with no structural changes along the Nemaha range. Galena or Stewartville-Prosser dolomites would require a deeper sea environment than the Decorah-Platteville section and some general subsidence is involved. During the formatiion of Maquoketa shale the marine environment was probably of a shallower sea type similar to the Decorah-Platteville time. In some places the Maquoketa formation at the top is marked by a red hematitic oolite and red shale that suggests a humid surface environment where weathering and oxidating of the shale took place. There is a suggestion that the Maquoketa formation thins over the Richfield anticline and uplift area of the Nemaha range which might have been generated by minor uplift along the axis of the Nemaha range. No marked structural disturbances are evidenced at the close of Ordovician time in the area.

Silurian time continued with invasion of the seas and deposition of dolomites in the Richfield anticlinal area that was submerged. About 150 feet of Silurian dolomite cover the Richfield anticlinal area with a general slight thinning to the north and west. Silurian dolomites thicken southeast and are over 400 feet thick in Richardson County, Nebraska.

The boundary between the Silurian and Devonian is marked by a local erosional unconformity which is expressed as a sand embedded dolomite at the base of the Devonian section. Invasion of seas continued throughout Devonian time in the Richfield anticlinal area. During Devonian time the Richfield began to develop as a positive feature unrelated to the older Nemaha range. The disappearance of the Shellrock-Cedar Valley interval and the upper part of the Wapsipinicon formations on the crest of the Richfield anticline is the result of local anticlinal development, in addition to regional thinning toward the northwest. The Shellrock-Cedar Valley and Wapsipinicon formations are present on the ancestral Nemaha range in central Sarpy County. Approximately 80 feet of Devonian dolomite is present in the highest well on the structure of the Richfield anticline in the Northern Natural Gas Company well #16 whereas 280 and 415 feet of Devonian dolomite are found in the Northern Natural Gas Company well #1 and the #1 Urhammer well on the east side of the Richfield structure. Devonian dolomite continues to thin more gradually from the Northern Natural Gas Company well #16 to wells #19 and #21 in Saunders County for a maximum dolomite interval of about 40 feet. The cross section presented with this paper shows the Devonian section thinning in the wells mentioned. A thicker Devonian section occurs to the west of the Richfield structure in the central Nebraska basin. Local folding on the Richfield anticline caused the formations older than Devonian and including the Precambrian surface to be raised at leat 300 feet above the surrounding terrain. The movement was gradual during Devonian time with a synclinal area developing west of the Northern Natural Gas Company well #21 in Saunders County which although exhibiting a somewhat thinner dolomite section than the high well #16 in Sarpy County is about 100 feet structurally lower currently on Silurian and older formations.

A recent well completed in April 1962, the #1 Radenslaben, located in section 28, township 13 north, range 8 east, of Saunders County is about 500 feet structurally lower on the Precambrian surface than Northern Natural Gas Company well #21 in Saunders County that is some ten miles east of the #1 Radenslaben. The #1 Radenslaben proves a synclinal area is present in eastern Saunders County not revealed by the "Precambrian Structure Map of Nebraska" published by the Nebraska Geological Survey, by E. C. Reed and R. F. Svoboda, 1957, revised by M. P. Carlson, 1961. The #1 Johnson well in section 33, township 13 north, range 7 east, of central Saunders County is about 300 feet higher on the Precambrian surface than the #1 Radenslaben which is about five miles east. Another well in north central Saunders County, the #1 Koutney, located in section 11, township 15 north, range 7 east, is also higher on the Precambrian surface at least 200 feet.

During Devoning time a broad arch called the Continental Arch, locally in Nebraska the Siouxana Arch, extended from northeastern Colorado through western and central Nebraska to eastern South Dakota and on into Minnesota and Canada. The Continental Arch together with the Cambridge Arch of western Nebraska and Kansas, and Ellis Arch of Kansas were positive areas of relief above sea level with pre-Devonian sediments being removed by erosion and the Precambrian surface exposed. The Devonian thinning in the Richfield anticlinal area and west may have been an extended arm or shelf from the Continental Arch.

To summarize Devonian developments, the Richfield anticline developed most of its structural form during Devonian time something like a "bump on a log" with respect to the Nemaha range, and was obscured by geological events during Mississippian and Pennsylvanian time plus the sedimentation during the Mesozoic and Cenozoic eras. The crest of the Richfield anticline is located about 12 miles west and slightly north of the crest on the Nemaha range which developed during Mississippian and Pennsylvanian time. The Richfield anticline differs from the Redfield Natural Gas Storage anticline in central Iowa and the oil field structures in Richardson County of southeastern Nebraska in that it is not revealed by surface or shallow formations of Mississippian or Pennsylvanian time. The Redfield Natural Gas Storage anticline is similar to the Richfield anticline in that the Redfield structure thinning of the Cedar Valley formation, Devonian age, over the structure results in increased closure on the older formations than is present in formations of Mississippian age. In the known oil field structures of Richardson County, Nebraska the surface and near surface Pennsylvanian formations accurately reveal the location of Devonian and Ordovician formations which have produced oil. Closure on the Pennsylvanian formations over the oil fields in Richardson County is less than half that developed on deeper lying formations.

During Mississippian time the entire Richfield-Nemaha anticlinal area subsided and marine limestones, dolomites, and shales were deposited over a wide area in Nebraska, Iowa, Missouri, and Kansas. The sediments deposited on the Richfield structure probably totaled over 300 feet but the structure retained its superior structural position with respect to the Nemaha range.

At the close of Mississippian time and during early Pennsylvanian time major orogenic movement occurred along the Nemaha range from Oklahoma through eastern Kansas and in southeastern Nebraska including the Richfield area. The Nemaha range was lifted high above sea level and all Mississippian age formations were removed and truncated on the flanks. In southeastern Nebraska on the portion of the Nemaha range called the Table Rock arch all sedimentary formations were eroded and removed exposing Precambrian granite. Thrust faulting and normal faulting on the east flank of the Table Rock arch caused a displacement of nearly 1,000 feet on the Precambrian surface and the fault line can be traced on the surface. The fault line has been mapped by the Nebraska Geological Survey on exposed Permian and Pennsylvanian formations in southeastern Nebraska. The uplife of the Table Rock arch and its erosion contributed materially to the sedimentation of sands and shales in the Forest City basin during Cherokee time. Along the Nemaha range the elevations above sea level from the surrounding Pennsylvanian seas was several thousand feet. In the Table Rock arch area of southeastern Nebraska and extending into northeastern Kansas for many miles, the Precambrian surface retains its high structural postion being over 500 feet above sea level. On the Richfield anticline the Precambrian surface is slightly less than mean sea level with depths to the Precambrian surface between 1100 and 1200 feet at the crest. In southern Kansas and Oklahoma on the Nemaha range, the Devonian and Ordovician age rocks were not removed from the crest during uplift and have been productive of oil in local anticlines created along the axis of the Nemaha range.

North of the Table Rock arch along the Nemaha range shallow seas during Marmaton time covered the area with shales and thin limestones. Marmaton shales and thin limestones average about 140 feet on the Richfield anticline and increase in thickness on the flanks which indicates that the northern end of the Nemaha range continued minor uplift during Marmaton time.

Throughout the period of Bronson-Kansas City-Lansing time the Nemaha range was again submerged including the Table Rock Arch area. A series of cylical deposits of limestones and shales covered the Richfield anticline with over 200 feet of sediments. Sedimentation continued through the balance of Pennsylvanian time depositing formations of the Pedee, Douglas, Shawnee and Wabaunsee groups. Upper Pennsylvanian and Permian rocks were entirely removed by erosion on the Richfield anticline coupled with broad regional uplift on the Nemaha range. The remaining Pennsylvanian formations are truncated above the Marmaton group.

Permian age sediments that were deposited over the Richfield anticlinal are entirely removed by erosion and broad uplift during Triassic and Jurassic time. The entire midcontinental area became a shallow plain area during Triassic and Jurassic time. In Cretaceous time the marine seas covered the Rocky Mountains area and most of Nebraska. Eastern Nebraska and western Iowa received sediments represented by the Dakota group. At the close of Cretaceous time, a vast orogenic uplift occurred which created the Rocky Mountains and Black Hills of South Dakota in their present location. The entire continent of North America was epirogenically uplifted during the Cenozoic era to generally its present land position. Thick continental Tertiary sands and gravels, and clays eroded from the Rocky Mountain area were deposited in central and western Nebraska but they did not extend to eastern Nebraska and the Richfield anticlinal area. The Richfield anticlinal area was of low plains relief being eroded by west-east Tertiary stream channels. During the Pleistocene the Richfield anticlinal area was covered by glacial drift and loess deposits with no structural movement occurring.

The structural history of the Richfield anticline is somewhat complicated but in general is focused on four main periods of time. Structural movement and uplift first occurred prior to deposition of the St. Peter sandstone. The second structural movement occurred during Devonian time which created the Richfield anticline as a separate feature from the Nemaha range and retained its superior position even though buried by sediments of succeeding periods. Pronounced uplift occurred during early Pennsylvanian time along the entire Nemaha range including the Richfield structure. In Cretaceous time some subsidence is recorded and broad low uplift of the entire midcontinental area during Cenozoic time with no local folding along the Nemaha range.

The present subsurface conditions of the Richfield anticline are shown on the structure maps, isopach map, cross section, and geologic columnar chart. A structural map for the St. Peter sandstone would be very similar to the Galena dolomite structure map.

CONCLUSIONS

The Richfield anticline is an arcuate domal type subsurface feature developed in Silurian and older age strata including the Precambrian surface. The approximate position of the crest of the Richfield anticline is about two and one half miles southwest of Gretna, Nebraska. Total closure on the Richfield anticline is of the order of 300 feet with 50 feet of closure contained with an area of about 8 square miles. There is no reversal of dip or spill point on the structure until a area of central and eastern Cass County is involved.

In Pennsylvanian strata the Richfield anticline is exhibited only as western regional dip off the flank of what is also called the Richfield anticline in central and eastern Sarpy County. The lateral shift of structure with depth is created to a large extent by thinning of Devonian strata plus local anticlinal development during Devonian time. About 12 miles separates the crest of the Richfield anticlines in different age formations.

The Northern Natural Gas Company #16 well, located in section 15, township 13 north, range 10 east, of Sarpy County on the Wainright farm is the highest well on the deep Richfield anticline. Additional structural closure of the order of 10 to 20 feet could probably be obtained since the #16 well was located on a broad regional basis and it would be only coincidental that the well is absolutely the highest point on structure.

Stratigraphically, Precambrian granite forms the "basement" rock under the sedimentary section on the Richfield anticline and is hard, dense, and impervious. The St. Peter sandstone overlies the Precambrian granite and averages about 50 feet in thickness. The sandstone has excellent porosity and permeability averaging 20 to 25 porosity for about 48 feet and severalhundred millidarcies vertical and horizontally for the 48 feet. The sandstone is filled with fresh water having an estimated hydrostatic pressure of about 600 pounds per square inch. Dissolved mineral content in the fresh water is about 1,800 parts per million with the bulk being sulfates and the amount of sodium chloride very small. Depth to the top of the St. Peter sandstone on the crest of the Richfield anticline is about 1,050 feet in the Platte River valley.

Overlying the St. Peter sandstone are the Decorah-Platteville shales and thin limestones which are dense, impermeable, and average about 120 feet in thickness. No evidence of jointing, vertical fracturing, or slickensides was present in cores taken from the Decorah-Platteville section.

On top of the Decorah-Platteville shales is the Galena (Viola) dolomite which averages in thickness between 290 and 310 feet. The dolomite exhibits porosity and permeability consisting gray and brown dolomite that contains chert and pyrite. Fresh water is present in the Galena formation.

Above the Galena formation is the Maquoketa shale which averages about 50 feet in thickness and is green in color. The formation is dense and impervious.

Overlying the Maquoketa shale are Silurian and Devonian dolomites, gray to brown, crystalline, exhibiting some porosity and permeability, and containing pyrite crystals and varicolored cherts. This section averages about 240 on the crest of the Richfield anticline but is variable on the flanks.

Marmaton-Cherokee shales, red and gray in color, are on top of the Devonian dolomite and average about 135 feet in thickness. The shales are dense and impervious. Kansas City and Bronson group limestones and shales are present above the Marmaton-Cherokee shales which are dense and impervious. The limestones have been used in outcrop areas along the lower Platte River for crushed rock, building stone, and in Portland cement manufacture. Average thickness of the Kansas City-Bronson group on top of the Richfield anticline is from 85 to 100 feet.

Above the Pennsylvanian section in the subsurface on the Richfield anticline is Dakota sandstone with a variable thickness that averages about 40 feet in the Platte River valley. The sandstone is water bearing and is a good aquifer although the water is discolored by ironlike rust.

The Pleistocene section occupies the upper portion of the subsurface below the soil cover. The section averages about 100 feet in thickness and consists of glacial till, sand,and gravel on the Platte River valley with loess on the upland area. Excellent water in quality and quantity has been obtained from the Pleistocene sands and gravels.

The Richfield anticline is a geological oddity for the midwestern area in that it does NOT follow the time honored concept which says that Pennsylvanian and Mississippian accurately reflect deeper formations in structural outline. Oil fields in which have been found in the Forest City basin with production from the Devonian and Ordovician dolomites and sandstones have been located on the basis of structure developed in surface or near surface Pennsylvanian beds. The Redfield Natural Gas Storage anticline was located based on the structure developed in shallow Mississippian formations. The Richfield anticline was not located until sufficient drilling had been done to Ordovician formations.

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