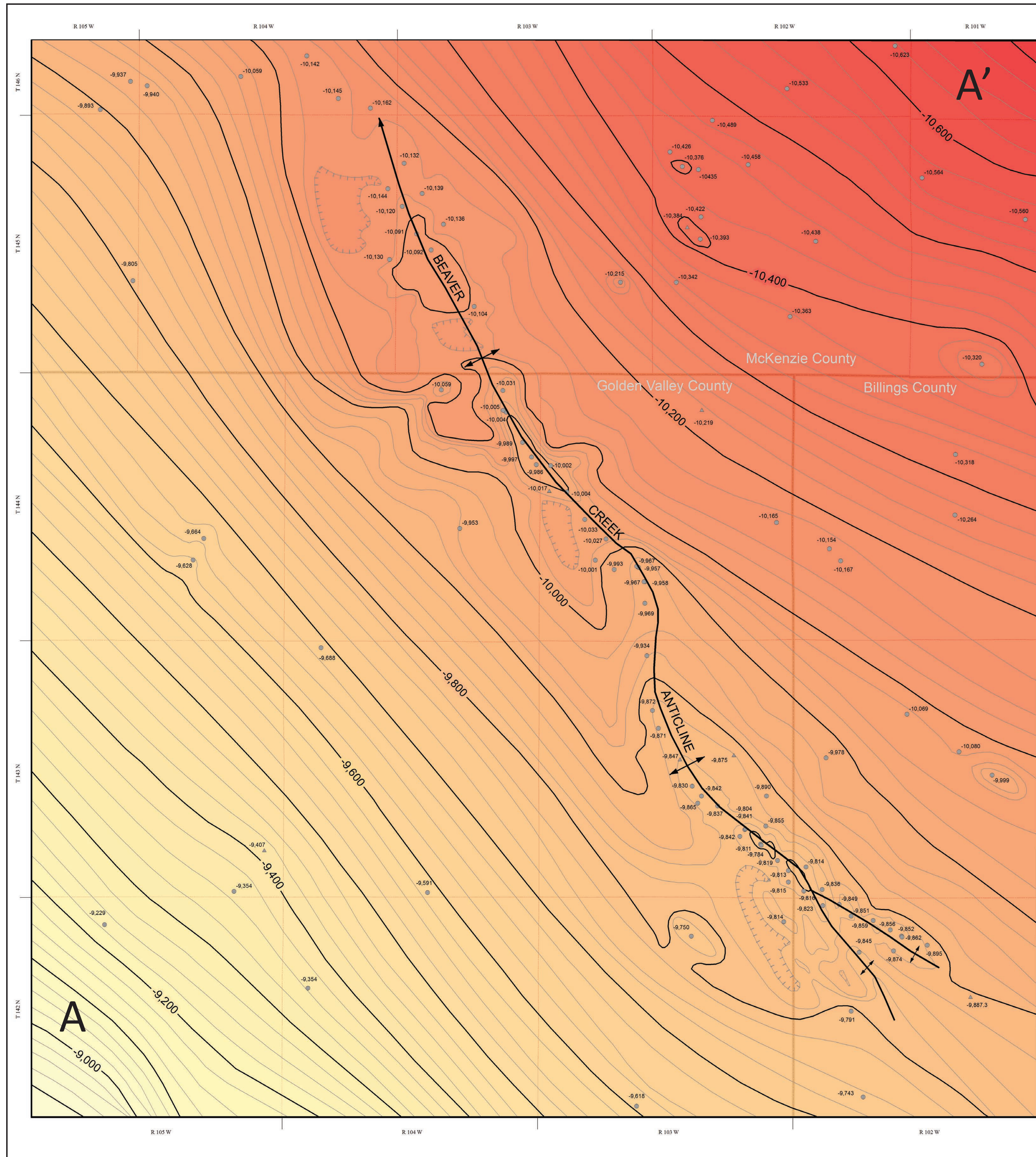
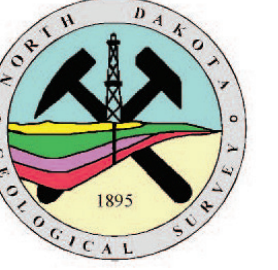


Beaver Creek Anticline, West-Central North Dakota

Timothy O. Nesheim



Beaver Creek Anticline

← Axial Trace and Direction of Plunge

Control Wells

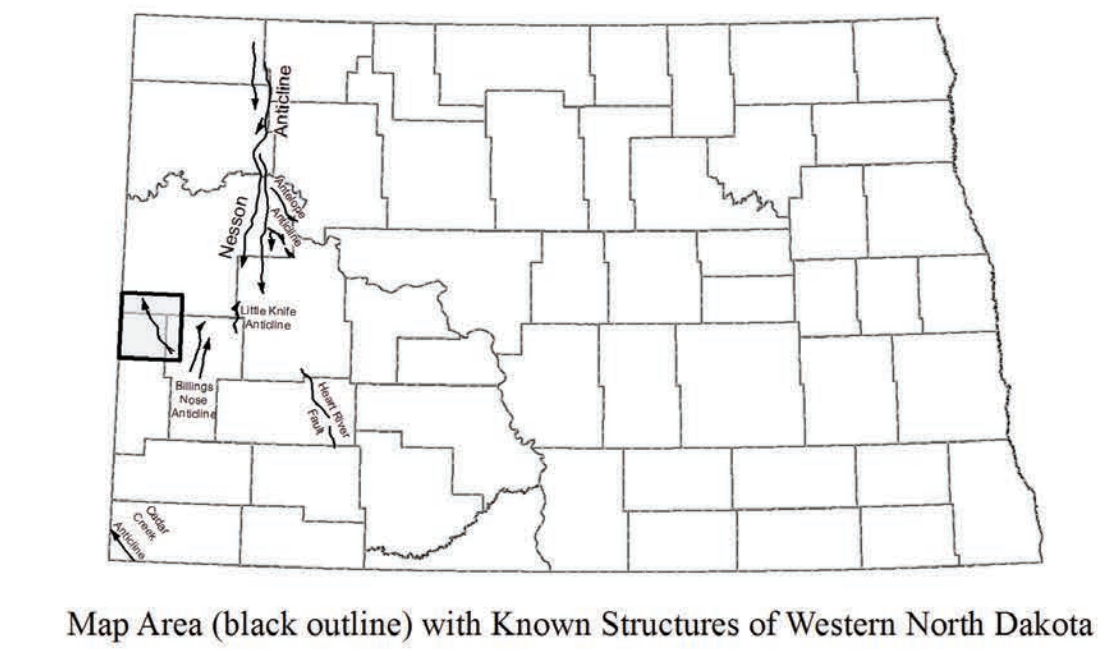
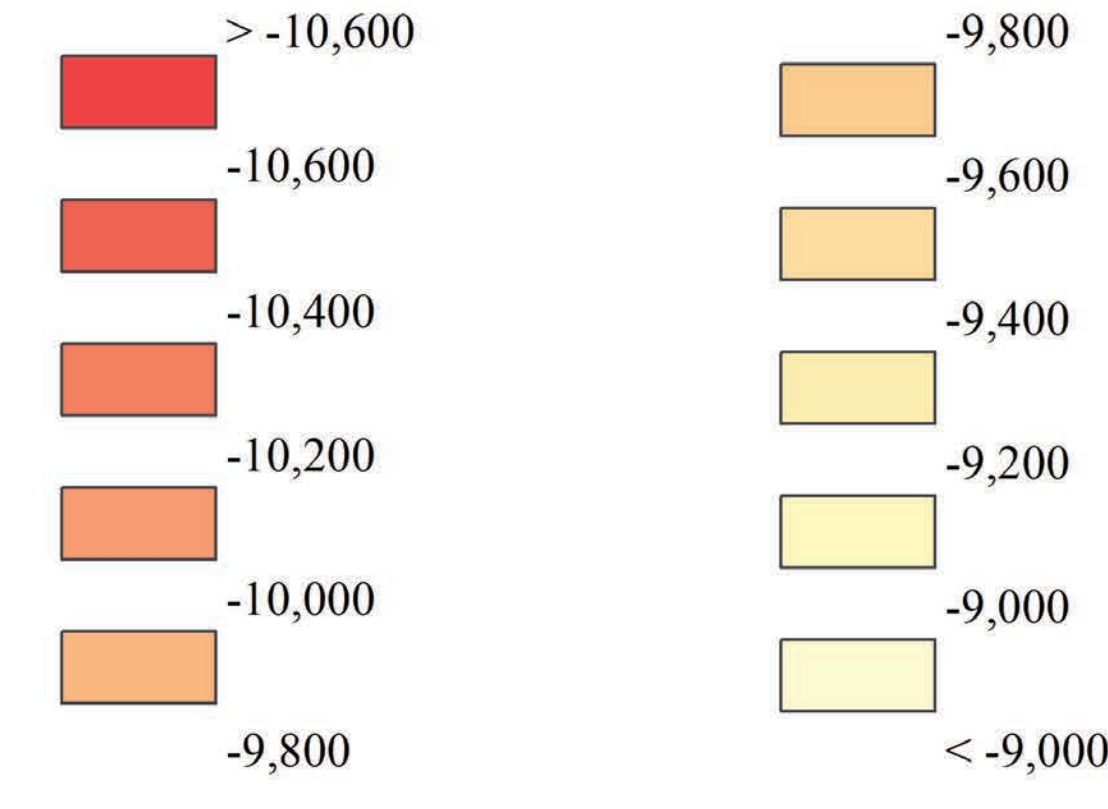
- Vertical Well
- ▲ Directional Well (Red River Formation top adjusted to true vertical depth)

-10,560 Red River Top (feet below sea level)

Red River Formation Top Structure Contours (feet below sea level)

- 25 feet Contour
- 100 feet Contour

Red River Formation Structure Contour Intervals (feet below sea level)



- County Boundary
- Township Boundary

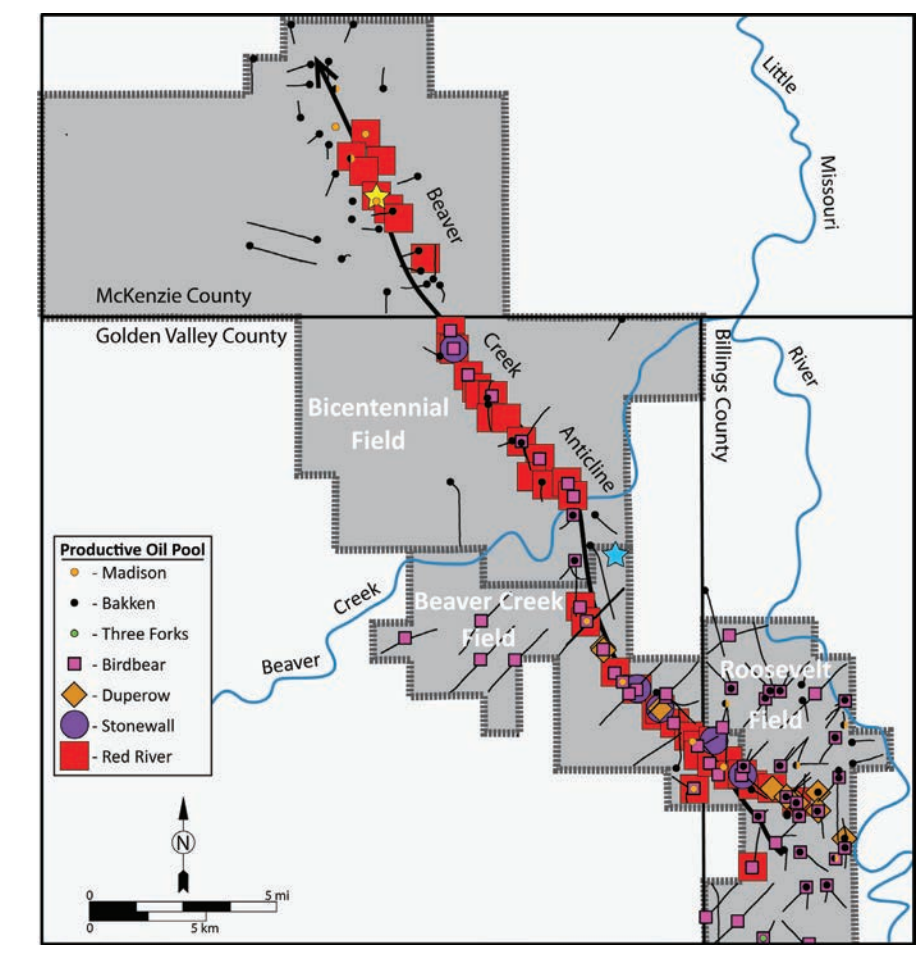
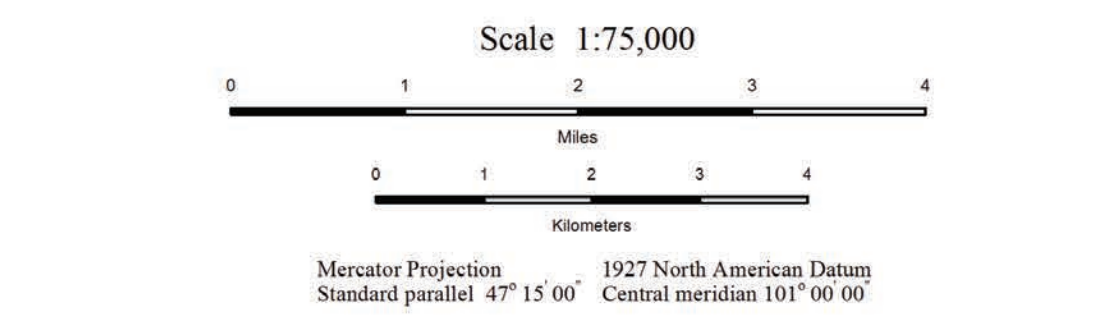


Figure 2. Oil and Gas Field map along the Beaver Creek Anticline showing productive wells. The blue star represents Gulf Oil's Federal Land #1 (NDIC: 586), the first exploratory oil and gas well drilled along the Beaver Creek Anticline. The yellow star indicates Farmland International Energy's Federal #1-18 (NDIC: 5909), the discovery well of the Bicentennial Field and the first well to commercially produce oil and gas from along the Beaver Creek Anticline. The black lines represent horizontal laterals.

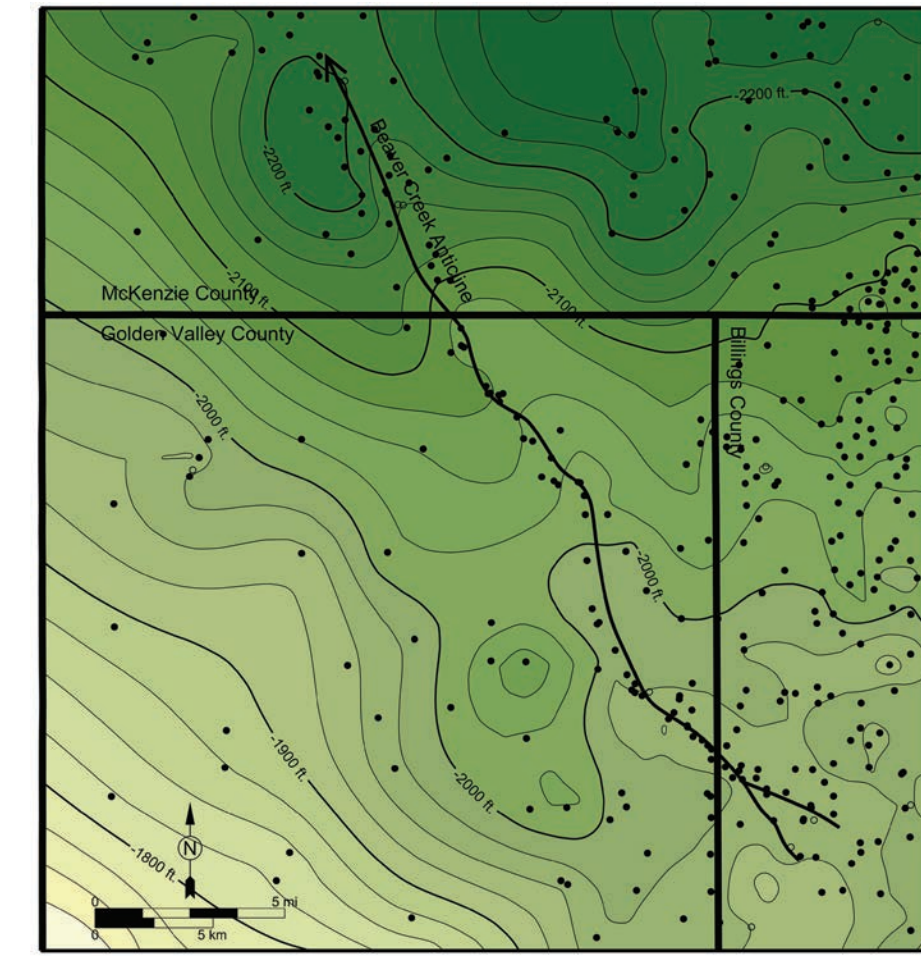


Figure 3. Structure contour map of the Greenhorn Formation within the study area showing the axial trace of the Beaver Creek Anticline from Figure 1. Structure contours were generated using available well control within the map module of Petra®.

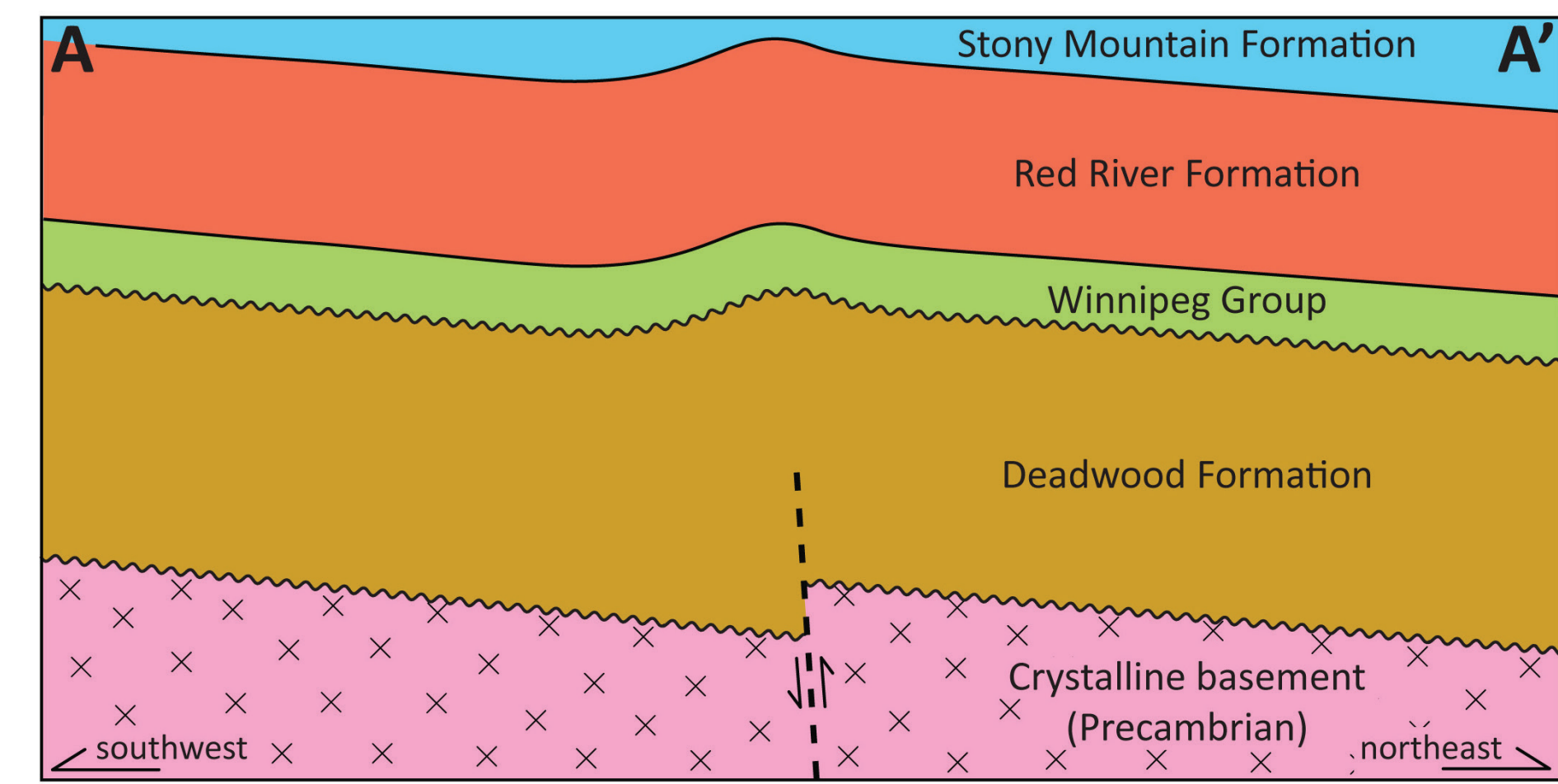


Figure 4. Schematic southwest-northeast oriented structural cross-section across Beaver Creek Anticline.

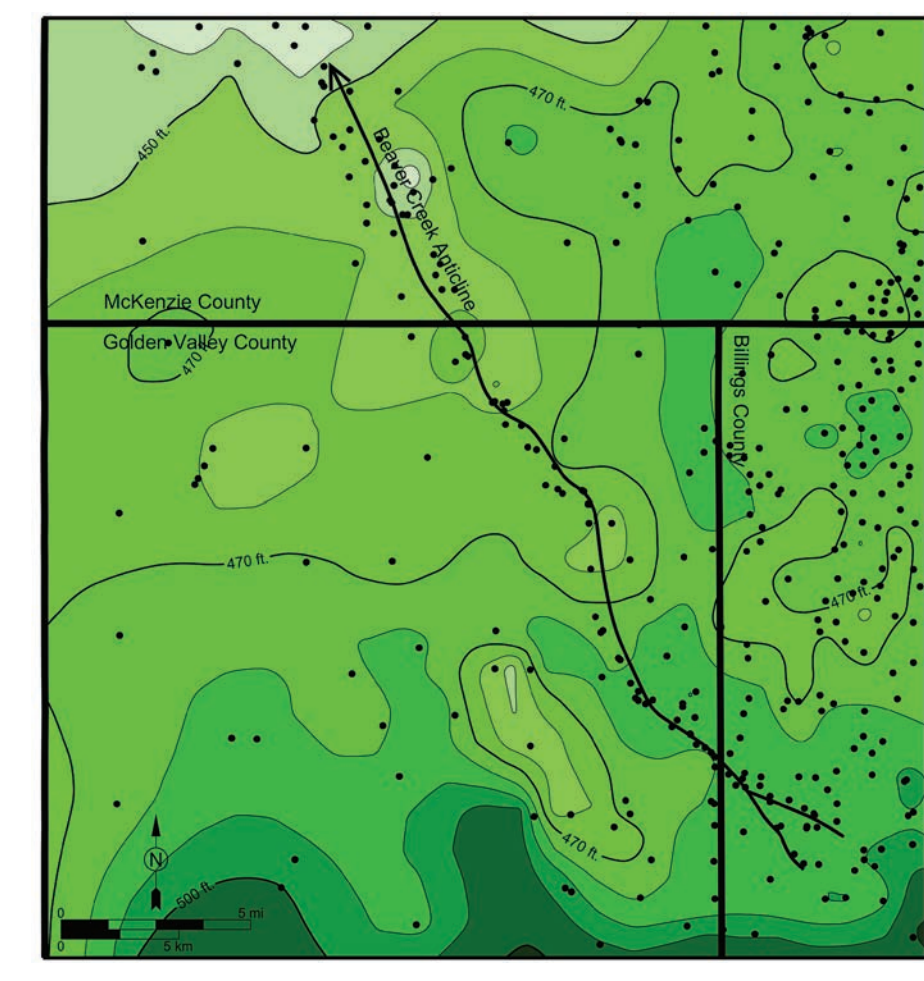


Figure 5. Isopach (thickness) map of the Greenhorn and Belle Fourche Formations within the study area showing the axial trace of the Beaver Creek Anticline from Figure 1. Isopach contours were generated using available well control within the map module of Petra®.

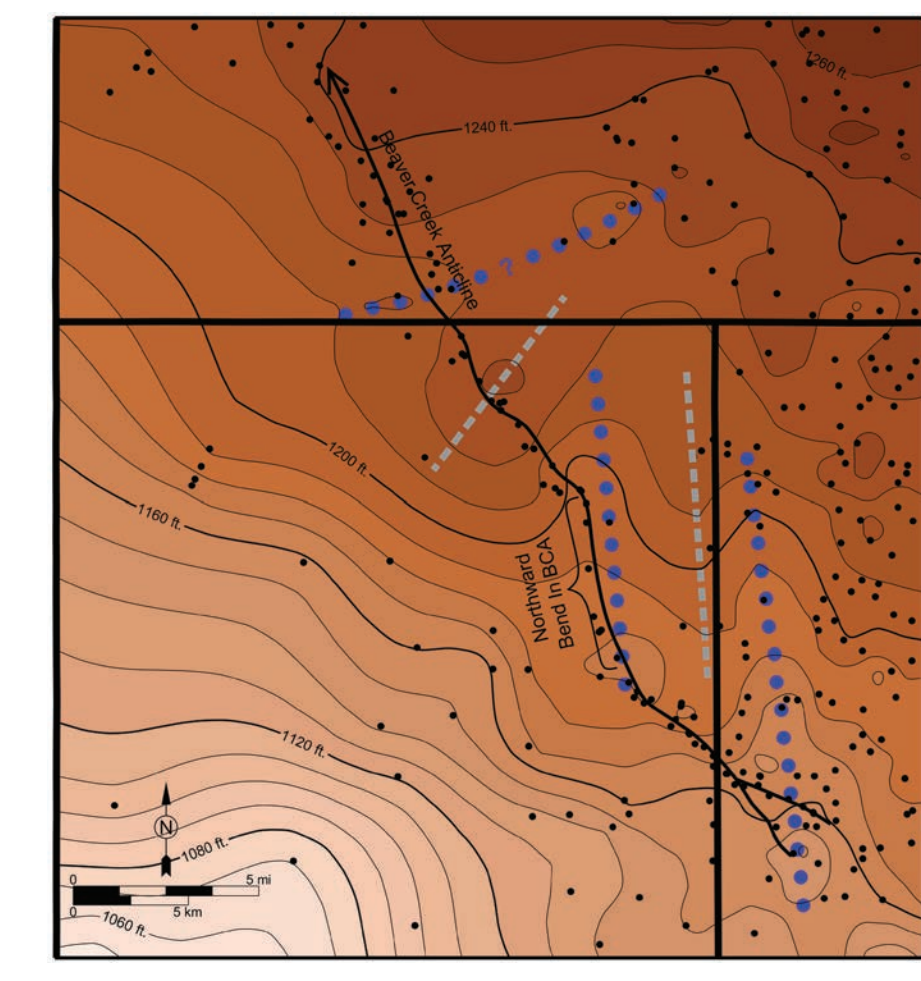


Figure 6. Isopach (thickness) map of the Charles and Mission Canyon Formations within the study area showing the axial trace of the Beaver Creek Anticline from Figure 1. Isopach contours were generated using available well control within the map module of Petra®.

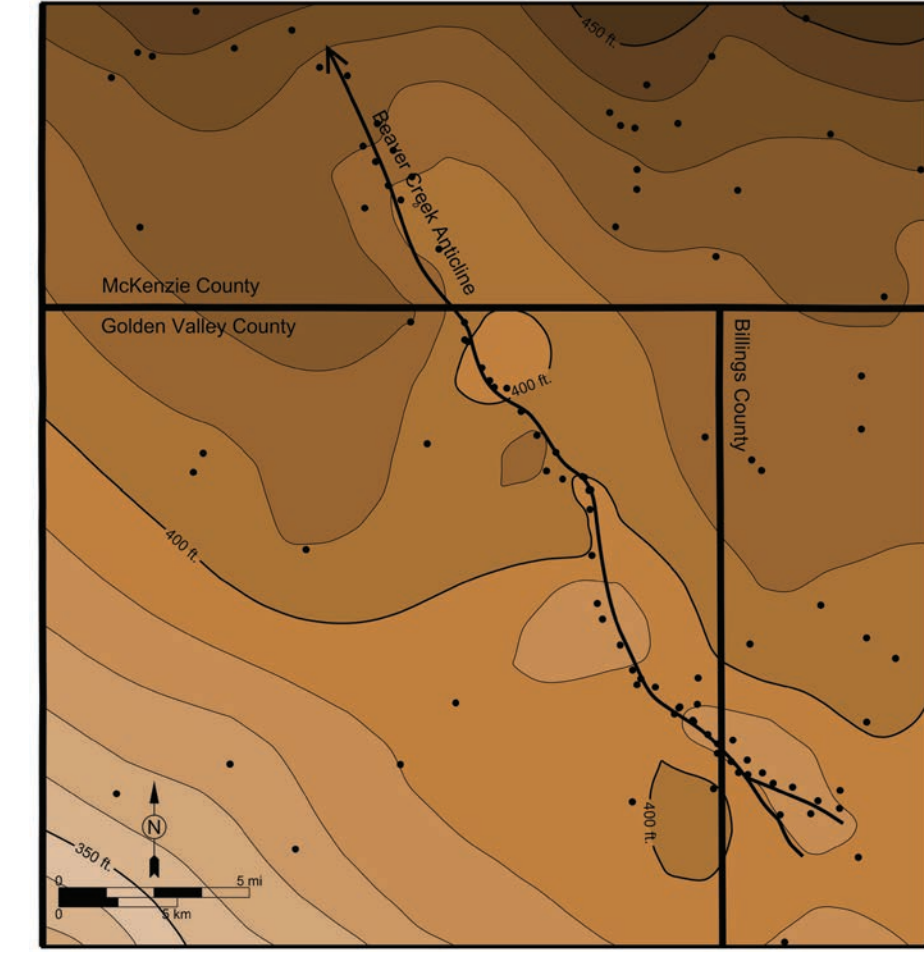


Figure 7. Isopach (thickness) map of the Jefferson Group (Birdbear and Duperow Formations) within the study area showing the axial trace of the Beaver Creek Anticline from Figure 1. Isopach contours were generated using available well control within the map module of Petra®.

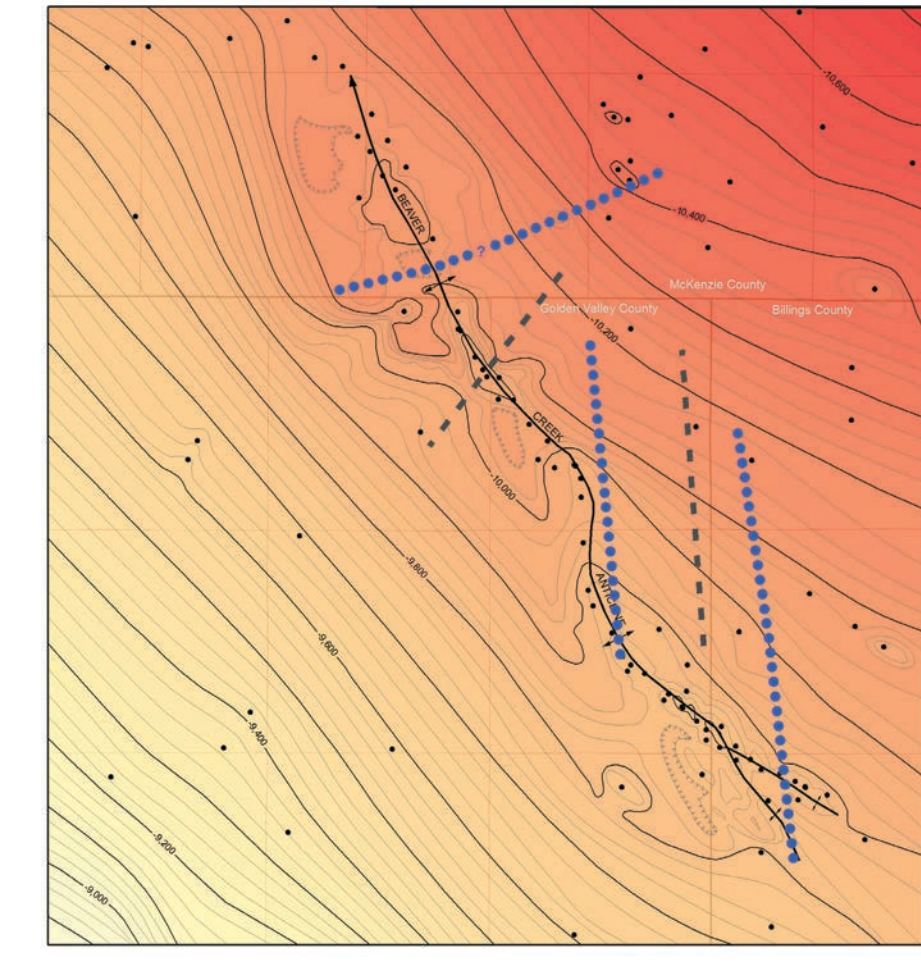


Figure 8. Structure contour map of the top of the Red River Formation (Fig. 1). Thickening (grey dashed lines) and thinning trends (blue dotted lines) from the Charles-Mission Canyon isopach (Fig. 6) are overlain on this map.

Introduction

The Beaver Creek Anticline (BCA) is a ~25 mile-long, northwest plunging structure located within the subsurface of northwestern Billings, northeastern Golden Valley, and southwestern McKenzie counties (Fig. 1). Three oil fields span the extent of the BCA: the Bicentennial, Beaver Creek, and Roosevelt Fields, which have together cumulatively produced over 29 million barrels of oil (MBO) and 28 billion cubic feet (BCF) of gas from several different oil and gas pools (Fig. 2). The BCA is named by this report after the Beaver Creek, which trends southwest to northeast across northern Golden Valley County and crosses the axis of the BCA (Fig. 2). The purpose of this publication is to formally document the presence and extent of the BCA and provide a preliminary examination into its origin and development history.

Structural Description

Data from pre-existing structure contour maps of the Icebox (Ordovician), Red River (Ordovician), and Birdbear (Devonian) Formations (obtained from oil and gas hearing exhibits, see appendix) were combined with current well control to create a structure contour map of the Red River Formation top which identifies the approximate axial trace of the BCA (Fig. 1). The current trace of the BCA extends over 25 miles across southwestern McKenzie, northeastern Golden Valley, and northwestern Billings counties, which are underlain by igneous and metamorphic rocks of the Trans-Hudson Orogen. The BCA terminates to the southeast as it nears the Rough Rider and Billings Nose fold sequence, which trends north-south, approximately perpendicular to the BCA trend. Along this southeastern margin, the BCA appears to diverge into two anticlines (Fig. 1). The structural closure of the BCA appears to vary considerably along the Red River Formation surface with an apparent maximum closure of between 100 and 125 ft (Fig. 1). The BCA consists of two separate elongate domes along its northwestern extent whereas along the southeastern portion, the BCA has more of a continuous axial trace (Fig. 1). The BCA is interpreted to extend upwards into at least the Cretaceous Greenhorn Formation based on the Figure 3 Greenhorn structure contour map. The Greenhorn Formation is located over 7,000 ft. above the Red River Formation.

Hydrocarbon Production Review

Exploratory drilling along the BCA began in 1954 with Gulf Oil's Federal Land #1 (NDIC: 586, API: 33-033-00003-00-00, Sec. 3, T142N, R103W) (Fig. 2, blue star). The Federal Land #1 well was drilled to a total depth (TD) of 9,328 ft. near the Beaver Creek/Bicentennial Field boundary. After several drill stem tests in the Madison Group, the Federal Land #1 was plugged and abandoned as a dry hole. After two more dry holes were drilled along structure, commercially producible oil was discovered in 1976 along the BCA with Farmland International Energy's Federal #1-18 (NDIC: 5909, API: 33-053-00671-00-00, Sec. 18, T145N, R103W) (Fig. 2, yellow star). The Federal #1-18 was drilled several thousand feet deeper than previous test wells drilled along the BCA and penetrated the Ordovician Red River Formation with a TD of 13,065 ft. The Federal #1-18 was completed on September 1st, 1976 within the Red River Formation with a 24 hour IP (initial production) of 488 barrels of oil, 689 thousand cubic feet (MCF) of gas, and no reported water. To date, the Federal #1-18 has cumulatively produced over 1.1 MBO and 0.85 BCF gas and is still actively producing from the Red River Pool.

Between the Bicentennial, Beaver Creek, and Roosevelt Fields, oil and gas has been produced from seven different pools along the BCA, these include: the Bakken, Birdbear, Duperow, Madison, Red River, Stonewall, and Three Forks pools (Fig. 2). A total of 168 oil and gas wells have been drilled within the Bicentennial, Beaver Creek, and Roosevelt Fields with only fifteen dry holes. Cumulative production from all three fields is 29.7 MBO, 33.7 million BBLs water, and 28.5 BCF gas through August, 2014. Over 90% of the production to date has been from the Bakken, Birdbear, and Red River pools, where each pool has cumulatively produced over 9 MBO.

Some oil and gas produced from the Bicentennial, Beaver Creek, and Roosevelt Fields has come from horizontal wells. Most of these horizontal wells have produced from the Bakken and/or Birdbear Formations, and a few from the Madison. Most horizontal Bakken wells are located either along or immediately adjacent to the BCA (Fig. 2). The majority of the horizontal Birdbear wells, however, are located off-structure in relation to the BCA (Fig. 2). Production from the horizontal wells located off-structure from the BCA may be related to structural elements created during the development of the BCA such as natural fracture systems, faulting, and/or minor folding.

Origin and Development of the Beaver Creek Anticline

Structure contour maps of the Red River and Greenhorn Formations were generated and examined to determine the stratigraphic range of influence of the BCA (Figs. 1 and 3). The Red River Formation is the deepest geologic horizon with adequate well control and other available structural information to construct a structure contour map within the area of interest. The Greenhorn Formation is the shallowest geologic formation top consistently listed for wells within the Oil and Gas Division formation top database. The BCA is present on both the Red River and Greenhorn structure contour maps (Figs. 1 and 3), which indicates the fold extends throughout most of the sedimentary section. Current well control is biased towards deeper, oil and gas productive formations (e.g. Duperow and Red River Formations) and therefore the fold axis of the BCA may be less precise on the shallower Greenhorn Formation than on the deeper Red River Formation. However, based on the available data, the BCA's axial trace does not appear to vary significantly between the contoured surface of the Red River and Greenhorn Formations (Fig. 3). The negligible shift within the anticline's axial trace may reflect a near vertical fault at depth (Fig. 4). If the fault plane was dipping significantly either southwest or northeast, there would be a shift in the BCA's fold axis trace between the Red River and Greenhorn horizons as well as a shift in the thickening and thinning trends within the various isopach maps across the sedimentary section (which is not observed as discussed below).

Isopach (thickness) maps of various geologic units were generated to conduct a preliminary examination into the structural development of the BCA. Isopach mapping has been previously utilized to examine the developmental history of the Cedar Creek and Nesson Anticlines within the Williston Basin (Clement, 1987; Gerhard et al. 1987). The isopach intervals generated and examined for this study include the Interlake Formation, Elk Point Group (Ashern, Winnipegosis, and Prairie Fms.), Manitoba Group (Souris River and Dawson Bay Fms.), Jefferson Group (Birdbear and Duperow Fms.), Lodgepole Formation, Charles + Mission Canyon Formations, Mowry Formation, and Greenhorn + Belle Fourche Formations (Fig. 5-7 + appendix). These intervals were selected based both on the author's familiarity and the ease with which the various formation tops involved can be picked on wireline logs.

Significant thinning and/or thickening can be observed within the Greenhorn-Belle Fourche Formations, Mission Canyon-Charles Formations, and Jefferson Group isopachs (Figs. 5-7). All three of these geologic intervals are believed to have conformable upper and lower boundaries, and the isopach maps of the geologic units underlying the Greenhorn-Belle Fourche, Mission Canyon-Charles, and Jefferson isopachs each show negligible to minor (<10 ft.) thickness variation along the BCA (see appendix). This indicates the following: 1) deformation (folding) along the BCA was not continuous but occurred episodically, and 2) there was positive structural relief along the BCA that affected sedimentation during deposition of the Jefferson Group, Mission Canyon-Charles Formations, and Greenhorn-Belle Fourche Formations. Thickness variations (primarily thinning) within the Greenhorn-Belle Fourche and Jefferson isopachs trend along the BCA's axial trace and indicate syn-depositional folding took place resulting in partial development of the BCA's anticlinal structure (Fig. 5 and 7). However, thickness trends within the Mission Canyon-Charles isopach tend to not parallel the BCA's fold axis, especially to the north, and indicate a more complex style of deformation during the Mississippian (Fig. 6). Mission Canyon-Charles thickness variation trends are oriented approximately north-south along the southeastern margins of the BCA and northeast-southwest oriented along the BCA's northwestern margins (Fig. 6).

Summary

This study shows that the BCA formed through episodic deformational phases based on the evaluation of isopach maps of geologic intervals from throughout the stratigraphic section that bracket the timing of separate deformational events. Two of these deformational phases, likely compressional events, took place during deposition of the Devonian Jefferson Group and Cretaceous Greenhorn-Belle Fourche Formations. Folding likely occurred as a result of vertical movement along a northwest-southeast-oriented fault within the Precambrian basement. Another phase of deformation occurred during the Mississippian, during deposition of the Mission Canyon-Charles Formations, resulting in a more complex style of deformation than identified on the Devonian and Cretaceous horizons. To date, nearly 30 MBO and 29 BCF of gas have been produced from 154 wells located within the three oil and gas fields that span the BCA. Oil and gas has been commercially produced from intervals within Ordovician Red River Formation up through the Mississippian Madison Group.

References

Clement, J. H., 1987, Cedar Creek: A Significant Paleotectonic Feature: in Williston Basin Anatomy of a Cratonal Oil Province, edited by Mark W. Longman, p. 323-336.
Gerhard, L. C., Anderson, S. B., and LeFever, J. A., 1987, Structural History of the Nesson Anticline, North

Figure 1. Red River Formation top structure contour map of the northern Golden Valley County area. The Red River structure contours were generated by combining current well control with previously generated structure contour maps of the Icebox (Bicentennial Field), Birdbear (Beaver Creek Field), and Red River (Beaver Creek and Roosevelt Fields) Formations from oil and gas hearing exhibits. Figures 2, 3, and 5-8 display the same area as Figure 1.