The Ames Impact Crater
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Introduction

Since the first recognition of an anomalous structural low near the town of Ames, in the southeastern part of Major County, Oklahoma, the origin of this and possibly related subsurface structural features in the area of T20–21N, R9–10W, has been the subject of much speculation. Detailed maps on subsurface horizons from the Devonian to the Upper Pennsylvanian show an intriguing circular–shaped closure around a low that occupies about 20 square miles, approximately centered near the town of Ames. Because drilling in secs. 1 and 2 of T20N, R10W, had revealed an unusually thick and low Hunton (Silurian–Devonian) section, an early characterization of this part of the larger multi-pay Ringwood Field was known as the “Hunton graben.” Recent deeper drilling has established oil and gas production from the Arbuckle dolomite on a circular rim around this low, leading to the characterization as the “Ames hole.” The Oil Creek shale (Middle Ordovician), which seals the structure and directly overlies the Arbuckle Group, indicates the age of the crater is late Early Ordovician. Figure 1 is a stratigraphic column for the Anadarko Basin.

Subsequent drilling and mapping has provided enough new data to allow description of the deep structure as an impact crater or astrobleme. Initial Arbuckle wells by J. L. Thomas Engineering, Inc. and DLB Oil and Gas, Inc. (DLB), now known to be located on the rim of the impact crater, were significant Arbuckle dolomite discoveries; however, the discovery of prolific oil production in wells located on the crater floor from brecciated granite, granite wash, and dolomite has proved to be even more significant.

The first crater–floor well, the D. & J. Oil Co. (D. & J.) Gregory 1–20, sec. 20, T21N, R9W, may be the most productive oil well established from a single pay in Oklahoma. The pay zone is in an essentially continuous section of brecciated granite that formed as a central rebound structure, a common feature in impact craters larger than a few miles in diameter. More than 200' of very effective porosity and very low water saturation combine to provide a conservatively estimated primary recovery of more than four million barrels of oil.

Other crater–floor wells have established production from granite overlying brecciated dolomite and from outstanding solution–enhanced porosity and fracture systems that are developed in intact, but not in–place, blocks of Arbuckle dolomite. Oil and gas production from both the rim and the crater–floor features, all sealed by shales within the Oil Creek Formation, will probably make the Ames impact feature the most productive known astrobleme.

Background

A structural feature near the south-
east corner of Major County, Oklahoma, has been known for years as the “Hunton graben” to geologists who study the subsurface geology of the northern Anadarko shelf area. The feature is centered two miles southwest of the town of Ames. The Hunton thickens from 225 ft to as much as 475 ft in the local area. The base of the Hunton is locally as much as 200 ft lower than regional. This local preservation of thick and structurally low Hunton carbonates suggests a graben.

It is now recognized that the Hunton graben is a small part of a much larger feature that has become known as the “Ames hole.” This unusual feature has no relationship to major faults or uplifts on a map of major geologic provinces (Fig. 2); the location of an impact structure occurs randomly and is unrelated to other tectonic features.

A three-dimensional map of the Ames structure (see cover) illustrates common features of an impact crater: an outer rim with local closed highs and an interior low, including an irregular central high area that is also characterized by local closed highs (Sawatzky, 1975; Cannon, 1977; Roddy, 1977; Donofrio, 1981; Hartung and others, 1990; Anderson and Hartung, 1992; Kirschner and others, 1992). Although the local structural closures on the outer rim have been recognized on a structural contour map on the Sylvan Shale (Upper Ordovician), the relationship of the rim to the deepest part of the structure in the southwest-ern part was not recognized prior to the construction of the computer-generated model.

Several Arbuckle tests had been conducted in the area before the actual origin of the feature was recognized. J. L. Thomas drilled the Ott #1 and #2 wells in the SW and SE, respectively, of section 4, T21N, R9W, on mapped north dip. When DLB Oil and Gas, Inc. drilled their Cecil well in the NW of sec. 27, T21N, R10W, these Ott wells were recognized by DLB as being positioned, like the Cecil well, on small structures high on a common rim surrounding a central low. The realization that a substantial gas and oil column was present in Arbuckle dolomite with significantly enhanced reservoir properties led to early speculation about the origin of the structurally high Arbuckle feature and its possible association with the Hunton graben. Later discovery of brecciated granite in the inner ring of the central feature provided additional evidence that it had been created by the impact of an asteroid. This suggested that the rim had been uplifted and fractured by crater-forming processes associated with the impact.

Origin of the Ames Structure

An interpretation for this structural anomaly is as follows. Sometime shortly before or soon after the end of the

Figure 3. Diagram of the Ames graben and the position of the Hunton graben as a part of the Ames structure.

Figure 4. Interpretive cross section of a larger and younger, analogous impact crater near Manson, Iowa. The position of the transient cavity present during formation of the structure is indicated by the curved dashed line. Rough estimates of the movement of material required to fill the transient cavity and produce the central peak are indicated by the arrows. Arrows extending above the ground surface suggest some material in the rising central peak may have been airborne for a short time before crashing back to Earth and producing an impact breccia. (Modified from Hartung and others, 1990.)
Arbuckle deposition, an asteroid exploded low over the surface of what is now the southeast corner of Major County, Oklahoma, creating a bowl-shaped crater centered near the present town of Ames. It is apparent that ~2,000 ft of Cambrian-Ordovician carbonate and some basement rock was excavated by the explosion. Basement granite under the bottom of the crater was subjected to enormous compressive stress and fractured as the result of the exploding meteorite. The granite basement subsequently rebounded, particularly in the central portion of the crater (Fig. 4). Brecciated granite is the major component of the ridges that form the inner ring. Some of the ridges are as much as one mile across and two miles long, and as much as 1,600 ft thick.

Part of the crater was filled with breccia that had become airborne and fell back after the explosion. That breccia is a mix of basement granite and Arbuckle dolomite rocks. The outer ring, composed mostly of fractured blocks of Arbuckle dolomite, was formed when part of the crater rim collapsed into the central low along arcuate normal faults. There is evidence that fragments of Arbuckle rock and granite excavated by the explosive event were heated sufficiently to resemble pyroclastic rock. Several feet of such pseudopyroclastic rock occurs locally on the crater floor, overlying the more abundant granite and carbonate breccia. It may have been some time before deposition of shales of the overlying Oil Creek Formation began.

The rim and breccia highs were exposed to subaerial weathering and erosion. The rim, composed mostly of Arbuckle Group, became karstic. The highs eroded and were redeposited as carbonate and arkosic clastics that occur on the crater floor, lying on top of brecciated rock that had previously fallen back into, and partially filled, the crater. A stratified cap of tight dolomite overlies the crater-floor breccia, and these strata grade upward into the Oil Creek Formation. The entire feature is overlain by Oil Creek shales, forming structural traps that may have hydrocarbon columns of several hundred feet.

The Ames hole was filled during Paleozoic and Mesozoic deposition, during which time the underlying breccia continued to compact. Strata from the Oil Creek Formation (Middle Ordovician) through the Flowerpot Shale (Upper Permian) are preserved within and beyond the structural low. Structure maps on the base of the Woodford Shale (Upper Devonian) (Fig. 6A), and on the top of the Oswego lime (Middle Pennsylvanian) (Fig. 6B), clearly show the closed low. These maps document the continuing compaction and collapse of crater-floor breccia despite the progressive masking of the structure by sedimentation.

Astrogeologists Roddy (1977; personal communication, 1992) and Cannon (1992) concur that the feature is an astroblme on the evidence of its circular shape, the central high composed of fractured crustal rock, the outward-dipping rim, and the presence of shock-metamorphosed quartz.

Exploration and Development

Arbuckle discoveries at Cottonwood Creek (Read and Richmond, in press), Wilburton (Carpenter and Evans, 1991), and in the subject area have caused renewed interest in drilling exploration wells into the Arbuckle. The Arbuckle dolomite does not normally have significant matrix porosity or permeability, and reservoir size and quality are commonly limited. However, in April 1991, DLB completed the no. 27-4 Cecil well (N/2 NW sec. 27, T21N,
The Arbuckle Group. The well was expected in the Arbuckle dolomite (Roberts and Sandridge, 1992). The Arbuckle was penetrated by DLB's discovery well, the D. J. no. 1-17 Lloyd (SW SE sec. 19) to the south of the Arbuckle dolomite, at a depth of 8,800 ft, based on seismic data. At 8,800 ft, below an estimated 110 ft below the top of the breccia, flowed 40.4 API gravity oil to the surface at a rate in excess of 50 bbl of oil per hour (BOPH). Final flowing tubing pressure (FTP) was 4,025 psi, as compared to a final shut-in pressure (SIP) of 4,045 psi, a bottom-hole pressure (BHP) of 4,005 psi, and a hydrostatic pressure of 4,181 psi. Surface flowing pressure was 1,200 psi through a 16/64-in. choke. More than 320 ft of brecciated basement rock were penetrated without encountering carbonates of the Arbuckle Group. This well yogurted from only 30 ft of perforations without stimulation. The top perforation is located 1,041 ft below the top of the breccia, and far above any indications of water. Initial flow was 731 bbl of oil in 14 hrs, at a flowing tubing pressure of 1,080 psi using a 16/64-in. choke. No water was produced on any test. A conservative estimate of reserves from the Gregory well is greater than four million bbl by primary recovery. Subsequent drilling has established a deeper water level in the granite breccia and suggests a water drive. The well has flowed its allowable since completion in November 1991 and produced more than 13,000 bbl of oil and 3,700 MCFG in less than one year without water production or significant loss of pressure. (Through July 1994, these wells on this lease have produced 1,650,074 BO and 365 MCFG.)

Cuttings and thin sections of the basement rock were examined, using scanning electron microscope and X-ray diffraction techniques, to identify the mineral composition. The analysis indicated that the rock is granitic, composed of 31% quartz, 11% potassic-feldspar, and 52% sodic-feldspar. This analysis was reconfirmed by later examination of rotary sidewall cores from the D. J. no. 1-17 Lloyd (SW SE sec. 17, T21N, R9W) drilled to the northeast of the Gregory. The age of the granite is 1,400 million years, according to Rb-Sr isotopic analysis. This is similar to other basement rock dates in the area when adjusted for strontium enrichment from the Arbuckle dolomite (Roberts and Sandridge, 1992).

Several confirmation wells have been drilled. The D. J. Herman (NE NW sec. 20) in the northeast also penetrated brecciated granite but was low and uncompensated water. Two wells to the west, the CRI Dorothy (NE NE sec. 19) and D. J. no. 1-17 Lloyd (SW SE sec. 19), also penetrated brecciated granite but were dry.
Figure 6. Resistivity, porosity, and nkonbg of hro ArhKkte ddornite intW&, tested separately by drillllm ted (DW) and thmnh oedonted intends horn without rmior stidation in the DLB 27-4 Cecil dl. (hc wulcm rim of the dructure in Figure 9. Rcrirtivity, porosity, d inindog of two bmdatcd gnitc intmali tmted squat* by Dn and phatd inrmab hwn wi(houl hulatiom in the D.

The Dorothy and Peggy wells are completed in granite wash and in the underlying brecciated Arbuckle dolomite. One well penetrated an abnormally thick section of Oil Creek shale, followed by granite breccia, overlying Arbuckle breccia (Fig. 10). It is apparent that the granite breccia was deposited in this position as the result of mass movement. The Gregory well continues to flow with little difference between shut-in and flowing tubing pressures. Its direct offset is the D. & J James, which flowed 492 BOPD from granite breccia. CRI drilled successful offsets of the Gregory well, to the east at the Stansberry (SE NW sec. 21) and to the west at the Heinrich (SW NE sec. 19), testing seismic closures. However, both of these wells produce from Arbuckle dolomite, with each well having tested at an initial rate of 50 BOPD. DLB also Summer Arbuckle production in their Allen no. 12-11 rim well (NE SW sec. 13, T21N, R10W) on the south side of the structure. They were also successful in establishing production from Arbuckle dolomite breccia in their DeHaas well (NE NW sec. 21, T21N, R10W). CRI drilled two rim wells on the east side. The Terry (SW NE sec. 13, T21N, R10W) is an Arbuckle gas well, and the Fisher (SW NE sec. 3, T20N, R9W) was not commercial.

Current Activity

As of October 1992, 26 wells had been completed on the Ames feature. Of these 21 are producing or waiting for production facilities. One of these is a horizontal extension of a vertical hole. Seven have been plugged or temporarily plugged, but some of these may be recompleted in shallower reservoirs or as horizontal extensions. Approximately eight wells were drilling as of November 1992. Two of these will be drilled as horizontal extensions in directions that will be determined by information obtained from the vertical hole. There are locations or spacing and increased density applications pending with the State Corporation Commission for an additional 40 wells. One company (DLB) accounts for most of these wells and locations. D. & J, each have 19. A total of 21 companies make up the balance of about 40 additional wells and locations, for a total of 61 potential wells. Many locations await the results of three-dimensional seismic surveys, currently being processed. Others await better completion and stimulation techniques to overcome problems related to high paraffin content, early water coning, and possible migration of fines, which may have infiltrated into the open fractures on the rim and breccia on the crater floor.

A significant precedent was set with the redrilling of CRI’s Chet well (NW NW SW sec. 19, T21N, R9W). The original crater-floor well was drilled vertically and intersected a hydrocarbon-saturated reservoir in the breccia. CRI made the decision to recomplete the well as a horizontal extension, which intersected the tops of several Arbuckle and granite breccia highs on the Crater floor. The well tested >700 bbl per day Houston Geological Society Bulletin – November 1994
before being shut in to apply for a special allowable. This technique promises to increase production rates and to salvage wells that are structurally low and close to water, or that lack sufficient fracturing and dissolution porosity in the hydrocarbon column to produce at commercial rates. DLB has acquired three-dimensional seismic over a structurally complex portion of the inner ring near the Gregory well. This approach is intended to reduce the risk of drilling off-structure wells and to provide locations that will not be drained by conventional well patterns.

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