The Ames Structural Depression: *An Endogenic Cryptoexplosion Feature Along a Transverse Shear*

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Abstract

A long history of tectonic activity is documented for the origin of the Ames depression: subsidence in lower Ordovician is demonstrated prior to the uplift and volcanism which occurred in earliest Middle Ordovician time. The "Chestnut Volcanics" as herein defined and described are composed of classic ignimbrites of volcanic breccia and welded tuff. These rocks comprise the first recognized volcanic rocks of Early Ordovician age in Oklahoma.

The volcanic rocks, and the Ames depression in which they are located, are genetically related to transcurrent faulting associated with the Mid–Continent Rift. Further evidence is presented which suggests a relationship of the Ames depression to an alignment of cryptoexplosive features found across Kansas, Missouri, and Kentucky.

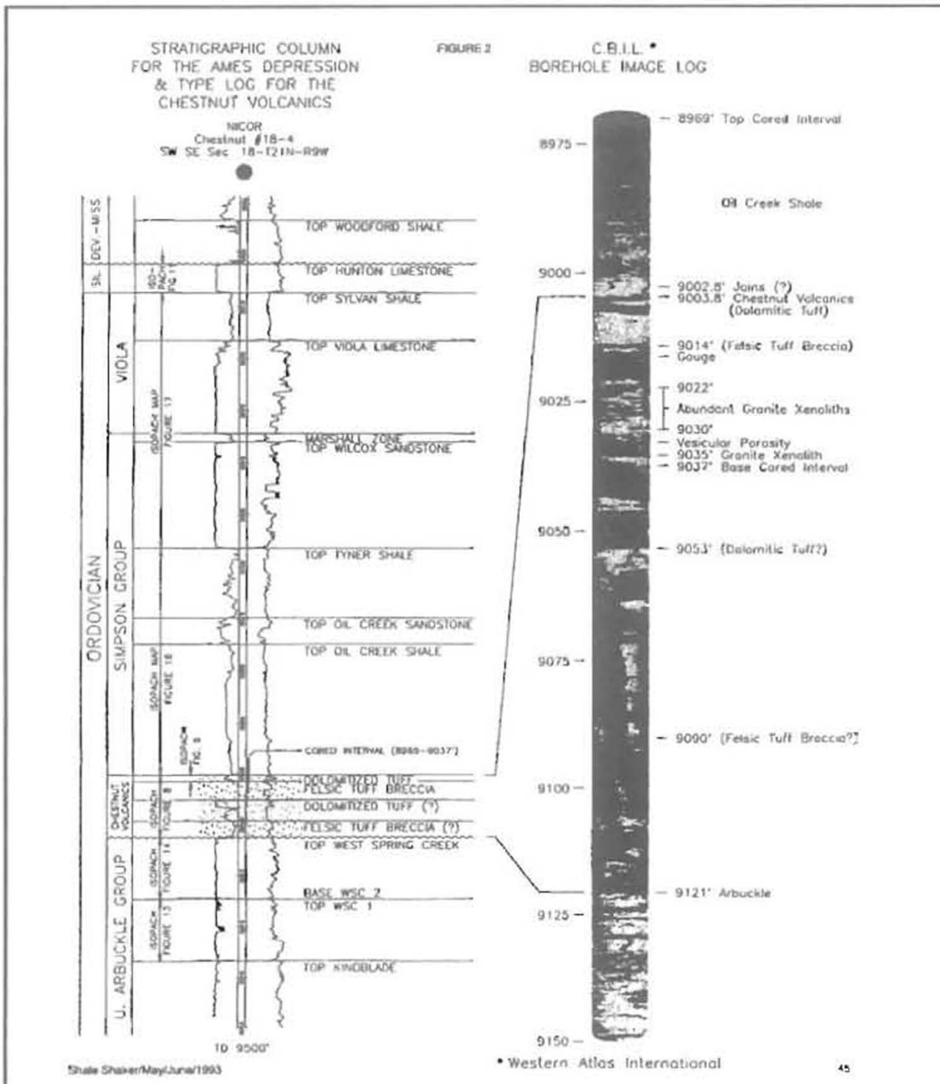
Introduction

The Ames structural depression is located along the Northwest Shelf of the Anadarko Basin in T20 and 21N, R9 and 10W, Major County, Oklahoma (see Figure 2, page 21 of this *Bulletin*). Detailed subsurface mapping from lower–middle Ordovician up through the Siluro–Devonian Hunton (Figure 2) indicates an anomalous, circular depression, of approximately 36 square miles, centered near the town of Ames (Carpenter and Carlson, 1993).

Recent discoveries of prolific oil and gas wells from truncated, karsted and brecciated Ordovician age Arbuckle dolomites and post–Arbuckle ignimbrites have generated considerable drilling activity within and proximal to this structural depression. Detailed descriptions of individual wells drilled to date are documented in publications by Hamm & Olsen, 1992; Roberts and Sandridge, 1992; Shirley, 1992; Carpenter and Carlson, 1993; and Heyer, 1993; and, therefore, are not discussed herein.

Recent publications regarding this feature have either inferred a meteor impact origin (Hamm and Olsen, 1992; Roberts and Sandridge, 1992; Shirley, 1992; Carpenter and Carson, 1993) or a volcanic origin (Roemer and others, 1992). The impact theory suggests a meteor of low–angle trajectory exploded low over the surface of what is now the southeast corner of Major County, Oklahoma. This event supposedly occurred shortly before or soon after the end of Arbuckle deposition, gouging out a bowl–shaped crater centered near the present town of Ames (Carpenter and Carlson, 1993).

Contrary to the impact theory, Roemer and others (1992) has suggested a volcanic origin and implies that three stages of geologic activity occurred. These are: 1) circular emplacement of residual magnetic masses on the surface of the Precambrian igneous basement; 2) igneous doming and subsequent ex-



trusion prior to the end of the Arbuckle time; and 3) subsidence of the Sylvan and pre–Sylvan shale section.

Recently obtained whole core data, from the NICOR Production Company's Chestnut 18– 4 well, SW SE Section 18–T2lN–R9W, Major County, Oklahoma, in conjunction with subsurface geological data, seismic, gravity, and magnetic data suggests that the Ames structure formed as a discrete pull–apart basin, in response to trans–crustal or trans– lithospheric shearing obliquely bisecting the Mid–Continent Rift. Isopach data from intervals within the Kindblade and West Spring Creek formations of the Arbuckle Group show that the Ames depression was in existence prior to the Late Ordovician (post– Arbuckle, pre–Oil Creek) and that these intervals were subsequently domed, eroded, and brecciated in response to stretching and thinning over an upward rising mantle plume. This plume ultimately reached the surface, resulting in extrusion of highly sialic ignimbrites which were deposited on the Arbuckle surface. Isopach data of post– extrusion rocks shows resumed subsidence at least through the Siluro–Devonian Hunton.

Arbuckle Stratigraphy

The Cambro–Ordovician Arbuckle Group was deposited on an extremely broad, shallow platform which has been referred to as the Great American Bank. The Arbuckle Group is equivalent to strata of the Ellenberger Group in the Permian basin, the El Paso Group in extreme southwestern Texas, and the Knox Group in the Appalachian uplift and Black Warrior basin (Wilson and others, 1991).

The Ames structural depression is situated along the platform of the Great American Bank where deposition was dominated by ramp–type peritidal carbonates which can be subdivided into cycles based on facies types and depositional patterns. Wilson (1991) suggests that parasequences which can be defined as relatively conformable successions of genetically related, usually upward shoaling beds that are bounded by marine flooding surfaces are common within the Arbuckle Group.

Although individual parasequence sets are problematical when correlating wireline log signatures, certain observations regarding the Arbuckle Group can be made. Most noticeably, a repetitious pattern of similar upward–increasing resistivity profiles is common (Figure 3). A comparison of the Ames area Arbuckle Group with published Arbuckle correlations (Gatewood, 1976; Derby and others, 1991) suggests these sequences represent portions of the Kindblade and West Spring Creek formations of southern Oklahoma.

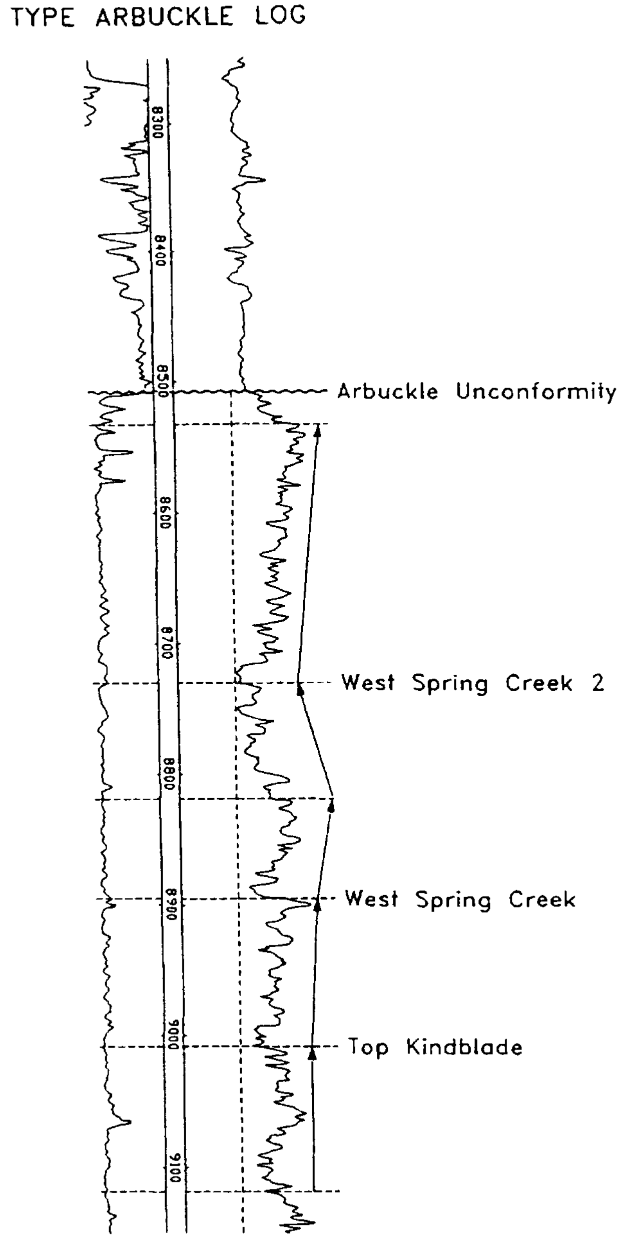


FIGURE 3: Repetitious pattern of similar upward-increasing resistivity profiles and corresponding upward-decreasing gamma ray profiles. These are suggestive of parasequence sets of upward-shoaling strata. Interval between West Spring Creek 1-2 is suggestive of shoaling upward cycle followed by a deepening event.

Post–Arbuckle Stratigraphy

Perhaps the most intriguing stratigraphic horizon in the Ames area is the presence of a herein defined, highly vesicular, devitrified, lithic–rich, felsic tuff breccia (FTB) overlain by a massive, poorly sorted crystal and lithic–rich, partially dolomitized tuff (DT). These lithologies were determined from whole cores recovered in the NICOR Production Company's Chestnut 18–4, NE SW

SE Section 18–T21N–R9W, from 8,969' to 9,037' and are herein referred to as the Chestnut Volcanics.

Chestnut Volcanics: Rationale for Defining and Naming Formation

Current investigators of the Ames depression are using differing nomenclature for the rock comprising the primary oil reservoir in the area. For example, Hamm and Olsen, 1992, describe the oil reservoir rock as "glass rock", whereas Carpenter and Carlson, 1992, have described the same rock as a breccia mix of basement granite and Arbuckle dolomite with an overlying pseudopyroclastic rock. Still others are informally referring to this unusual reservoir as "magic rock". Such names and descriptions illustrate the difficulty and limitations in describing rocks from drill cuttings and limited sidewall cores. One purpose of this paper is to propose a lithodermic column for the volcanic rocks using the whole core recovered from the NICOR #18–4 Chestnut as the basis for unit definition. Reference to the core will provide a large continuous sample of rock in unquestionable sequence to permit proper description and, thereby, interpretation of origin. Additionally, as it is unlikely that these rocks will ever be found at the surface, correlation of the core with the geophysical well logs should aid in the identification of rock types in those wells without cores, and to allow future workers to further define the stratigraphic sequence.

We propose to name the volcanic rock described herein the "Chestnut Volcanics" in conformity with the North American Stratigraphic code (AAPG, 1983) for a compound name specifying geographical location (the wellbore), and a descriptive rock name. Further, the Chestnut Volcanics are easily identifiable in the subsurface from either samples or well logs and are now found over an area of approximately 15 square miles. After publication of this paper, the core will be donated to the Oklahoma Geological Survey for further study and preservation.

The Chestnut core begins at a depth of 8,977' in a dark gray or black, finely planar–to–laminated silty shale. This rock was encountered from 8,977' to 9,002.8' and represents the lowermost section of the Middle Ordovician Oil Creek Shale. In conformable contact beneath the Oil Creek Shale, the well encountered 1' of laminated, slightly silty dolomitic micrite. From normal stratigraphic sequence, it is believed that this rock is equivalent to the Joins Formation. Beneath the dolomitic micrite at a depth of 9,003.8', the well drilled into 10.2' of massive, poorly sorted, medium–gray dolomitized volcanic tuff.

Scattered throughout this tuff are lithic xenoliths of medium–crystalline granite, polycrystalline quartz crystals (with vague flow lineations), and pumice. These clasts range in size from 1 mm to 10 cm. Fragmental crystals of feldspar and quartz showing deformation lamellae and chaotic mosaic extinction are restricted to this lithologic interval.

From a depth of 9,014' to 9,037', the core is described as a vesicular, devitrified, lithic– rich, felsic tuff breccia. The groundmass of this rock is a light to medium, yellowish– gray vesicular material consisting of devitrified felsic glass now altered to potassium feldspar and variable amounts of quartz. Embedded in the glassy matrix are abundant lithic fragments. These are angular to rounded, mostly less than 5 cm in diameter, but reaching up to 20 cm. The largest are coarse–grained granite, of which all the quartz and feldspar grains show chaotic mosaic extinction but no deformation lamellae. The granite clasts are believed equivalent to granitic sidewall cores and cuttings from the D&J Lloyd and Gregory wells as described by Roberts and others, 1992. Carpenter and others, 1992, have used radiometric analysis to determine these clasts to be 1.69 billion years old. The present authors interpret these clasts (at 9,014.5') to be xenoliths of Precambrian basement caught up in Ordovician–aged igneous rocks. Fine polycrystalline quartz fragments are also common. These fragments are mostly less than 1 mm in diameter but range up to 2 cm. They show a variety of shapes from bulbous to flattened and lensoid. The lensoid variety commonly show dark, contorted lineations that are concentrated near the clast margin and probably formed by viscous flow. Between 9,014' and 9,017' there are several large pumice–like clasts similar in morphology to the lensoid clasts described above but of a more basic–composition glass.

The dolomitic tuff (DT) and the felsic tuff breccia (FTB) units described above total 35' in thickness as cored. However, the gamma–resistivity log (Figure 2) shows that the FTB unit extends downward to 9,052' at which point another unit with the log signature of the DT interval is repeated (9.052' to 9,090'). Below 9,090' an interval similar in log character to the FTB, though with less gamma radiation, extends to the top of the Arbuckle dolomite at 9,122'. Neutron–density logs of the volcanic rocks described above show that the DT intervals are low porosity with a density of 2.66 gm/cm^3. In contrast, the FTB intervals show high porosity (greater than 30%) and density readings of only 2.57 gm/cm^3. The difference in gamma readings between the upper and lower FTB intervals may be due to secondary concentration of uranium near the surface during weathering. Micrologs across either DT or FTB are similar, showing good separation; however, effective porosity appears to be limited to the FTB interval where vesicular porosity has been fracture enhanced. Finally, borehole imaging logs reveal the presence of clasts which are directly correlative to the granite and pumice clasts in the core (Figure 2).

The proposed lithodemic column is presented with the expectation that other workers will identify and describe genetically related rocks to form a composite stratotype. Certainly the long column of brecciated "granites" drilled in the D&J Gregory (NE NW Section 20–21N–9W) and James (NW NW Section 20–21N–9W) wells needs to be re– examined in light of the descriptions of large granite xenoliths found in the fine–grained devitrified felsic glass matrix of the Chestnut core. Together, the rocks in the Chestnut, the Gregory, and the James wells define a petrogenetically distinct volcanic and plutonic association.

Interpretation

Both the dolomitic tuff and the felsic tuff breccias of the Chestnut Volcanics show evidence of a volatile pyroclastic origin. The texture of the DT and the blocky subequant shapes of many of these pyroclasts suggests shard formation by explosive interaction of molten material with water during

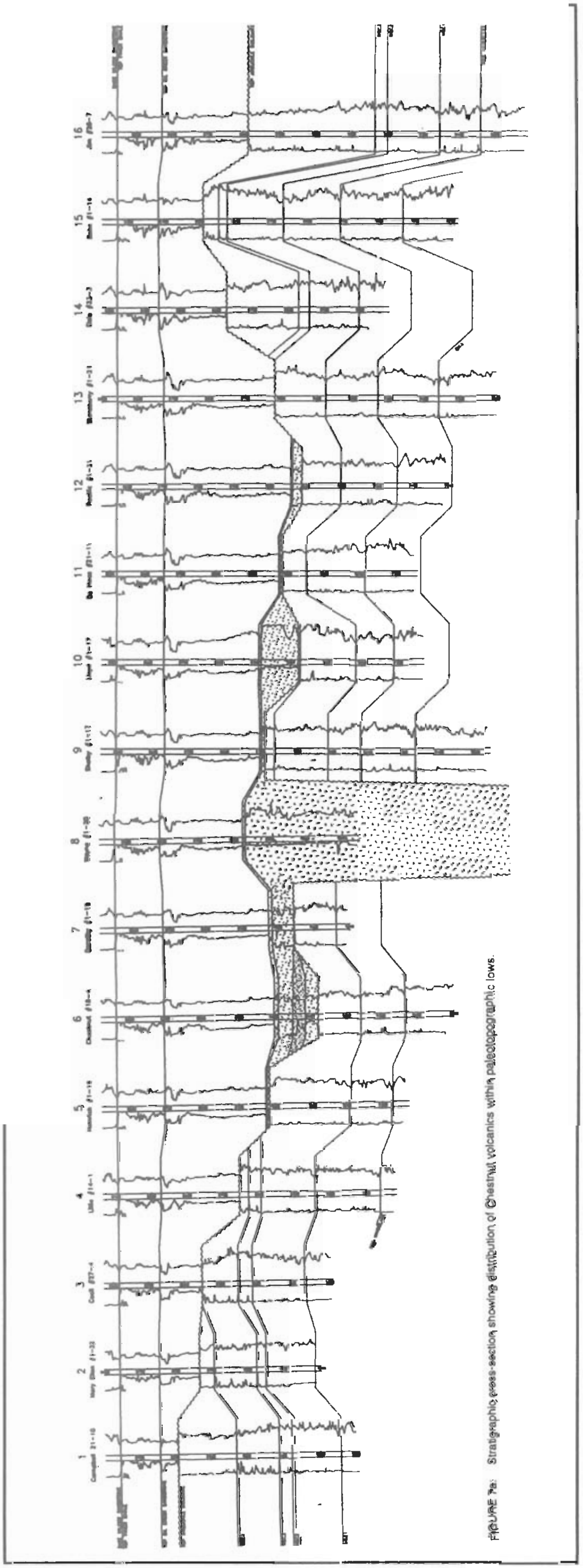


FIGURE 7a: Stratigraphic cross-section showing distribution of Chestnut volcanics within paleotopographic lows.

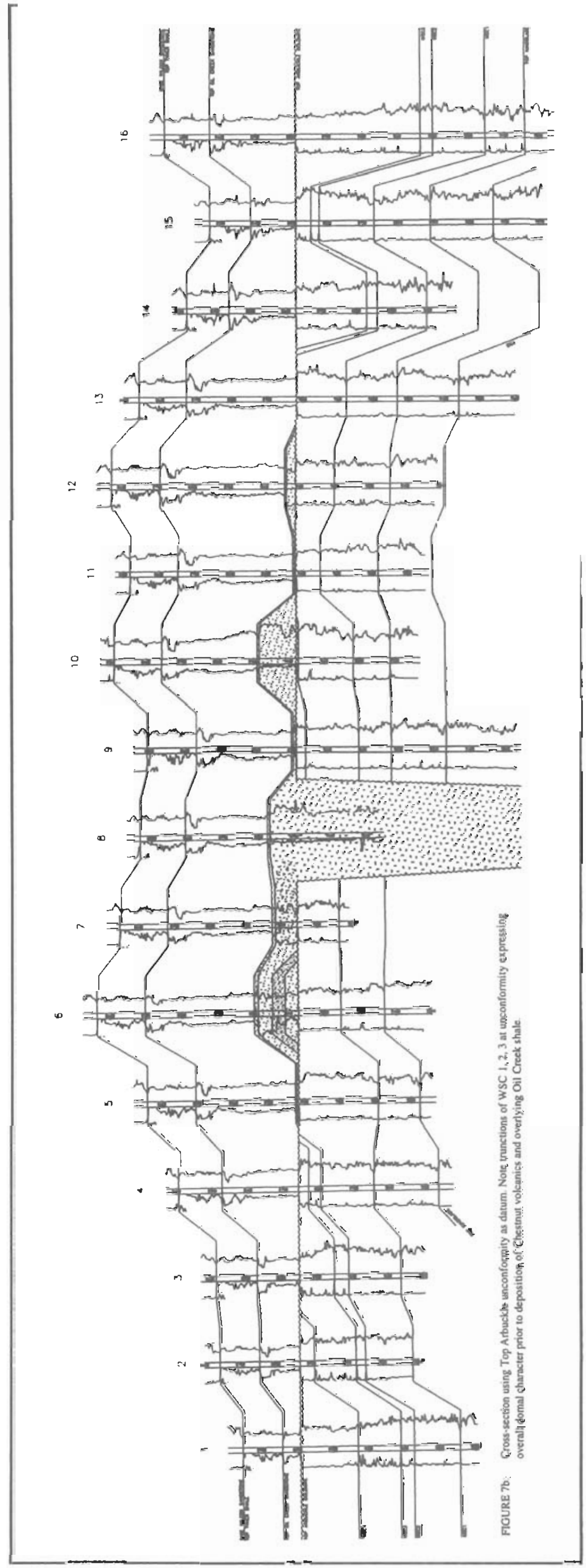


FIGURE 7b: Cross-section using Top Arbuckle unconformity as datum. Note truncations of WSC 1, 2, 3 at unconformity expressing overall domal character prior to deposition of Chestnut volcanics and overlying Oil Creek shale.

phreatomagmatism or hydrovolcanism. The texture and composition of the FTB interval suggests a welded ash–flow tuff. This identification is based upon the spherulitically devitrified ground mass in combination with the presence of flattened, elongate–to–lenticular clasts texturally similar to fiamme, or compacted pumice. Additional textures of polycrystalline quartz show dark colored, internal lineations that are highly contorted and concentrated at clast margins. The margins of many clasts are also gently bulbous to undulatory as if they had once been molten. Although these features are not common within welded ash–flows, they do occur during movement after compaction while still plastic, producing contorted foliation.

Similar lithologic relationships to the Chestnut Volcanics have been described by Snyder and Gerdeman (1965) of the Furnace Creek volcanics in Washington County, Missouri. Here, granite and rhyolite porphyry clasts up to 3" in diameter are incorporated within tuffaceous volcanics. The supposition is that alkaline–rich magmas penetrated into Precambrian basement along a pronounced structural lineament. A sudden release of gas pressure, triggered by fault movement, vacated the magma chamber and domed the overlying sediments. This was followed by phreatomagmatism and massive brecciation with vertical collapse of the central core. Continued streaming of gasses carrying rock fragments formed intensive breccia dikes. This interpretation appears to apply to the Chestnut Volcanics and, as will be discussed later, supports a transverse shear origin where mid–lithospheric zones of partial melting are connected to the surface by narrow and vertical upper mantle and lower crustal shear zones. These zones splay into the brittle upper crust in a braided, discontinuous pattern of normal and strike slip faults.

Distribution of Volcanic Rocks

Figure 7 is a west–to–east stratigraphic cross section through the Ames hole depression. The previously described Kindblade and West Spring Creek formations are labeled Ok and $Owsc_1$, while upper zones within the West Spring Creek are noted by $OWSC_{234}$ respectively. The major conclusions indicated by this cross section include the following: 1) obvious truncation of the West Spring Creek formation; and 2) the presence of the Chestnut Volcanics occupying paleotopographic lows where the underlying West Spring Creek has been deeply truncated.

Within the Ames area, the Chestnut Volcanics are presently found and appear limited to an area of approximately 7,700 acres generally described as the southwest quarter of T21N–R9W. Four areas occur within that region where wells have drilled in excess of 250' of igneous rock without encountering Arbuckle Dolomite. These areas are identified on Figures 8 and 9 and hereafter referred to as igneous pipes.

Igneous pipes are identified not only from anomalous thickness of igneous material encountered, but also from a change over short distances from thick igneous suites to unaltered Arbuckle Dolomite. This relationship is observed in the SW SW NE Section 31 T2IN–R9W, where the Continental Resources 1–31 Fred, which drilled 508' of igneous rocks, was offset only 1,000' to the southwest by the DLB 31–11 Jimmy. The

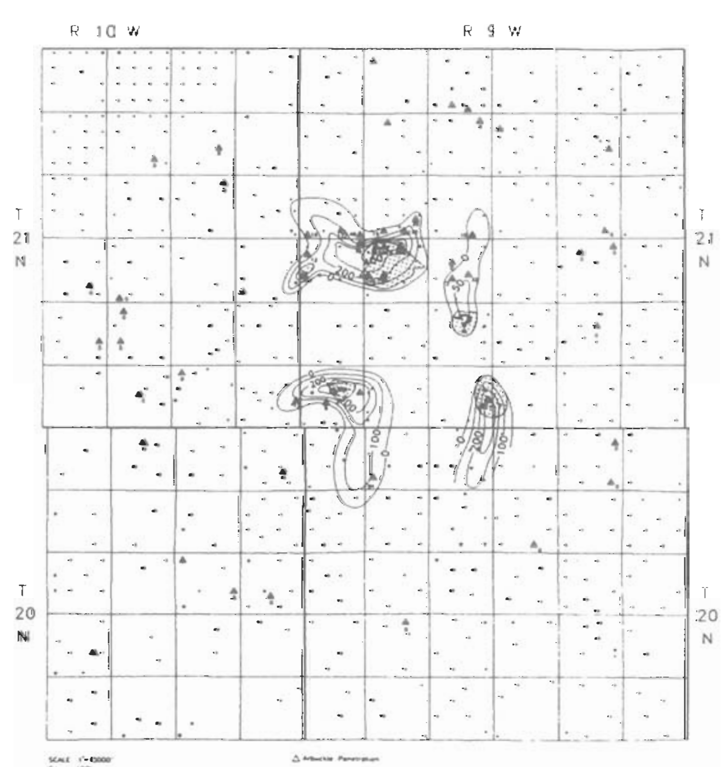


FIGURE 8: Gross Isopach Map of the Chestnut Volcanics. Map includes both Dolomitic Tuff (DT) and Felsic Tuff Breccia (FTB) described in text. Stipplied areas are igneous pipes.

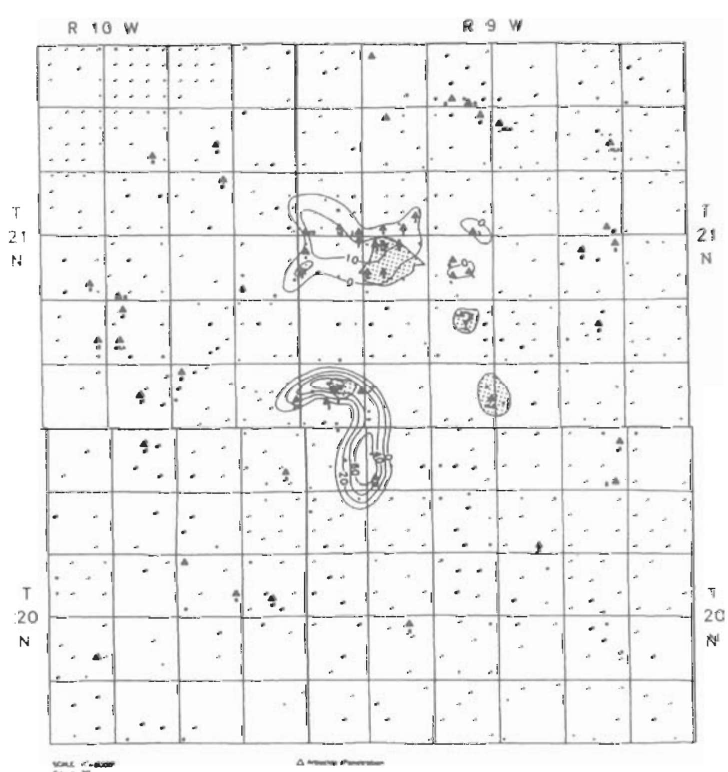


FIGURE 9: Isopach Map, Upper Dolomitic Tuff (DT) of Chstnut Volcanics. Stipplied areas are igneous pipes.

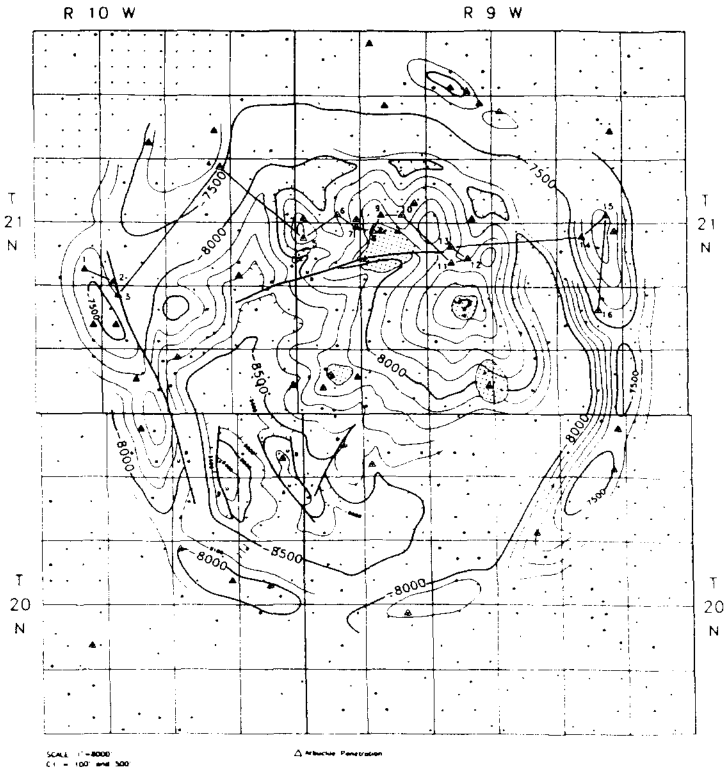


FIGURE 10: Top Arbuckle Unconformity. Represents the surface on which the Chestnut Volcanics accumulated. Line of cross-section is figures 7a and 7b.

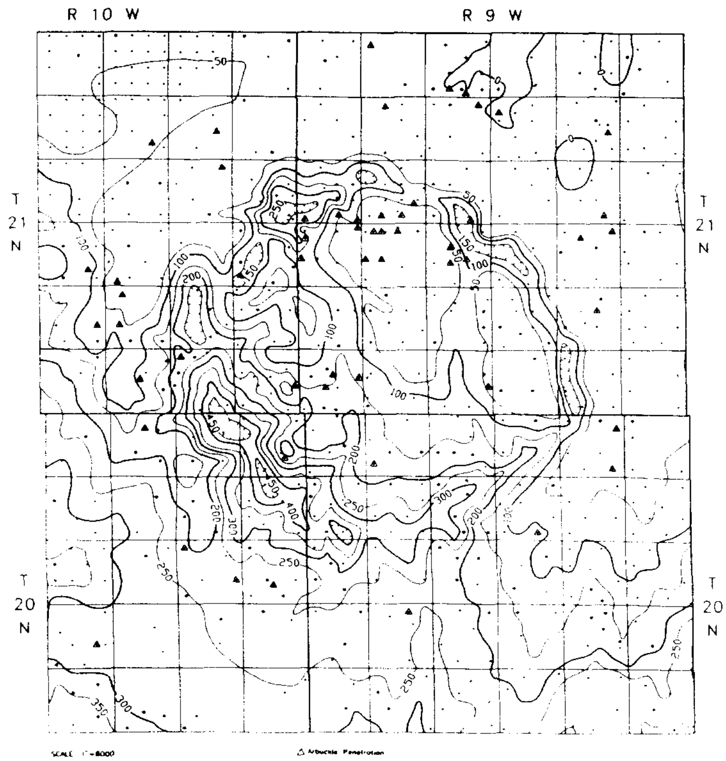


FIGURE 11: Isopach Map, Hunton Limestone.

Jimmy found only 8' of volcanic tuff overlying the Arbuckle Dolomite. Interestingly, the structure at the top of the Arbuckle unconformity in the Jimmy was 33' above the top of igneous rock in the Fred well. It would appear that the Fred well represents a lateral vent out the side of a hill located immediately to the south.

A similar feature may exist at the Continental 1–19 Chet well (NW SW section 19). This well originally encountered 203' of igneous rock and was later whipstocked toward the east as a horizontal igneous Arbuckle penetration. The igneous rock in the sidetrack portion of the well only measured 35' thick. It is uncertain whether these boreholes encountered the edge of an igneous pipe or a volcanic flow.

In addition to those wells which are identified as drilling into igneous pipes, at the time of this paper, 14 wells had drilled volcanic rocks overlying Arbuckle Dolomite. As previously mentioned, Figure 7a illustrates, in cross–section form, the relationship of "pipes" to "flows" to paleotopographical relief. The NICOR 18–4 Chestnut is an outstanding example of this relationship. The Chestnut well encountered 111' of felsic tuff breccia capped with 11' of volcanic tuff in conformable contact with overlying Oil Creek Shale. The upper 37' of volcanic interval was cored. The lower 85' of volcanic section was identified from sample log descriptions, downhole geophysical logs and imaging devices.

Regional mapping of igneous and volcanic units in the Ames structural depression is revealing. Figure 8 is a gross "igneous" isopach showing the limited distribution of these rocks to small areas around the suspected igneous pipes (i.e., source areas). Figure 10 is a structure map on the Arbuckle unconformity, the surface on which the volcanic rocks rest. This map reveals the relationship between paleotopographic lows and volcanic thicks. For example, the Chestnut 18–4 encountered the Arbuckle unconformity 108' low to the offsetting D&J Peggy 1–18 (SE SE SE Section 18–21N–9W) and 71' low to the U.R.C. Dixon 2–18 (SW SW SW Section 18–21N–9W). In contrast to the 122' of volcanics encountered in the Chestnut 18–4, the Peggy 1–18 found 46', and the Dixon 16'.

Figures 8 and 10 put the above comparison into a broader regional picture. A similar relationship to that described above can be illustrated in the south half of Section 17–21N– 9W. Here, the D&J Lloyd 1–17 (SW SE Section 17–21N–9W) is 98' low to the D&J Shelby 1–17 (SW SE Section 17–21N–9W) and 37' low to the D&J Mary Helen (NE NE SE Sec. 17–21N–9W) as measured on the post–Arbuckle unconformity. The Lloyd found 112' of volcanic flow rocks, while the Shelby encountered 15' and the Mary Helen 20'.

The two lows measured on the post–Arbuckle unconformity in the Chestnut 18–4 and Lloyd 17–1 wells appear to represent topographic "valleys" leading away from the igneous pipe (Wayne 1–20 NW NW Section 20). This reasoning is further substantiated by the distribution of dolomitic tuff (DT) which was recovered in the Chestnut 18–4 core. Detailed mapping of this unit (Figure 9) shows that its depositional limits are essentially identical to those areas of Felsic Tuff Breccia (FTB). This correlation, in conjunction with the identification of ignimbrite thicks within paleotopographic lows implies that both the FTB and DT extrusions sought out topographic lows and flowed laterally away from the source vent. The limited area over which the tuff is found also suggests that this was a minor extrusive event and little material actually ex-

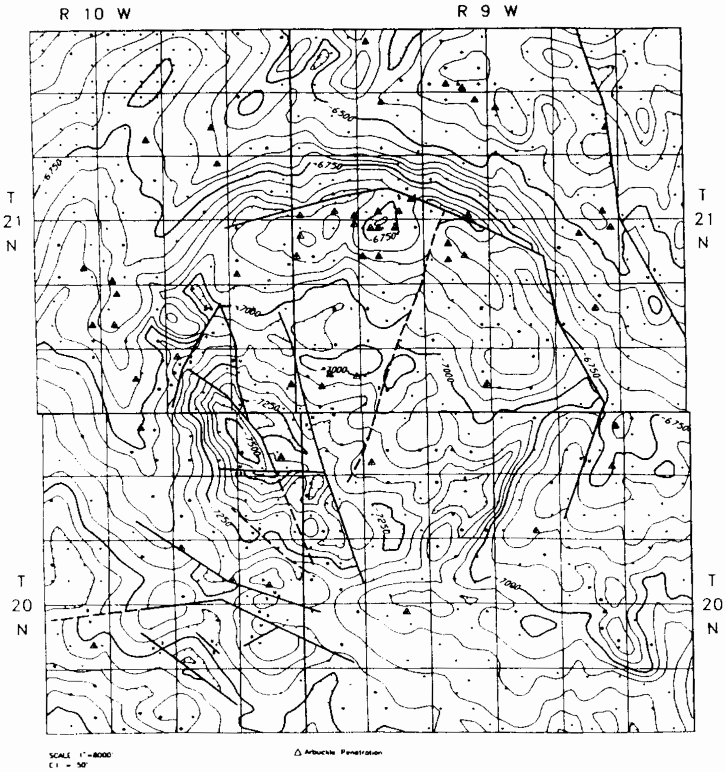


FIGURE 12: Structure Map, Top Sylvan Shale.

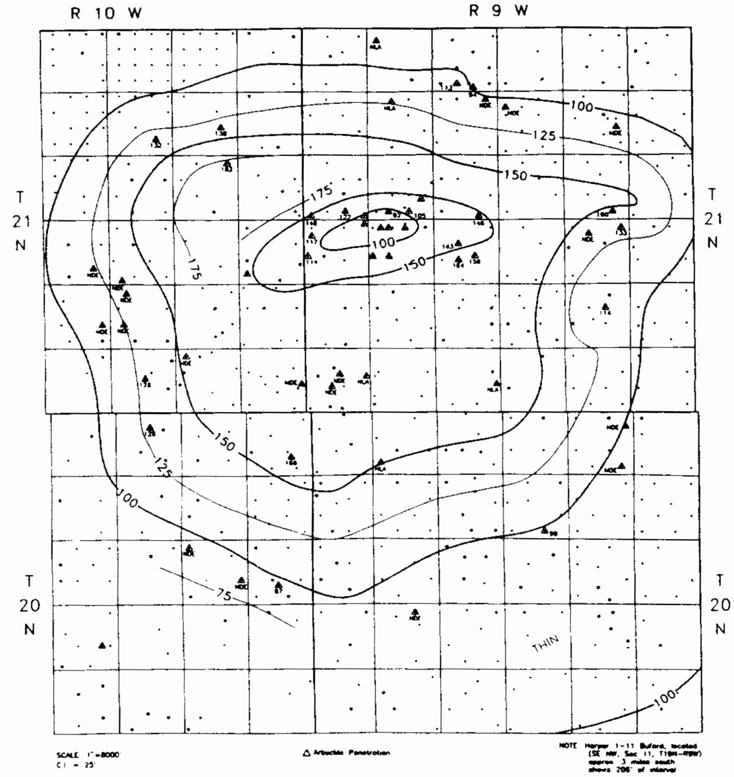


FIGURE 13: Isopach Map, Lower West Spring Creek interval; Top Kindblade to WSC 1. Shows early subsidence of Ames depression. Early development of thin within depression.

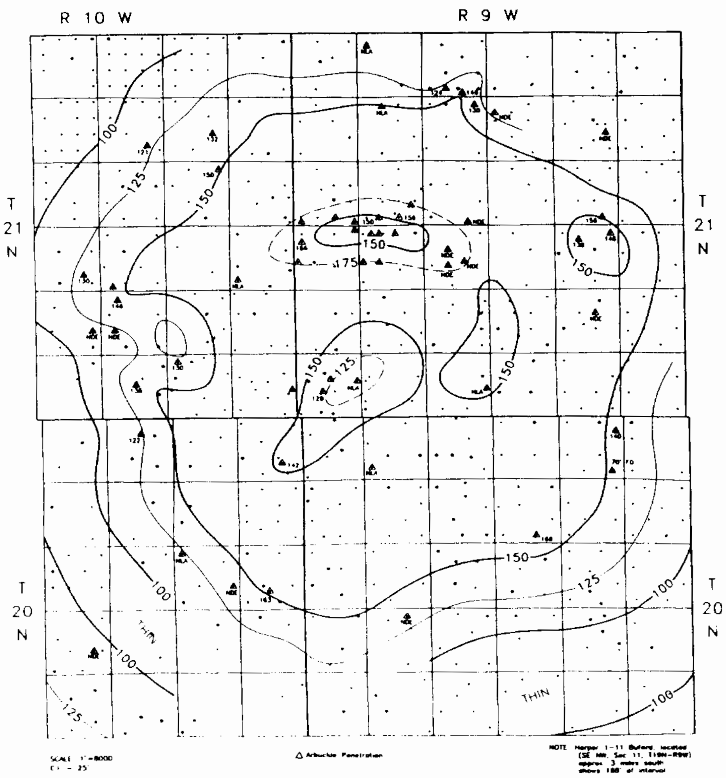


FIGURE 14: Isopach Map. Middle West Spring Creek interval WSC1 to WSC2. Map shows continued subsidence of Ames depression and further development of intra-depression thins.

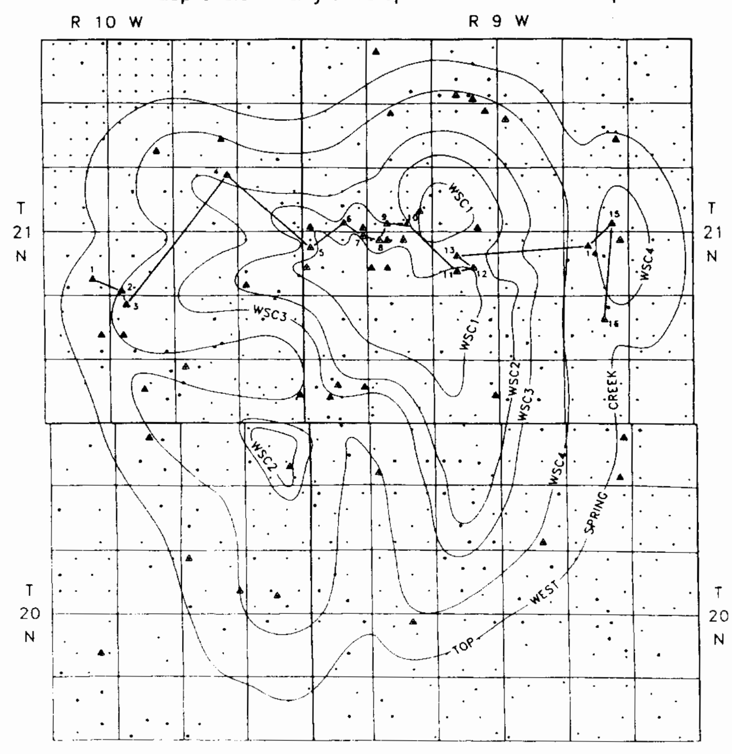


FIGURE 15: Subcrop Map prior to accumulation of Chestnut Volcanics. Stratigraphic sequence, WSC1 is older than WSC2 thru Top West Spring Creek. This reveals presence of broad dome following post-Arbuckle erosion. Line of cross-section is Figures 7a and 7b.

truded airborne.

Finally, the lower tuff in the Chestnut 18–4 implies a multistage diachronous extrusive event. The Chestnut well records two separate episodes of ignimbrite flows separated by the accumulation of volcanic tuff (9,052 to 90') subsequently capped by another volcanic tuff (9,002' to 9,012'). The Continental Resources Chet 1–19 NW NW SW Section 19– 21N–9W shows a similar relationship of two felsic tuff breccias separated by a dolomitic tuff (9,097' to 9,114') and subsequently capped by another dolomitic tuff (9,070' to 9,076').

Geologic Evolution of the Ames Structural Depression: Description of Maps

A series of isopach maps have been constructed to explore the timing of movements within the Ames anomaly. Without exception these maps, from the Hunton Formation downward to the top Kindblade member of the Arbuckle Group, show that the southwest quadrant of township 21N–R9W was thin throughout the Ordovician, suggesting that this area was always structurally positive. This central high was surrounded by a pronounced paleotopographic thick or structural low which is best observed on the Hunton interval isopach (Figure 11) where thick Hunton strata have been preserved. This area has been referred to by some writers, as the "Hunton Graben". The structural low area is itself surrounded by an outer isopach thin which corresponds to a structural high as expressed on the present–day Sylvan structure map (Figure 12).

Correlations within the West Spring Creek Member of the Arbuckle Group have permitted the construction of two isopach maps, Figures 13 and 14; and a subcrop map, Figure 15. The isopach map of West Spring Creek Unit 1 is a series of rocks 85' to 200' in thickness directly overlying the Kindblade member of the Arbuckle Group. West Spring Creek Unit 2 is the companion isopach map for that group of rocks which varies in thickness, from 121' to 168', directly overlying Unit 1. Both isopachs reveal a concentric thin that happens to underlie the much shallower Sylvan concentricline. Thickening of both Units 1 and 2 occurs toward the southwest quadrant of T21N–R9W, although within the center of each map, isolated thins occur in areas previously identified as igneous pipes.

Although the two isopachs discussed above reveal a small basin with central thins, the subcrop map, Figure 15, on the pre–Oil Creek Shale, pre–igneous (Arbuckle Unconformity) surface shows just the opposite. Correlations within the Arbuckle are found to subcrop in a concentric fashion, oldest rocks in the center, outward to progressively younger rocks. It is intriguing that the older interior rocks are structurally as high today as those younger fringing rocks, thus indicating a structural dome that was uplifted at the end of Arbuckle deposition and eroded prior to deposition of the previously described Chestnut Volcanics or the overlying Oil Creek Shale. This is further illustrated by Figure 7b.

Comparison of the Arbuckle Group Subcrop Map, Figure 15, with the Sylvan Shale Structure Map, Figure 12, suggests that a relationship of the Sylvan concentricline to the Arbuckle cuesta surrounding the Ames Hole may exist. The cuesta may have propagated itself upward, through thinning and differential compaction, to at least be partially responsible for the Sylvan structure.

Following eruption of the Chestnut Volcanics, the Ames anomaly once again began to subside. Figures 16 and 17 show thickening into the Ames hole from early Oil Creek time through the end of Sylvan deposition. Central thins closely related to known igneous pipes continue to persist up through the beginning of Hunton time. Stability of the central thin area can be attributed to strength imparted by an underlying igneous intrusion and the existence of vertical pipes of igneous rocks piercing the surrounding Arbuckle carbonates. These pipes probably acted as structural "struts" around which the overlying sediments were deposited and differentially compacted. The late subsidence may be the result of further collapse into a rift system, as will be discussed further in this paper.

Map Summation

The foregoing discussion of maps permits the following conclusions regarding the evolution of the Ames depression:

1. The "Hunton Graben" is actually as old as late Kindblade (lower Ordovician) as evidenced by isopachs of the West Spring Creek formation.
2. Thin areas within the depression also persisted throughout the Ordovician and are closely related to the source pipes of the Chestnut Volcanics.
3 Domal uplift occurred at the end of Arbuckle deposition followed by erosion and thereafter extrusion and accumulation of volcanic rocks on the post–Arbuckle topographic surface.
4. By earliest Oil Creek time, the Ames depression was again subsiding.

Tectonic Regime & Setting of the Ames Structural Depression

The Ames structural depression is situated within the southern portion of the Mid– Continent Rift (MCR), an extensive Precambrian feature that extends from north Texas northeastward to Lake Superior (Figure 18). Yarus and others, 1987, describes the southern portion of the MCR as showing high gravity and magnetic values in the rift center, flanked by lower values along the edges. These flank areas are believed to be basins filled with low–density rocks.

On a local scale, Figure 19 shows a Bouguer gravity anomaly map for north–central Oklahoma. The major gravity positive areas mark the position of the MCR. These gravity positives are also associated with magnetic highs. The Ames depression is the circular gravity low centered in T20 and 21N, R9 and 10W. This feature has a corresponding magnetic minimum and is, thus, suggestive of a flanking basin peripheral to the rift center. The low–density, highly sialic composition of the Chestnut Volcanics would appear to substantiate this conclusion.

Immediately north of the Ames depression is a pronounced east–west lineation (Figure 19) extending across T21N, R5,6,and 7W which Luza and others, 1983, have designated as a right–lateral, strike slip fault with 10–12 miles of offset. This fault shows offset through Late Pennsylvanian time; however, these authors suggest that it may have originated as early as the Precambrian. Lyons, 1987, notes that the course of the MCR is broken in continuity by frequent offsets similar to "transform" faults as-

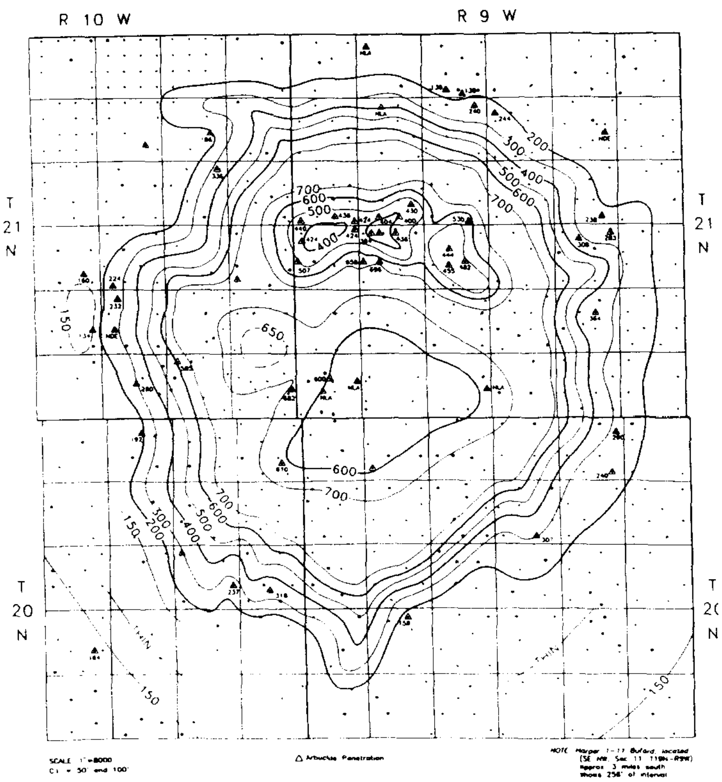


FIGURE 16: Interval Isopach, Top Oil Creek (Tyner) Shale to Top Arbuckle Unconformity or Top Igneous Unconformity.

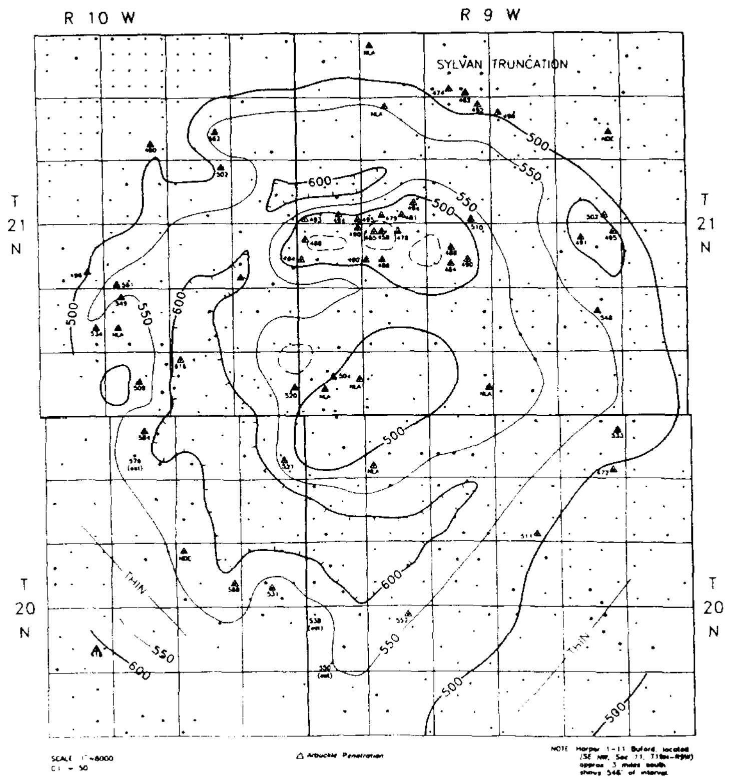


FIGURE 17: Interval Isopach, Top Sylvan to Top Oil Creek (Tyner) Shale.

sociated with the Mid–Atlantic Ridge. He suggests that portions of the MCR are connected via these transform systems to portions of the Appalachian Trough in the Eastern United States. Support of this theory can be demonstrated by a series of circular, explosive, igneous disturbances which occur along the 38th parallel latitude. These features extend from a line immediately north of the Kansas–Oklahoma border and extend eastward through southeast Kansas, Missouri, and Southern Illinois (Figure 18). Snyder and Gerdemann (1965) describe these circular features as cryptoexplosion events characterized by intrusive or extrusive igneous activity and/or localized deformation. Two of these features appear as roughly circular disturbed areas, each with an intensely brecciated core, a well–defined ring pattern, and a central zone containing abundant shatter cones. The ages of these events range from Late Cambrian to Permian and suggest deep–seated, explosive activity along a zone of transverse shear. Cartwright (1992) suggests that magmas generated at depths of 37 miles often are associated with transverse shear zones and individualized pull–apart basins along the Rio Grande Rift in the Western United States.

In Wisconsin, a well–documented cryptoexplosion structure of Ordovician age (i.e., Rock Elm structure, Figure 18) like the Ames anomaly, is located proximal to a suspected transform fault system along a flanking basin within the Mid–Continent Rift. Cordua, 1985, describes a central dome, breccia pipes, ring basin fill and a ring boundary fault of similar size to the Ames depression. Like Ames, this feature shows plastic deformation of pyroclastic clasts but no megascopic deformation features such as shatter cones, tektites, or shattered quartz. The coincident age and tectonic setting of the Rock Elm structure with the Ames structural depression is suggestive of an Ordovician age reactivation event along the Mid–Continent Rift, and/or its associated transform systems.

Another cryptoexplosion structure of significance is the Manson anomaly in Pocahontus County, Iowa. This 21.9 mile diameter crater is coincident with the end of the Cretaceous Period (65.7 Ma) and is thought to have originated from an impact of a chondritic bolide with a diameter of about 1.3 miles (Anderson, 1992). The Manson anomaly has similar geomorphic expressions to both the Ames and Rock Elm features. Although the Manson anomaly exhibits features characteristic of a meteor impact, and its age is much younger than either the Ames or Rock Elm structures, its coincident location adjacent to the Mid–Continent Rift is suggestive of a common origin.

Finally, Byler, 1992, has documented over 100 circular features in the U.S. and Canada which he interprets as manifestations imposed by deep basement structures. The implication of circular features with or without megascopic deformation commonly associated with meteor impacts (i.e., shattered quartz, shatter cones, tektites, etc.) must be reviewed in context of both timing and regional tectonic setting before an implication of origin can be made.

Conclusion

The evidence presented herein supports the following conclusions:

1. The Ames structural depression originated as a small sub–basin peripheral to the Mid– Continent Rift.

2. The West Spring Creek and Kindblade members of the Arbuckle Group have been identified in the Ames depression. Correlation of these units is not difficult and allows for study of the early history of the structural anomaly.

3. Isopach maps of the West Spring Creek formation reveal depositional thickening into the Ames depression but with thinning over localized topographic highs. These topographic highs represent an upward rising magma plume.

4. Domal uplift with subsequent truncation and karstification of the Arbuckle Group occurred at the end of West Spring Creek deposition. Uplift resulted from an intrusion of magma triggered by fault movement.

5. Phreatomagmatism accompanied by massive brecciation and collapse of the central core resulted in the extrusion of the Chestnut Volcanics onto the Arbuckle topographic surface. Extrusion occurred as two distinct flows located proximal to igneous stocks and accumulated in paleotopographic lows.

6. The Chestnut Volcanics resulted from movement along a transverse shear where mid– lithospheric zones of partial melting are connected to the surface by narrow and vertical upper mantle and lower crustal shear zones. These zones splay into the brittle upper crust in a braided, discontinuous pattern of normal and strike–slip faults.

7. Evidence of strike–slip faulting immediately north of the Ames depression is evident on gravity and magnetic data.

8. The Ames depression and its volcanic rock assemblage is consistent with known circular cryptoexplosion features trending east to west along the 38th parallel latitude. It is also consistent with circular cryptoexplosion features trending north to south along the Mid–Continent Rift.

Circular, cryptoexplosion events of varying ages are common along regional tectonic lineament trends in North America. Therefore, the identification of circular features, as to origin, must be reviewed in context of both timing and regional tectonic setting. The isopach evidence presented herein documents an endogenic origin with a prolonged history of development for the Ames depression.

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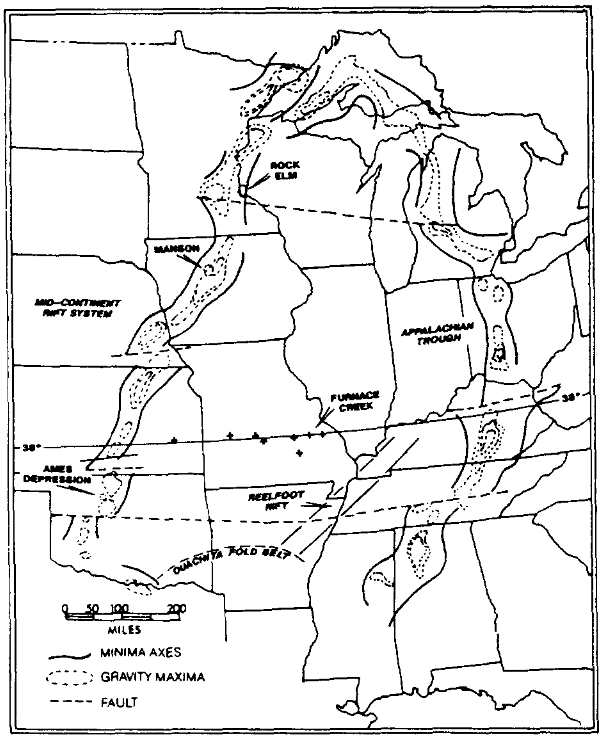

FIGURE 18: Proposed extent of the Mid-Continent Rift (modified from Lyons, 1987). Showing the regional setting of the Ames depression. Lyons' suggests that E-W trending lineaments are transform faults. The cryptoexplosion features along the 38° parallel suggests a connection between the Mid-Continent rift and the Appalachian Trough.

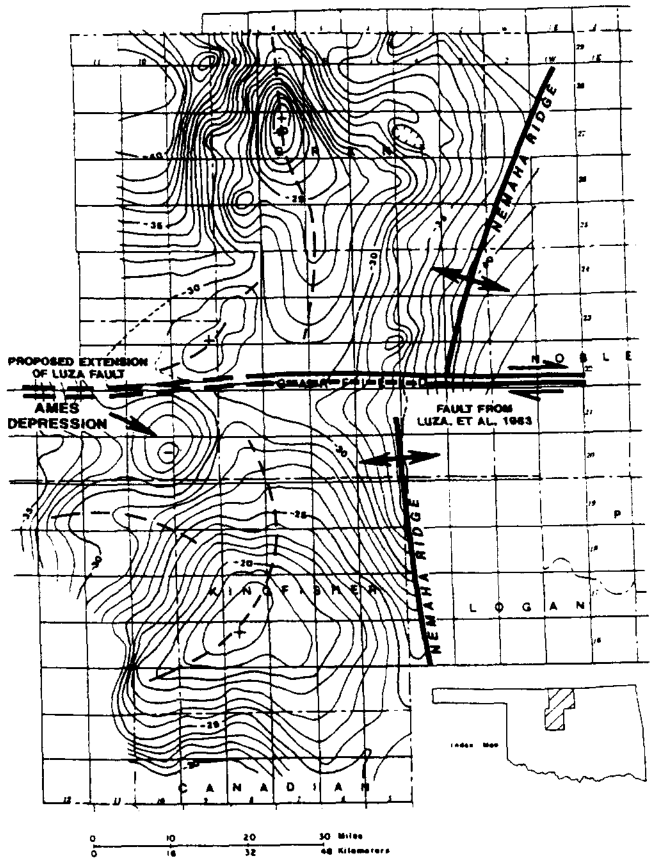

FIGURE 19: Bouguer gravity-anomaly map of north-central Oklahoma. Modified from Barrett (1980), Santiago (1979) and Luza and Lawson (1983). Showing positions of Ames gravity anomaly with respect to the Mid-Continent Rift gravity maxima and suspected Precambrian faulting.

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