Prepared in cooperation with Oklahoma State University and the Oklahoma Water Resources Board

Three-Dimensional Geologic Model of the Arbuckle-Simpson Aquifer, South-Central Oklahoma

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Contents

Figures

Table

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Abstract

The Arbuckle-Simpson aquifer of south-central Oklahoma encompasses more than 850 square kilometers and is the principal water resource for south-central Oklahoma. Rock units comprising the aquifer are characterized by limestone, dolomite, and sandstones assigned to two lower Paleozoic units: the Arbuckle and Simpson Groups. Also considered to be part of the aquifer is the underlying Cambrian-age Timbered Hills Group that contains limestone and sandstone. The highly faulted and fractured nature of the Arbuckle-Simpson units and the variable thickness (600 to 2,750 meters) increases the complexity in determining the subsurface geologic framework of this aquifer.

A three-dimensional EarthVision™ geologic framework model was constructed to quantify the geometric relationships of the rock units of the Arbuckle-Simpson aquifer in the Hunton anticline area. This 3-D EarthVision™ geologic framework model incorporates 54 faults and four modeled units: basement, Arbuckle-Timbered Hills Group, Simpson Group, and post-Simpson. Primary data used to define the model's 54 faults and four modeled surfaces were obtained from geophysical logs, cores, and cuttings from 126 water and petroleum wells. The 3-D framework model both depicts the volumetric extent of the aquifer and provides the stratigraphic layer thickness and elevation data used to construct a MODFLOW version 2000 regional groundwater-flow model.

Introduction

The Arbuckle-Simpson aquifer is the principal water resource for south-central Oklahoma and is designated a sole source aquifer by the U.S. Environmental Protection Agency. The geology that confines the Arbuckle-Simpson aquifer crops out over an area of about 850 square kilometers according to the Oklahoma Water Resource Board at: (http://www.owrb.ok.gov/studies/groundwater/arbuckle_simpson/arbuckle_study.php). The subsurface geologic framework of the Hunton anticline area (fig. 1) was poorly defined prior to this study because of the folded, faulted, and fractured nature of the geology, variable unit thicknesses from 600 to 2,750 meters, and minimal well control.

Previous geologic mapping was conducted primarily by academic institutions and the Oklahoma Geological Survey in the mid-twentieth century. During the last half of this century, most petroleum wells drilled in the Arbuckle, Hunton, and Tishomingo anticlines (fig. 1) were found to be unproductive. In the 1990s, a renewed interest to better understand the regional geology and continental tectonics of southern Oklahoma occurred.

A three-dimensional (3-D) EarthVision™ (EV) geologic framework model, which characterizes the geometric relations and subsurface architecture of the geology of the Hunton anticline area, is summarized in this report. This 3-D EV model contains four modeled geologic units (table 1) and 54 primary and secondary faults. For this report, major faults are defined as having long linear extents and displacements greater than 200 meters. The construction of the model involved integrating geologic and geophysical data from existing maps and surveys, and data from 126 drill holes.

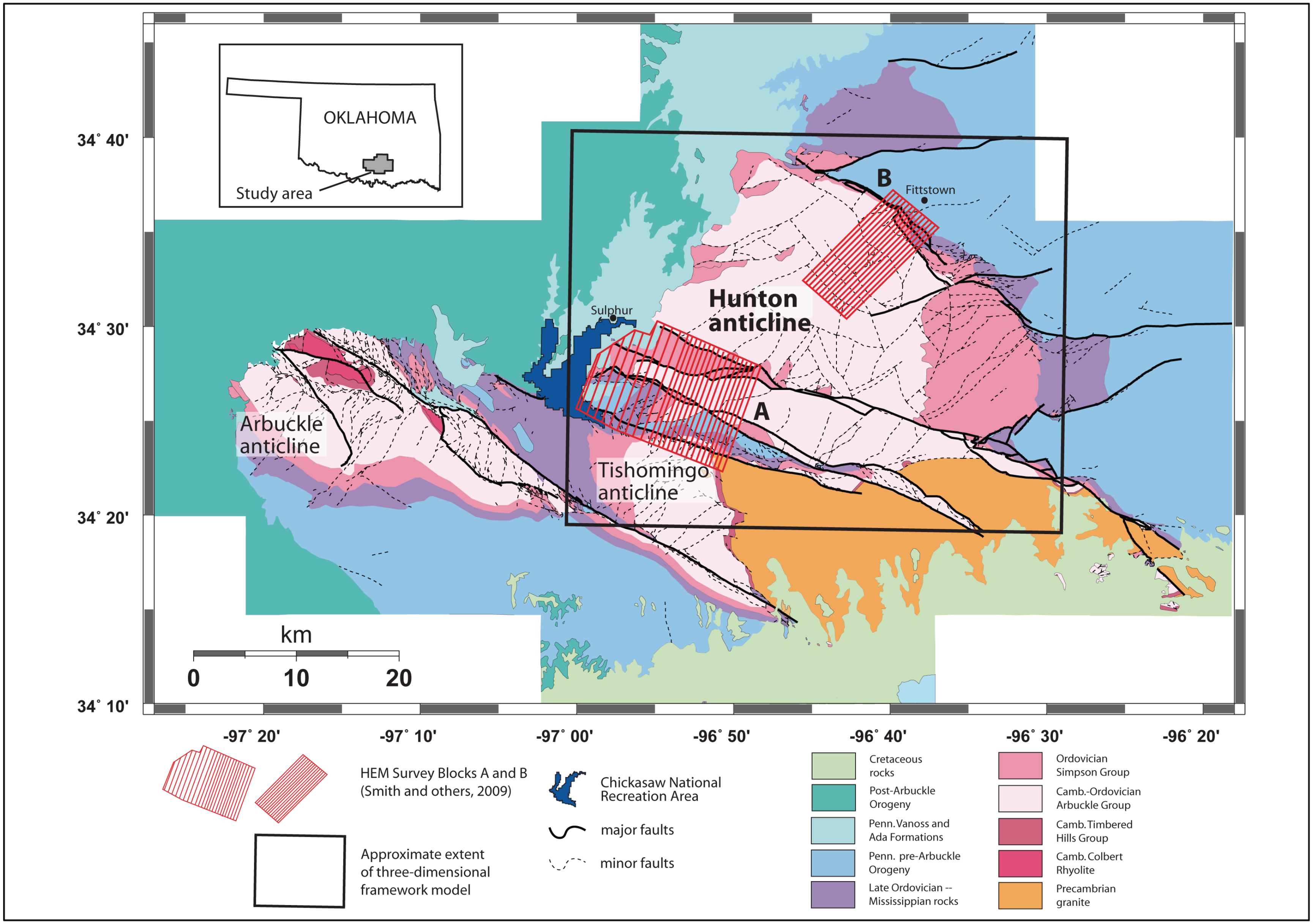

Figure 1. Generalized geology of the Arbuckle, Hunton, and Tishomingo anticlines, Oklahoma, and spatial extent of three-dimensional EarthVision™ model.

Purpose and Scope

In cooperation with the USGS Oklahoma Water Science Center, Okalahoma Water Resources Board, and Oklahoma State University, a three-dimensional geologic framework model was developed to more accurately define the Paleozoic geology and fault structures of the Hunton anticline area (fig. 1). This cooperative study was sought because the geologic framework of the Hunton anticline area affects groundwater-flow and aquifer volume. A 3-D EV model, supported by the USGS National Cooperative Geologic Mapping Program (NCGMP), was built to provide the stratigraphic and structural framework for constructing a MODFLOW (version 2000) groundwater-flow model of the Hunton anticline area. The USGS MODFLOW modeling effort was supported by the Oklahoma State- and federally-funded Arbuckle-Simpson Hydrology Study at: http://www.owrb.ok.gov/studies/groundwater/arbuckle_simpson/arbuckle_study.php.

Geologic Setting

The Arbuckle Mountains consist of folded and faulted Proterozoic granitic and metamorphic rocks, Cambrian rhyolitic rocks, and Cambrian through Early Permian sedimentary rocks. Within the Arbuckle Mountains, the Timbered Hills and progressively younger Arbuckle, and Simpson Groups, makeup the Arbuckle-Simpson aquifer (table 1). The Timbered Hills and Arbuckle Groups are modeled as a single unit because of limited subsurface control. These groups are underlain by Proterozoic and Cambrian rocks. Basement rocks within the 3-D EV model area crop out locally in a few small inliers within the Tishomingo anticline and in areas south of the Hunton anticline where intense faulting elevated the basement rocks to the surface (fig. 1). Basement rocks as deep as 2,500 meters below ground surface (Campbell and Weber, 2006), were identified in 11 drill-hole logs.

Paleozoic rock units thin across the Hunton anticline and thicken to the southwest in the Tishomingo and Arbuckle anticlines. The magnitude of structural deformation also increases to the southwest, with predominantly low-dip angle (less than 20 degrees) exposures of the Hunton anticline compared to complex faulting and steeply dipping to overturned stratigraphy in the Arbuckle anticline to the west (fig. 1).

<table>
<tr><th>Time-stratigraphic unit</th><th colspan="2">Rock-stratigraphic unit</th><th>Aquifer unit</th><th>Model unit</th></tr>
<tr><td>Permian</td><td rowspan="15">Post-Simpson</td><td>Stratford Formation</td><td rowspan="15">Upper confining unit</td><td rowspan="15">Post-Simpson</td></tr>
<tr><td rowspan="6">Pennsylvanian</td><td>Vanoss Group</td></tr>
<tr><td>Ada Formation (Collings Ranch Conglomeratet)</td></tr>
<tr><td>Deese Group (Desmoinesian Series)</td></tr>
<tr><td>Atoka Formation</td></tr>
<tr><td>Wapanucka Formation</td></tr>
<tr><td>Springer Formation</td></tr>
<tr><td rowspan="3">Mississippian</td><td>Caney Shale</td></tr>
<tr><td>Sycamore Limestone</td></tr>
<tr><td>Woodford Shale</td></tr>
<tr><td>Devonian</td><td rowspan="2">Hunton Group</td></tr>
<tr><td>Silurian</td></tr>
<tr><td rowspan="2">Upper Ordovician</td><td>Sylvan Shale</td></tr>
<tr><td>Viola Group</td></tr>
<tr><td rowspan="5">Middle Ordovician</td><td rowspan="5">Simpson Group</td><td>Bromide Formation</td><td rowspan="17">Arbuckle-Simpson aquifer</td><td rowspan="5">Simpson</td></tr>
<tr><td>Tulip Creek Formation</td></tr>
<tr><td>McLish Formation</td></tr>
<tr><td>Oil Creek Formation</td></tr>
<tr><td>Joins Formation</td></tr>
<tr><td rowspan="5">Lower Ordovician</td><td rowspan="8">Arbuckle Group</td><td>West Spring Creek Formation</td><td rowspan="10">Arbuckle-Timbered Hills</td></tr>
<tr><td>Kindblade Formation</td></tr>
<tr><td>Cool Creek Formation</td></tr>
<tr><td>McKenzie Hill Formation</td></tr>
<tr><td>Butterly Dolomite</td></tr>
<tr><td rowspan="5">Upper Cambrian</td><td>Signal Mountain Formation</td></tr>
<tr><td>Royer Dolomite</td></tr>
<tr><td>Fort Sill Limestone</td></tr>
<tr><td rowspan="2">Timbered Hills Group</td><td>Honey Creek Formation</td></tr>
<tr><td>Reagan Sandstone</td></tr>
<tr><td>Middle Cambrian</td><td colspan="2">Colbert Rhyolite</td><td rowspan="2">Lower confining unit</td><td rowspan="2">basement</td></tr>
<tr><td>Proterozoic</td><td colspan="2">Tishomingo Granite, Troy Granite, granodiorite, and granitic gneiss</td></tr>
</table>

Table 1. Comparison of time-stratigraphic, rock-stratigraphic, geologic, and model stratigraphic units in the Hunton anticline area

Stratigraphy

The oldest rocks in the Hunton anticline area include the Proterozic Tishomingo Granite, Troy Granite, unnamed granodiorite, and granitic gneiss as well as the Middle Cambrian Colbert Rhyolite. For this model, these rocks are combined as the "basement unit" (table 1).

The Cambrian-age Timbered Hills Group, consisting of the Reagan Sandstone and the Honey Creek Formation, unconformably overlies Proterozoic and Middle Cambrian basement rocks (fig. 1 and table 1). The Reagan Sandstone is a Paleozoic transgressive sandstone that lies directly on Precambrian basement rocks and its composition and texture are markedly influenced by the underlying basement. The Reagan Sandstone can either be quartzose, arkosic, feldspathic; or glauconitic, and ranges texturally from fine- to coarse-grained. The overlying Honey Creek Formation is a sandy dolomite in the Hunton anticline area. These units are up to 125 meters and 40 meters thick, respectively, in the model area. Because little is known about the water-bearing properties of the Timbered Hills Group, and there is no identifiable confining layer that separates the Timbered Hills Group from the Arbuckle Group, the Timbered Hills Group and Arbuckle Group are combined as the "Arbuckle-Timbered Hills model unit" (fig. 2 and table 1).

The Arbuckle Group of Late Cambrian to Early Ordovician age consists of a thick sequence of carbonate rocks, up to 2,050 meters thick in the western part of the Hunton anticline area. In areas where the Arbuckle Group is structurally high over the crest of the Hunton and Belton anticlines (fig. 2), the upper part has been eroded leaving it to be about 915 meters thick in the model area based on limited drill-hole data (Campbell and Weber, 2006). The Arbuckle Group is comprised of eight formations based on lithostratigraphy and biostratigraphy (table 1). These formations are, in ascending stratigraphic order, the Fort Sill Limestone, Royer Dolomite, Signal Mountain Formation, Butterly Dolomite, and the McKenzie Hill, Cool Creek, Kindblade, and West Spring Creek Formations.

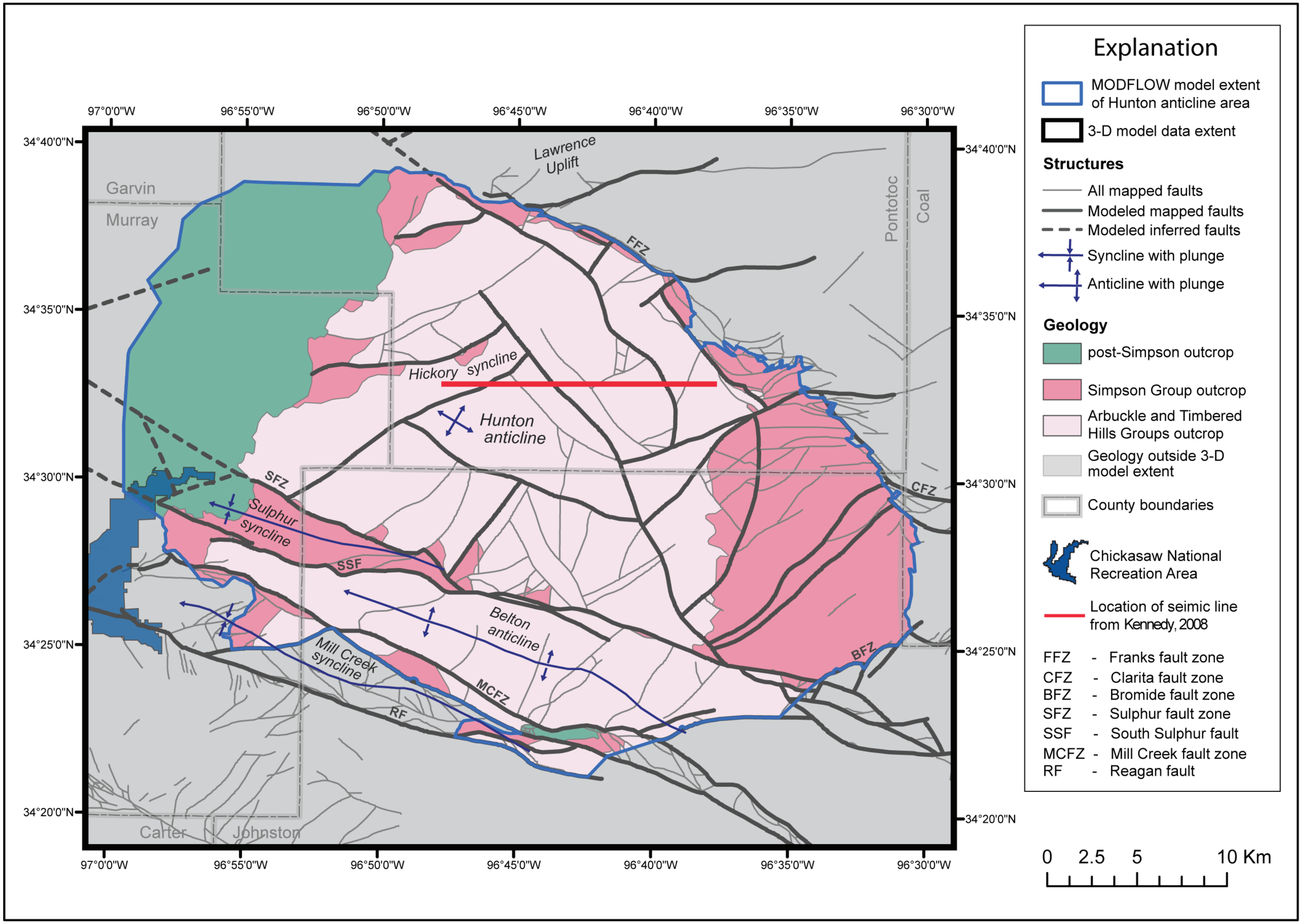

Figure 2. Three-dimensional EarthVision™ model area showing the generalized geology and associated fault structures.

It can be difficult to identify the Arbuckle Group formations on the surface because few marker beds are identifiable. Lithologic description of the Arbuckle Group was derived mostly from outcrops along Interstate 35 through the Arbuckle anticline (Fay, 1989). Arbuckle Group Formations in the subsurface of the Hunton anticline area are difficult to identify because of the scarcity of drill holes that have penetrated the entire Group. In addition, pervasive dolomitization in the Hunton anticline area masks the original depositional textures. In spite of these limitations, some formations have distinct characteristics that can be identified on geophysical logs and drill cuttings.

A well (Wirick 1-12), drilled for oil exploration northeast of the study area on the Lawrence Uplift (fig. 3), penetrated the Arbuckle Group. The gamma-ray log of this drill hole is used as the type log for the Arbuckle Group in the model area. Formation contacts were estimated from analysis of rock cuttings and correlation of the gamma-ray log with other well logs in the study area. The total thickness of the Arbuckle Group in this drill hole is 944 meters.

The Simpson Group (table 1) of Middle Ordovician age is the youngest lithostratigraphic unit that contains rocks of the Arbuckle-Simpson aquifer and is up to 310 meters thick in the model area. Simpson Group rocks are exposed over approximately 235 square kilometers along the margins of the Hunton anticline area and in structurally low areas, such as the Sulphur syncline (fig. 2). Simpson Group rocks are eroded in the structurally higher areas, such as the Belton anticline (Ham and others, 1973). The most prominent outcrop of Simpson rocks occurs in the eastern part of the Hunton anticline area.

The Simpson Group consists of, in ascending stratigraphic order: Joins, Oil Creek, McLish, Tulip Creek, and the Bromide Formations. The Oil Creek, McLish, and Bromide Formations crop out in the model area, whereas the Tulip Creek and Joins Formations are minimal or absent. The Joins Formation consists of thin limestones and shales with a thin basal conglomerate. Each of the four overlying formations consists of a basal sandstone overlain by a sequence of shale and limestone. There are numerous unconformities recorded in the stratigraphic record following deposition of the Simpson Group. Many of the unconformities are the result of the erosion of the paleo-topographic highs formed by older anticlinal features.

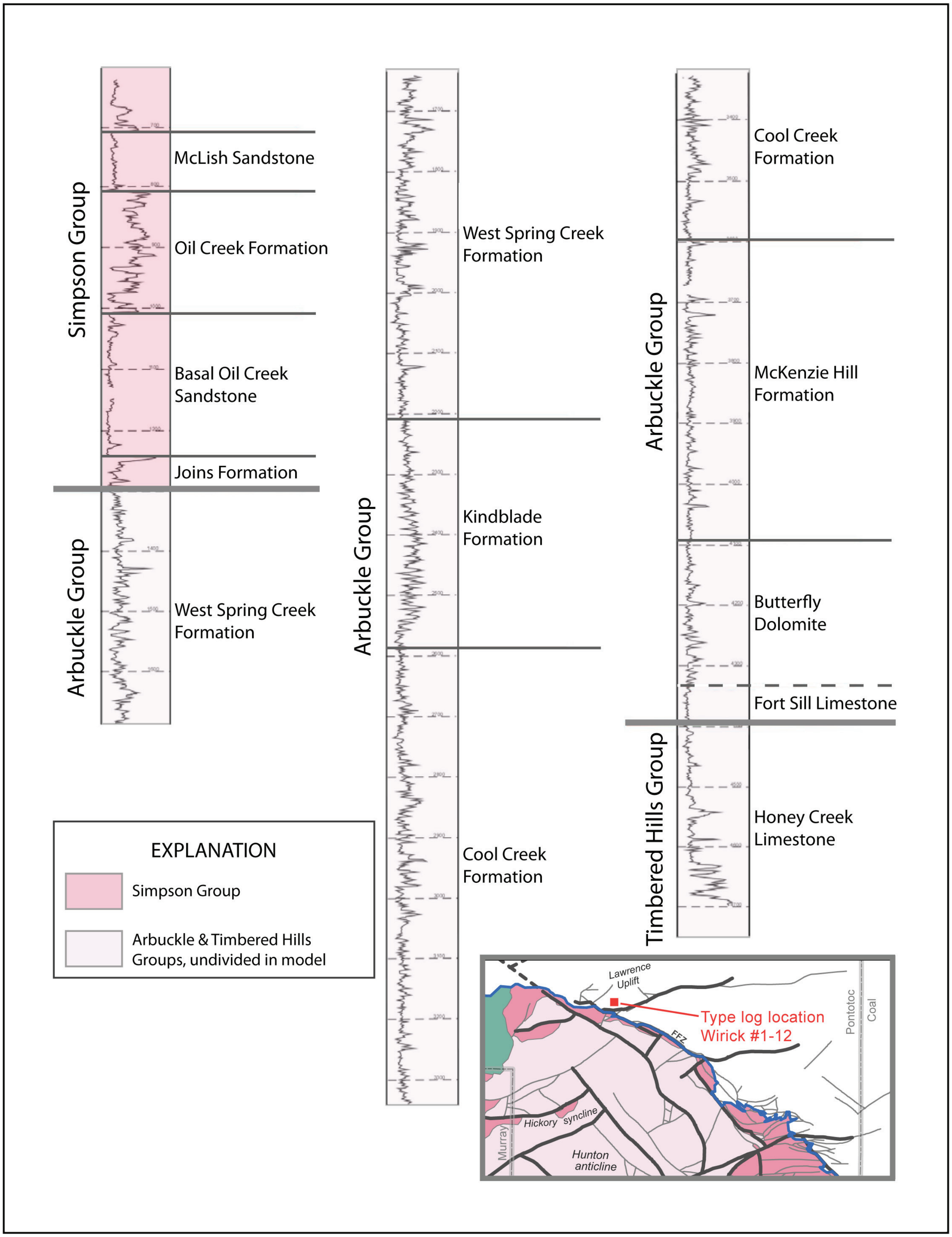

Figure 3. Type gamma-ray log of drill hole Wirick 1-12 showing subsurface geology of the Timbered Hills, Arbuckle and Simpson Groups.

All geologic units younger than the Simpson Group were combined and modeled as the "post-Simpson unit" (table 1). The post-Simpson geologic units include the Viola Group and Sylvan Shale (Upper Ordovician), Hunton Group (Silurian to Devonian), Woodford Shale (Upper Devonian to Lower Mississippian), Sycamore Limestone and Caney Shale (Mississippian), and a number of Pennsylvanian to Permian age units (table 1). The post-Simpson rocks are laterally discontinuous and are exposed as gently dipping strata west and east of the Hunton anticline area (fig. 1).

In the vicinity of Sulphur and the Chickasaw National Recreation Area (CHIC), the Arbuckle and Simpson Groups are unconformably overlain by the Pennsylvanian-age Vanoss Group. The Vanoss Group contains erosional remnants of the Simpson Group, Arbuckle Group, and underlying basement rocks, and has a maximum thickness of 198 meters (Ham and others, 1973). The lower Vanoss conglomerate member, west of the Hunton anticline area, consists of tightly cemented, well-rounded to subangular limestone and dolomite pebbles and boulders, with lesser amounts of sandstone, siltstone, shale, chert, granite, and gneiss. The Vanoss Group also contains an upper shale member and minor sandstone lentils of Late Pennsylvanian to Early Permian age that are mostly exposed outside the model area (fig. 1).

Epikarst/Karst

Epikarst refers to a portion of the bedrock that extends downward from the base of the soil zone and is characterized by extreme fracturing and enhanced solution pockets that may or may not be filled with water (Field, 1999). Epikarst, in general, is thought to be important in the near-surface hydrology of carbonate terrains (Klimchouk, 2004). Although recognized in the Hunton anticline area, epikarst is not consistently mapped. The Oklahoma Water Resources Board funded a study by Sample (2008), to characterize the geophysical, hydrologic, and geologic parameters of epikarst in the Hunton anticline area.

A helicopter electromagnetic (HEM) survey was flown over the Hunton anticline area to identify subsurface structures down to 200 meters below ground surface (Smith and others, 2009). Also identified were soil/epikarst signatures, that show resistivity variations in the resistivity-depth (less than 10 meters) inversions. Generally, the epikarst/soil has a markedly lower resistivity in comparison to the bedrock as verified by both ground and airborne geophysics. Epikarst/soil was mapped in the HEM survey block B (fig. 1). In figure 4, areas with epikarst/soil are stippled, whereas thin soil/bedrock outcrops are blank. The abundance of epikarst/soil in this geologic setting may have profound implications for groundwater recharge and storage.

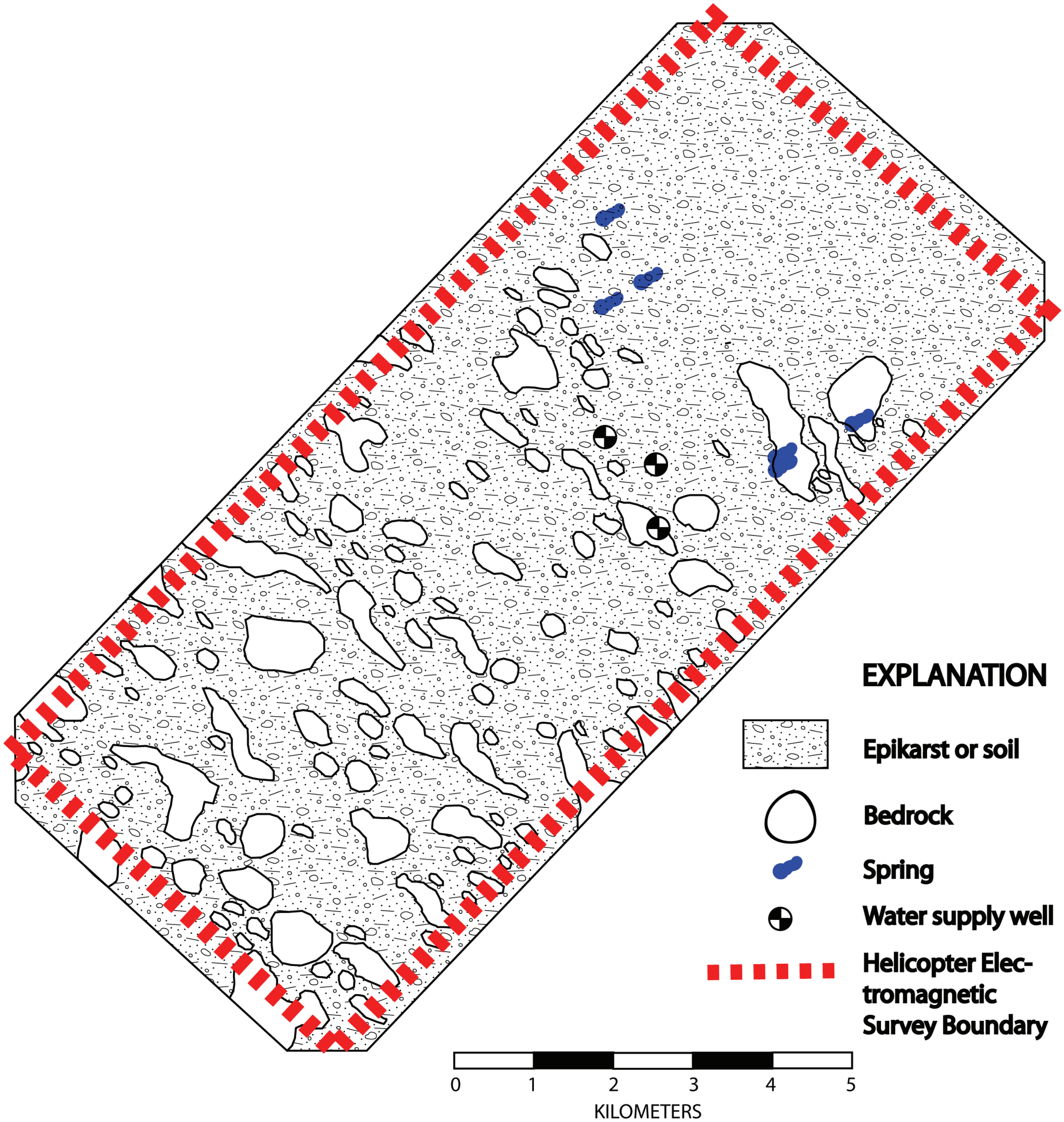

Figure 4. Epikarst or soil occurrence for block "B" (see figure 1) of the helicopter electromagnetic survey (Smith and others, 2009).

Small karst features can be seen over much of the Hunton anticline area, but caves large enough to explore are found only in a few locations. Lynch and Al-Shaieb (1991) have documented evidence of extensive paleokarst in Arbuckle Group rocks in Oklahoma. A test well drilled as part of their study encountered voids with red clay and calcite fillings that are indicative of carbonate dissolution and karst features at depth.

Geologic Structure

Information obtained from surface mapping and subsurface geophysical data indicate the rocks containing the Arbuckle-Simpson aquifer are highly faulted. The larger faults have been mapped at the surface (fig. 1), but many more have been identified through geophysical methods, including seismic, electric resistivity imaging (ERI), ground-penetrating radar (GPR), and HEM surveys (Scheirer and Hosford-Scheirer, 2006; Kennedy, 2008; Sample; 2008, Halihan and others, 2009; Smith and others, 2009). Numerous smaller faults throughout the region terminate against the major northwest oriented faults and against each other (fig. 2). These smaller faults are characterized by short linear lengths, small offsets of stratigraphic units, and a variety of orientations (Scheirer and Hosford-Scheirer, 2006).

A gravity geophysical survey by Scheirer and Hosford-Scheirer (2006) of the CHIC indicated that the South Sulphur fault (SSF) may project westward into the park, and an HEM survey flown in 2007 (Smith and others, 2009), substantiated their findings (fig. 1). The gravity survey also suggests that the South Sulphur fault dips steeply, faults in the Mill Creek fault zone (MCFZ) dip vertically, and the Reagan fault (RF) dips to the south, which is consistent with it being mapped as a thrust fault (fig. 2). In May, 2007, Scheirer and Aboud (2008) collected ground magnetic and gravity observations in the western part of the Hunton anticline area near Sulphur, Oklahoma, which complements the previous gravity work in CHIC.

A seismic survey interpreted by Kennedy (2008), suggests that the older rock units containing the Arbuckle-Simpson aquifer range from 270 to 1070 meters below ground level. Numerous faults are observed along a seismic line shown in figures 2 and 5, with a fault density of about 1.6 faults per kilometer. Figure 5 (Kennedy, 2008) shows that steeply dipping faults penetrate the granitic basement, at estimated depths of 800 to 1070 meters below ground level.

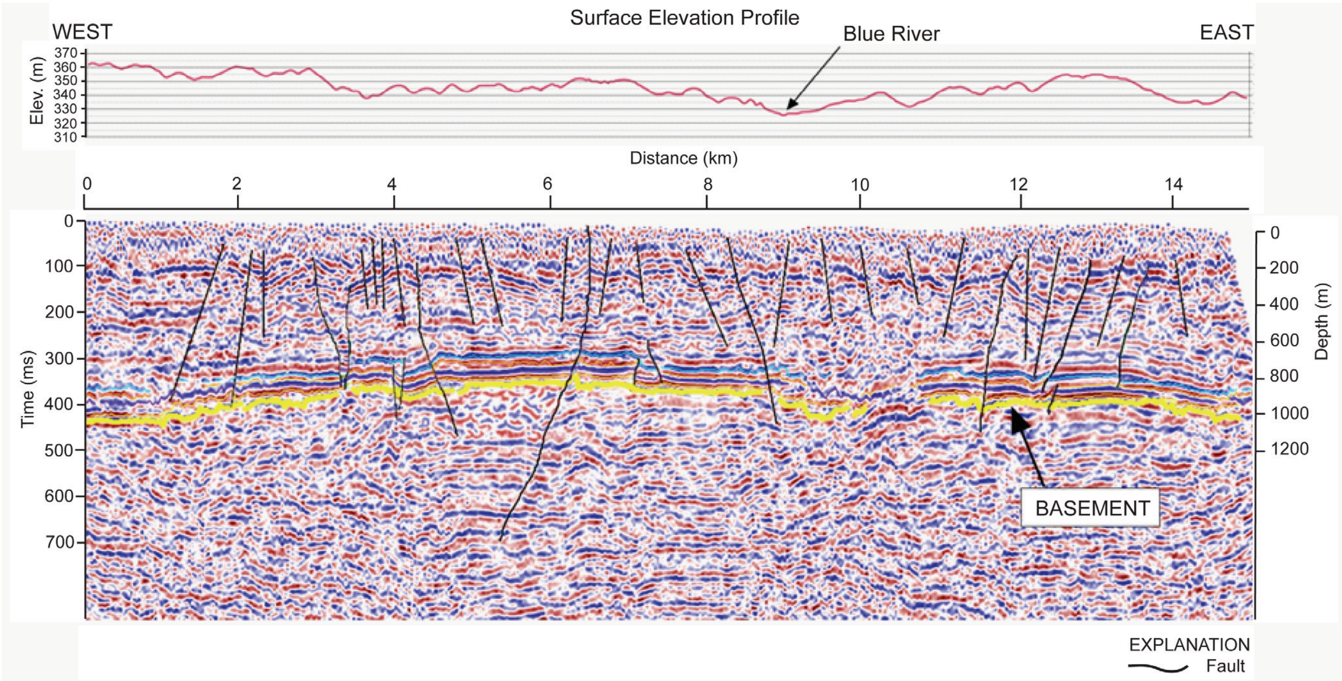

Figure 5. Seismic line across the Hunton anticline area (fig. 2) showing interpreted basement horizon and faults (modified from Kennedy, 2008).

Locally, on the western and eastern flanks of the Hunton anticline area, the strata dip gradually into the subsurface, such as near CHIC (fig. 2). In other locations to the north and northeast, the water-bearing strata are faulted downward and buried by thick sequences of younger rocks. To the south, uplift and displacement along reverse and strike-slip faults have juxtaposed Precambrian and Cambrian basement against the Timbered Hills, Arbuckle, and Simpson Groups. Deformation features characteristic of the study area include an abundance of fractures that represent joints, shears, broken folds, as well as faults, parallel folding, and pressure solution features (Donovan, 1991). Major strike-slip faults have lateral displacements over 60 kilometers according to Scheirer and Hosford-Scheirer (2006).

The Hunton anticline is a broad fold that is bounded on the northeast by the Franks and Clarita fault zones (FFZ and CFZ respectively, fig. 2), and on the south by the Sulphur fault zone (SFZ). The Franks fault zone is composed of a series of high-angle, down-to-the northeast faults. The southeastern boundary of the Hunton anticline area is the Bromide fault zone (BFZ). Arbuckle and Simpson Group strata are exposed in the central part of the anticline and dip gently beneath Middle Pennsylvanian formations on the northwestern and western flanks. On its eastern flank, the strata dip beneath progressively younger strata between the Clarita and Bromide fault zones (fig. 2).

To the south of the Hunton anticline, most major faults are high-angle (Halihan and others, 2009) and are considered to be the result of left-lateral strike-slip and thrust deformation. Found here is the northwest-plunging fault block of the Belton anticline (fig. 2). This anticline is bounded on the north by the South Sulphur fault (SSF) and Sulphur fault zone (SFZ, fig. 2), and on the south by the Mill Creek fault zone (MCFZ). Rocks of the Belton anticline are higher structurally than rocks of the Hunton anticline. As a result, the Simpson Group and upper Arbuckle Group units have been eroded exposing the lower Cool Creek and McKenzie Hill Formations.

The Sulphur syncline is wedged between the Belton and Hunton anticlines (fig. 2), bounded by the Sulphur fault zone to the north, and by the South Sulphur fault to the south. Preserved within the Sulphur syncline are rocks of the Simpson Group. Simpson Group exposures terminate east of CHIC and are unconformably overlain by Vanoss Group conglomerate. Geologic mapping by Ham and others (1990) show that the fault south of the Sulphur syncline deviates southward. Scheirer and Hosford-Scheirer (2006) named this fault the South Sulphur fault, and their gravity study suggests that a segment extends to the northwest through CHIC. Well data suggest that a segment of the Sulphur fault zone extends westward, to the north of CHIC. Drill hole data also suggest that two cross faults connect the South Sulphur fault and Sulphur fault zone in the vicinity of CHIC. Cates (1989) and Scheirer and Hosford-Scheirer (2006) suggest the Sulphur syncline does not extend beneath CHIC and may be a graben.

The Mill Creek syncline is bounded by the Mill Creek fault zone and Reagan fault (fig. 2). The Mill Creek syncline is a narrow, northwest-trending graben consisting of more than 2500 meters of tightly folded Paleozoic strata. Stratigraphic displacement along the Mill Creek fault zone is estimated to be 1,525 meters where Arbuckle and Simpson Group strata of the Belton anticline are juxtaposed against rocks of the Pennsylvanian Deese Group (Ham, 1945; table 1).

Three-Dimensional Modeling

A 3-D EV model characterizing the geologic framework and geometric relations of the rocks containing the Arbuckle-Simpson aquifer and its confining strata within the Hunton anticline area was constructed. The geologic layers were then discretized for the Arbuckle-Simpson hydrology study's regional groundwater-flow model. Other structures included in the model area are, from north to south, the Lawrence Uplift, Hickory syncline, Sulphur syncline, Belton anticline, and Mill Creek syncline (fig. 2).

Subsurface Geologic Data and Interpretation Methods

The geologic data used to interpret the subsurface were derived from geophysical logs, lithologic descriptions from municipal and domestic water supply-wells, oil and gas exploration wells, and subsurface geophysical surveys. The structural attitude of stratigraphic units was established by using geologic map and well-based data. In all, well records for more than 300 water supply and petroleum exploration wells in the study area were examined. Of these, stratigraphic tops from 126 wells were selected based on data quality and spatial distribution across the model area.

Software

Dynamic Graphic's EarthVision™ 3-D modeling software was used to create two-dimensional (2-D) and 3-D stratigraphic surfaces from x (easting/longitude), y (northing/latitude), and z (elevation) data, all in meters. The locations were compiled in an Albers Equal Area projection, GRS 1980/NAD83. In the model, x, y, and z input data values define the surfaces of the model geologic units. Unit volumes are constrained by two or more unit surfaces and/or their modeled or structural boundaries.

EarthVision™ software was used because of its ability to model various data types and accurately define faulted surfaces while maintaining both the stratigraphic and structural integrity and complexity in 3-D space. This software is designed to mathematically follow basic geologic and geometric rules of depositional, channel fill, or unconformable stratigraphic contacts. These rules can be modified by any or all of the following: (1) adding user-interpreted data points (designated by the prefix "Md" in the data files), (2) by altering gridding parameters or (3) using smoothing algorithms in any or all of the x, y, or z dimensions. This allows for considerable discretion to define a unit surface beyond the predefined "minimum surface-tension" gridding algorithm.

EarthVision™ uses minimum tension gridding to produce 2-D and 3-D surface grids from x, y, and z data (scattered data). Minimum tension gridding more closely models the data versus trend gridding which abstracts it. Specifically, EV uses a biharmonic cubic spline function to model the data. The gridded surfaces are generated in a two-stage process, an initial grid estimate followed by biharmonic iterations. Initial grid nodes are estimated from the scattered data. Data points used for the initial estimate depends on the distribution of the scattered data. Once the estimate is complete, a number of iterations using the biharmonic cubic spline function re-evaluate the grid nodes. So that grid nodes still adhere to the scattered data, a scattered data feedback algorithm follows each biharmonic iteration. These modeling steps result in the curvature of the surface being distributed rather than concentrated at data points. This generates a "more natural looking" modeled surface of the grid nodes that accurately reflect the scattered data. More information and other utilities are available from Dynamic Graphics Inc at: http://www.dgi.com.

Model Construction

Data for the geologic surfaces within the model were identified and defined from five primary data sources:

- 126 drill holes with well picks based on geophysical logs, cores, and cuttings
- Type log from Wirick drill hole 1-12 (fig. 3)
- Stratigraphic contacts and faults defined from surface geologic mapping by Ham and others (1990) and digitized by Cederstrand (1996)
- Fault extensions from Scheirer and Hosford-Scheirer (2006)
- Fault geometry, stratigraphic thickness, and tectonic-history data compiled from existing geologic and hydrogeologic reports and maps

The Arbuckle-Simpson 3-D EV geologic framework model (fig. 6) incorporates 54 faults and four modeled units: basement, Arbuckle-Timbered Hills unit, Simpson Group, and post-Simpson unit (table 1). Figure 7 is a west to east cross section through the model and figure 8 is a north to south cross section. With fault offsets greater than 2,000 meters along the flanks of the Hunton anticline area, the volumetric distribution of the model units is highly variable. This geologic framework model shows the volumetric extents of the Arbuckle-Timbered Hills and Simpson Group rocks, which are the primary water-bearing units of the aquifer (table 1). The top of the basement forms the lower confining unit of the aquifer. The post-Simpson rocks form the upper confining unit of the aquifer. A 10-meter U.S. Geological Survey (USGS) Digital Elevation Model (DEM) was used to define the surface topography and provides elevation data for the stratigraphic contacts from Cedarstrand's (1996) digital geologic map of the area.

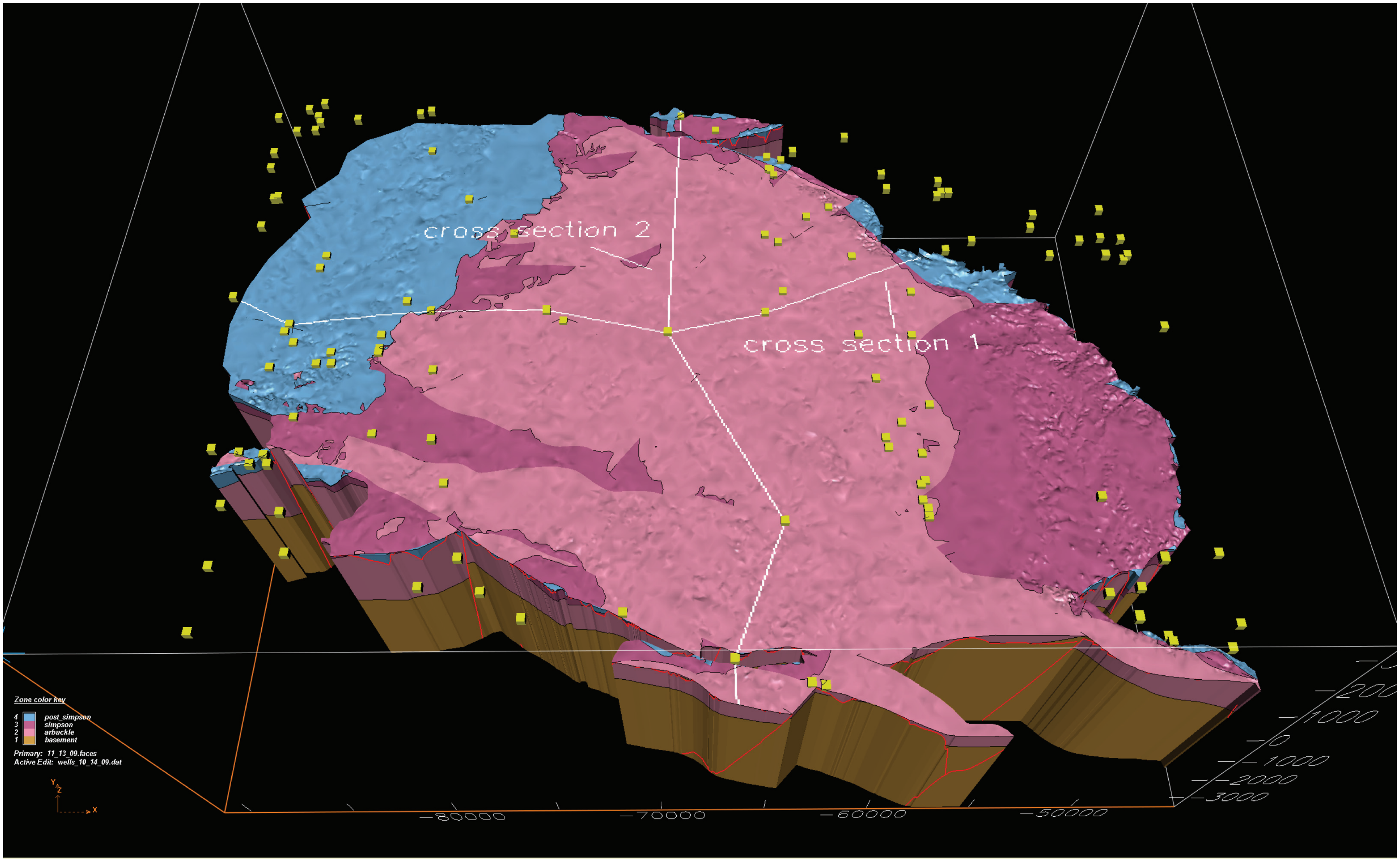

Figure 6. EarthVison™-derived block diagram showing the geologic units confining the Arbuckle-Simpson aquifer, selected drill hole locations, and locations of cross-sections shown in figure 7 and figure 8.

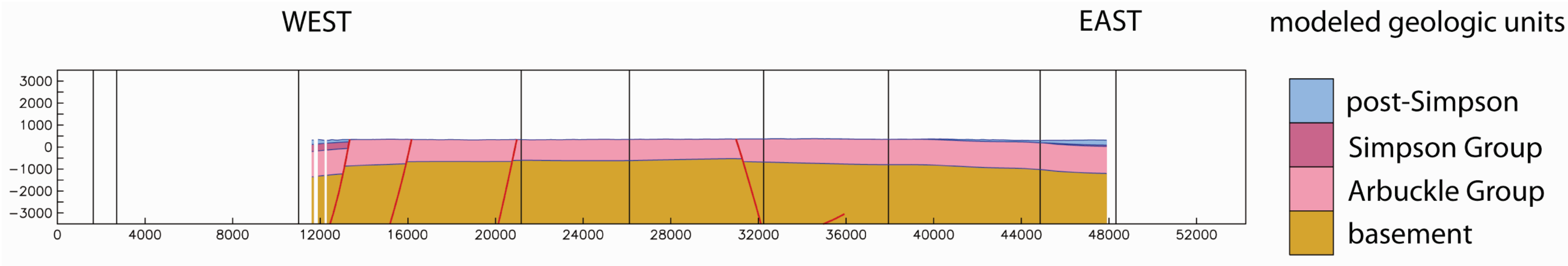

Figure 7. East to west cross-section showing the EarthVision™ modeled geologic units and fault structures.

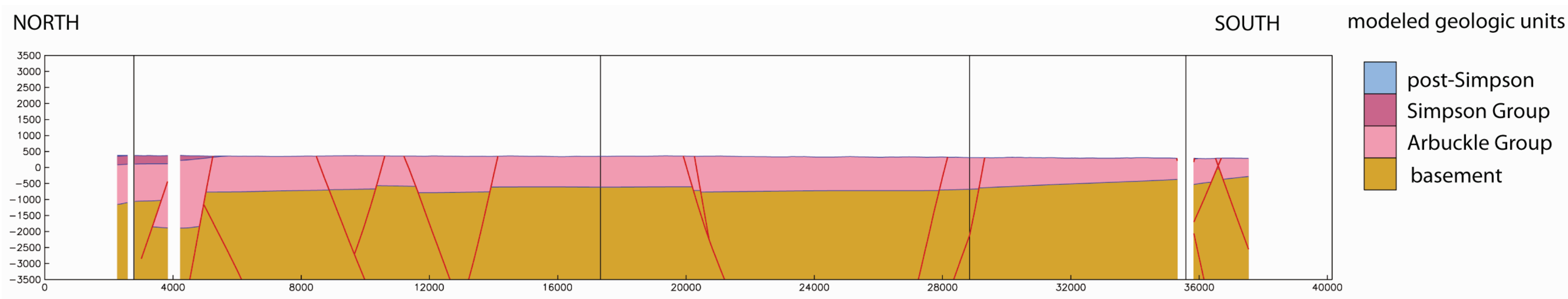

Figure 8. North to south cross-section showing the EarthVision™ modeled geologic units and fault structures.

Fault plane modeling was first conducted using approximately 20 normal and reverse faults dipping 80 degrees and 65 degrees, respectively. Fault complexity was increased to a total of 54 faults before the integration of stratigraphic control points. Fault structures included the geophysically-interpreted fault extensions of Scheier and Hosford-Scheier (2006, fig. 2). Drill-hole data constrained the model surfaces. The top of the basement was defined using data from 13 drill holes (fig. 9). The top of the Arbuckle-Timbered Hills Group was identified in data from 89 drill holes and represents the model's primary reference surface, which was used to define other model surfaces (fig. 10). The top of the Simpson Group was identified in 54 wells (fig. 11). Locally, pre-erosional surfaces for the Simpson Group and basement were projected based on x, y, and z values of a known contact. The post-Simpson model unit (fig. 12) was defined as the volume between the top of the Simpson Group and DEM surface. Over much of the model area, post-Simpson rocks are missing because of erosion.

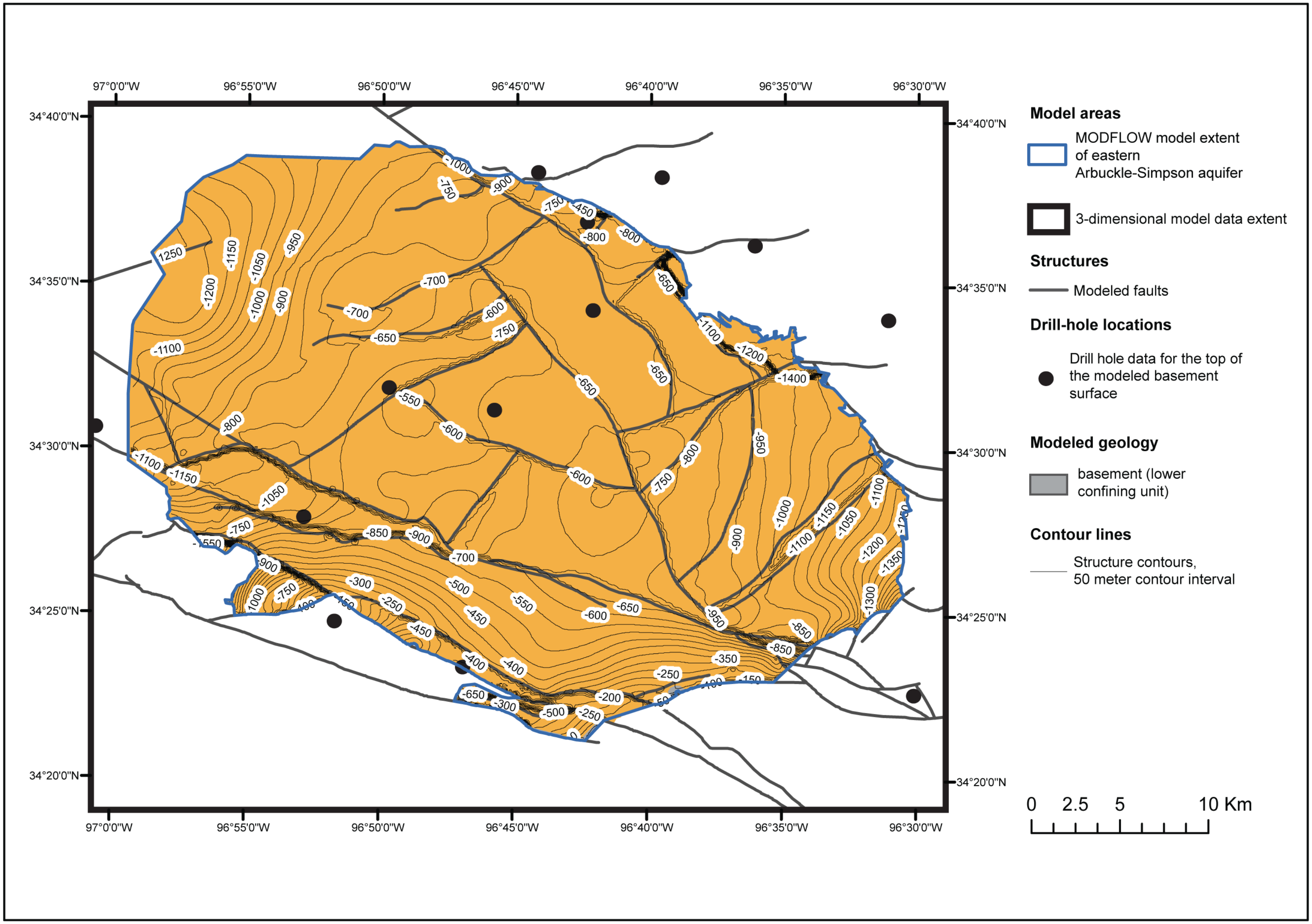

Figure 9. Structure contour map of the top of the modeled basement surface, fault structures, and data locations.

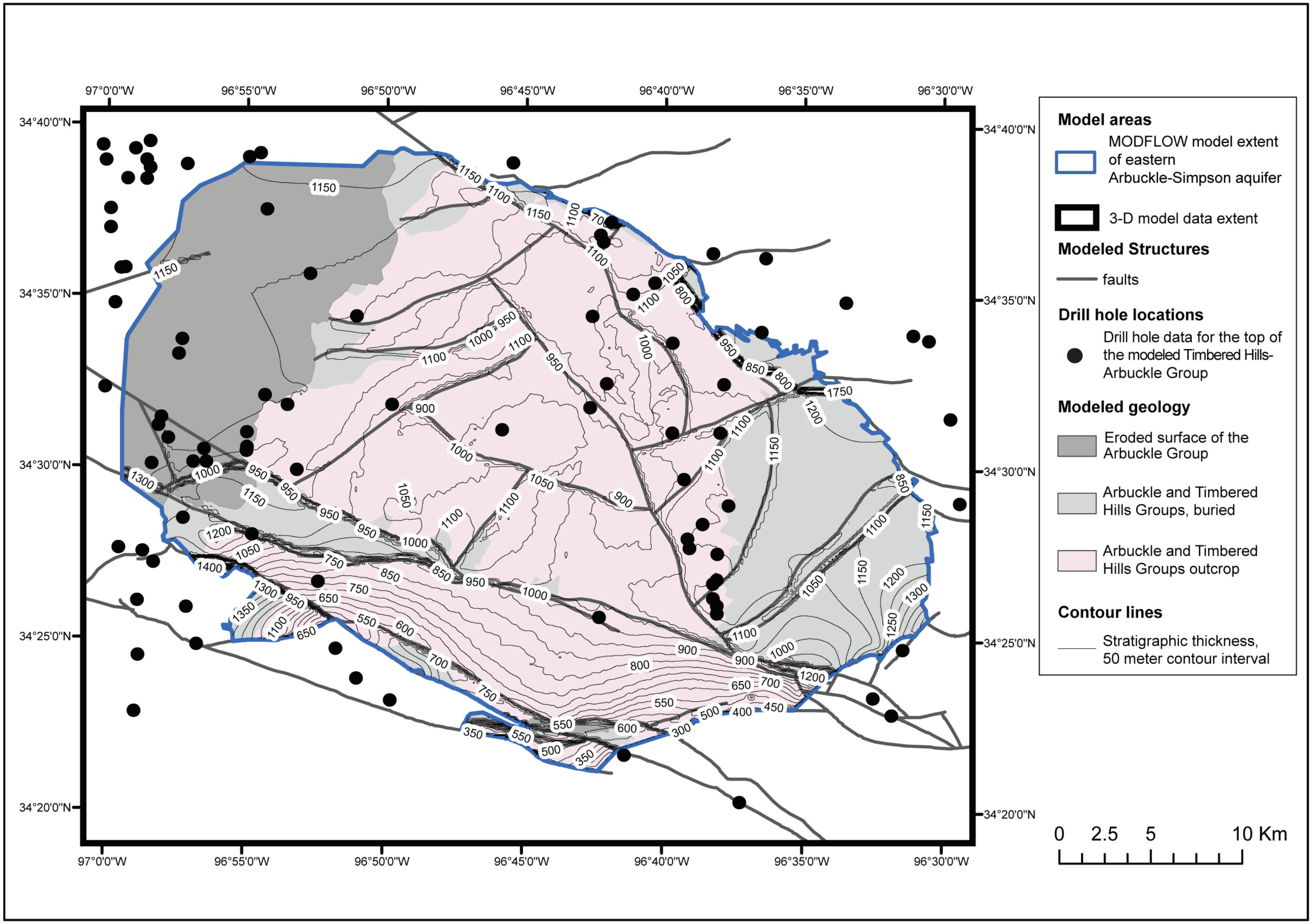

Figure 10. Stratigraphic thickness of the top of the modeled Timbered Hills-Arbuckle Group surface, fault structures, and data locations.

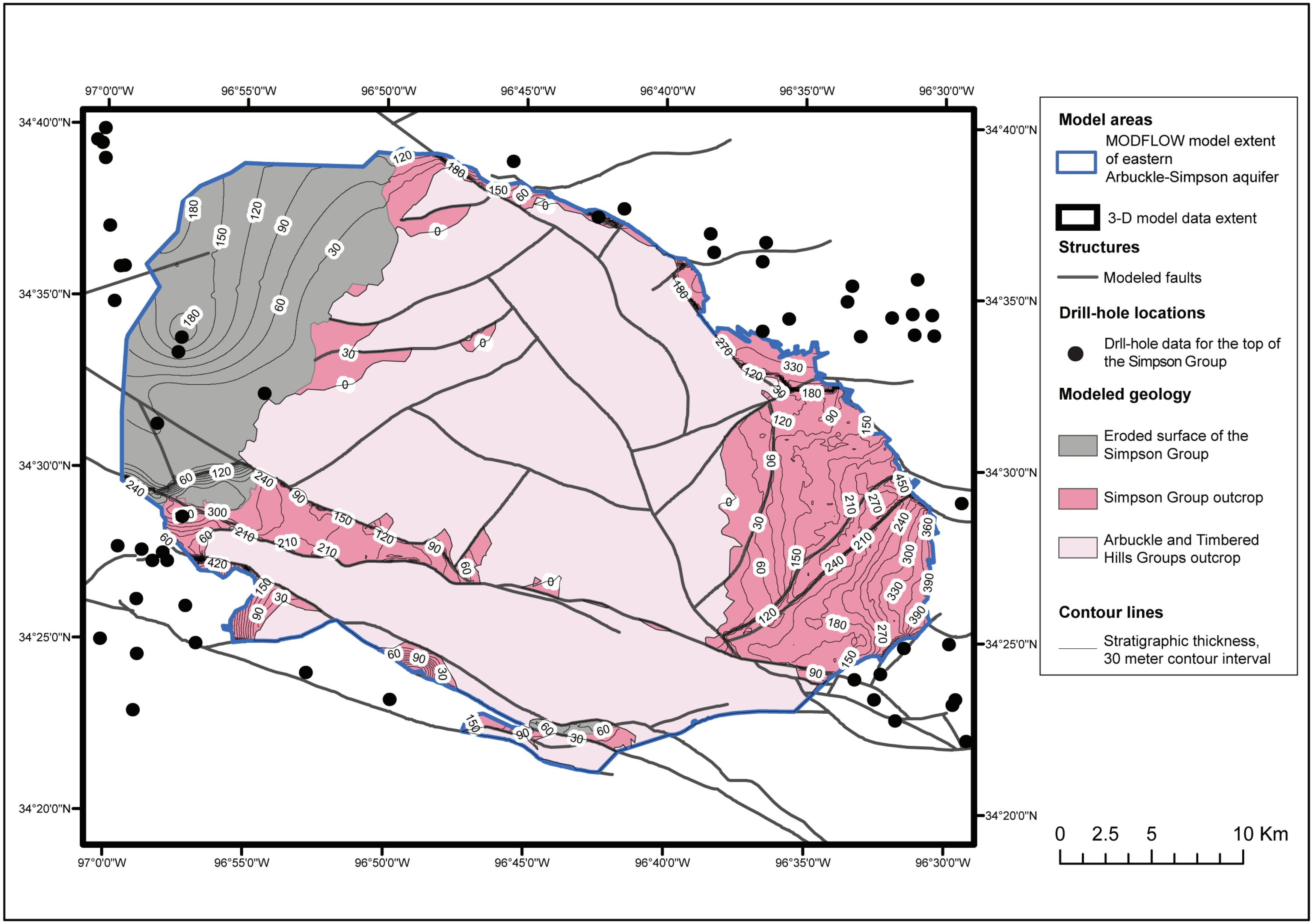

Figure 11. Stratigraphic thickness of the top of the modeled Simpson Group surface, fault structures, and data locations.

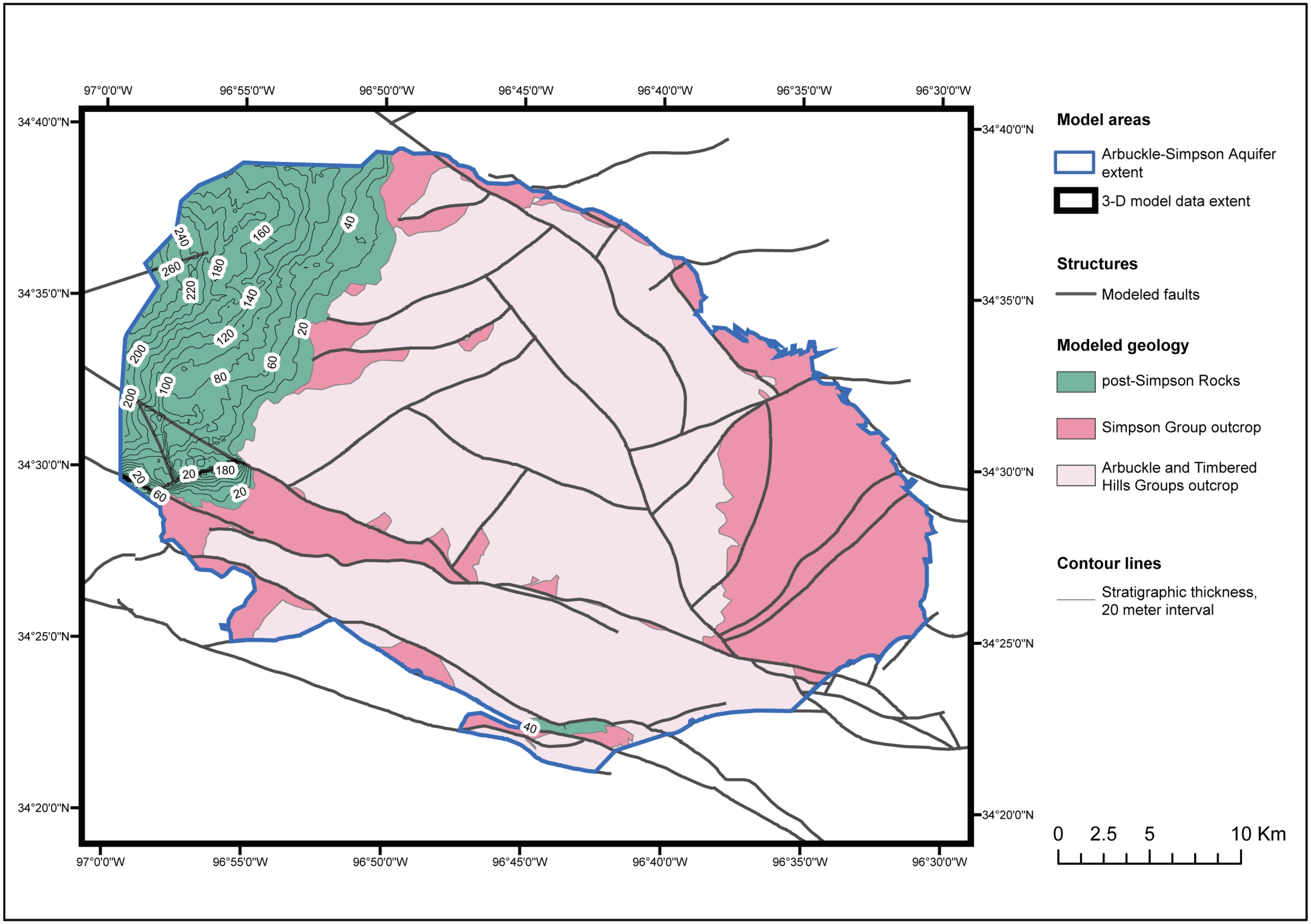

Figure 12. Stratigraphic thickness of the top of the modeled post-Simpson Group surface, fault structures, and data locations.

Significance of Three-Dimensional Geologic Modeling for Groundwater Modeling

The data provided as input into the groundwater flow model included the following surfaces: basement (lower confining unit), Arbuckle-Timbered Hills unit, Simpson Group, and the undifferentiated post-Simpson (upper confining unit, table 1). These surfaces, representing the tops of the model units, were exported for conversion to a data format compatible with MODFLOW version 2000. Skip Pack (Dynamic Graphics, Inc.) was instrumental in the data conversion process used to produce surface elevation and thickness grids representing the model geologic units. The reformatted data were successfully incorporated into the ongoing Arbuckle-Simpson MODFLOW groundwater flow model. The structure contour map of the basement rocks in figure 9 shows that the model surface elevations ranges from sea level to more than 1,400 meters below sea level. The isopach map of the Arbuckle-Timbered Hills unit (fig. 10) shows a range in thickness from 200 to 1,800 meters. In many locations, more than half of the thickness of this model unit has been removed by erosion. Across the model area, the Simpson Group isopach map (fig. 11) illustrates thickness variations from zero to 480 meters. The thickness variations are a result of the Hunton anticline area's complex structure and surface erosion. The thickness of the post-Simpson rocks shown in figure 12, range from zero to 300 meters on the western flank of the Hunton anticline area.

This 3-D EV framework model represents the first volumetric depiction of rocks that form the Arbuckle-Simpson aquifer in the Hunton anticline area. The 3-D framework model also provided the geologic framework used to construct a MODFLOW version 2000 model of the aquifer. Three-dimensional models, like the Arbuckle-Simpson 3-D EV model, are also interactive tools for visualizing the subsurface geology of groundwater aquifer systems. Other applications of 3-D EV modeling called “property modeling” are evolving where other data types such as, rock properties or water levels, are being modeled in three- or even four-dimensions (time).

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