Geohydrologic Framework of the Edwards and Trinity Aquifers, South-Central Texas

This five-year USGS project, funded by the National Cooperative Geologic Mapping Program (NCGMP), is using multidisciplinary approaches to reveal the surface and subsurface geologic architecture of two important Texas aquifers: (1) the Edwards aquifer that extends from south of Austin to west of San Antonio and (2) the southern part of the Trinity aquifer in the Texas Hill Country west and south of Austin (fig. 1).

The Edwards aquifer is one of the most productive carbonate aquifers in the United States. It also has been designated a sole source aquifer by the U.S. Environmental Protection Agency and is the primary source of water for San Antonio, the nation's seventh largest city. The Trinity aquifer forms the catchment area for the Edwards aquifer and it intercepts some surface flow above the Edwards recharge zone. The Trinity may also contribute to the Edwards' water budget by subsurface flow across formation boundaries at considerable depths. Dissolution, karst development, and faulting and fracturing in both aquifers directly control aquifer geometry by compartmentalizing the aquifer and creating unique ground-water flow paths.

The Edwards aquifer and the southern extent of the Trinity aquifer are characterized by three areas (or zones): (1) catchment area (exposed Trinity aquifer rocks), (2) recharge zone, and (3) artesian or confined zone. The stratigraphic and structural framework of the Edwards and Trinity aquifers are conceptualized along cross-section A–B (fig. 2).

Precipitation falls on Lower Cretaceous Trinity Group rocks in the catchment area (also called the contributing area) and travels down gradient as surface water until crossing the Edwards recharge zone. There, the water enters the aquifer through fractures and faults and eventually reaches the artesian zone (fig. 2).

Figure 1. Distribution of the Edwards aquifer and catchment area (Trinity aquifer).

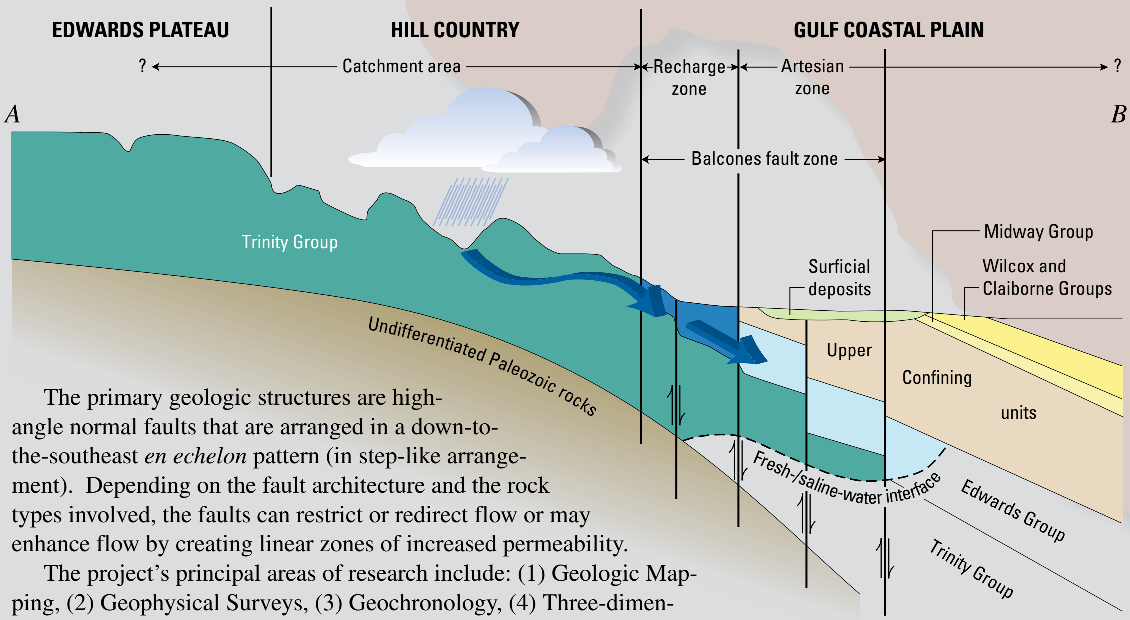

Figure 2. Structural schematic cross section of the Edwards aquifer and catchment area (Trinity aquifer).

The primary geologic structures are high-angle normal faults that are arranged in a down-to-the-southeast *en echelon* pattern (in step-like arrangement). Depending on the fault architecture and the rock types involved, the faults can restrict or redirect flow or may enhance flow by creating linear zones of increased permeability.

The project's principal areas of research include: (1) Geologic Mapping, (2) Geophysical Surveys, (3) Geochronology, (4) Three-dimensional Modeling, and (5) Noble Gas Geochemistry. Individual study areas (fig. 3) and published products can also be viewed at *http://esp.cr.usgs.gov/info/edwards/index.html*

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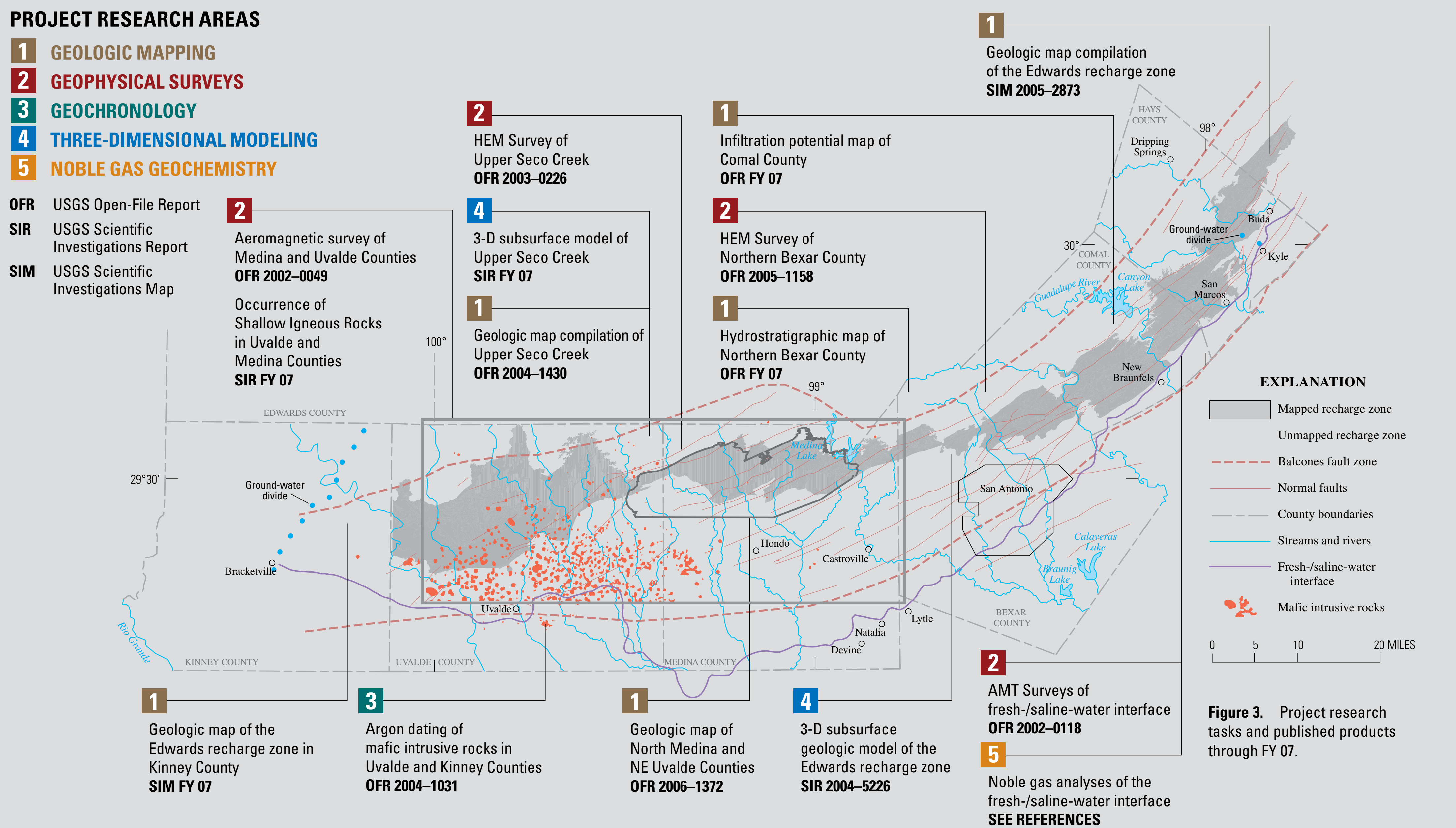

Figure 3. Project research tasks and published products through FY 07.

2 Geophysical Surveys

The presence of volcanic intrusive rocks in south-central Texas has been known since the earliest surveys. A large exposure of volcanic rocks, sometimes called the Uvalde igneous field, is centered in Uvalde County and extends west into Kinney County, south into Zavala County, and north and east as far as the city of Austin. The rocks comprising the Edwards aquifer and the lower and upper confining units are essentially nonmagnetic, with magnetic susceptibilities on the order of $0\text{-}5 \times 10^{-5}$ (SI units). In contrast, the igneous rocks have susceptibilities of $200\text{–}3{,}000 \times 10^{-5}$ SI. New occurrences of intrusive bodies at both surface and subsurface levels were unveiled by the 2001 aeromagnetic survey (*http://pubs.usgs.gov/of/2002/ofr-02-0049/*) which reveals how the intrusives may control the unique morphology of the Edwards' major flow paths (fig. 5).

Another geophysical method used in studying the subsurface geohydrology of the Edwards and Trinity aquifers is audio-magnetotelluric sounding or AMT (*http://pubs.usgs.gov/of/2002/of02-118/*). AMT is an electrical technique that uses either natural signals or a controlled transmitter to measure earth conductivity as a function of depth.

The AMT sounding locations were specifically selected to resolve a number of key geological issues, including a volcanic plug along the Frio River near the town of Knippa in Uvalde County. Additional AMT studies conducted in and around selected transect wells near Kyle, Texas, mapped the fresh-/saline-water interface (fig. 3).

A helicopter electromagnetic and magnetic (HEM) survey (*http://pubs.usgs.gov/of/2003/ofr-03-226/*) was completed in 2002 for a 209-square-kilometer (81-square-mile) area in the Seco Creek drainage area, Medina and Uvalde Counties. The surface geology can be viewed at *http://pubs.usgs.gov/of/2004/1430/*. The survey area was centered on Woodard Cave (Valdina Farms sinkhole), a significant karst feature in northwestern Medina County. The primary objective of the survey was to image the subsurface electrical resistivity of select geologic features that control the area's ground-water resources.

1 Geologic Mapping

The complex geology of the recharge zone, as defined by the Texas Commission on Environmental Quality (TCEQ), includes lithologic units assignable to the Lower Cretaceous Edwards Group, which is underlain by the Glen Rose Limestone (lower confining unit) and overlain by the Upper Cretaceous Del Rio Clay, Buda Limestone, and Eagle Ford and Austin Groups (upper confining units).

The geology of the Edwards aquifer in the northeastern part of the recharge area is characterized by the Kainer, Person, and Georgetown Formations, which are subdivided into eight informal hydrostratigraphic units. In the area west of San Antonio in Medina, Uvalde, and Kinney Counties, significant facies changes (fig. 4) exist across the Devils River trend reefal facies (Devils River and Georgetown Formations) and into the deeper water Maverick Basin facies (West Nueces, McKnight, and Salmon Peak Formations).

Past and present 1:24,000-scale geologic mapping in the Edwards aquifer area by the USGS Texas Water Science Center was conducted county-by-county but was never compiled at a regional scale. Compilation efforts for this project began in late 2002 and resulted in the publication of U.S. Geological Survey Scientific Investigations Map 2873 (*http://pubs.usgs.gov/sim/2005/2873/*). This compilation is the first effort of its kind to digitally synthesize the geology of the Edwards recharge zone.

Geologic mapping of four-quadrangles along the upper Seco Creek area, Medina and Uvalde Counties (*http://pubs.usgs.gov/of/2004/1430/*), represents a digital compilation of work by the Texas Bureau of Economic Geology and contains new geologic interpretations for the southern two quadrangles. This map, as well as geologic mapping to the east in Medina County (*http://pubs.usgs.gov/of/2006/1372*), has been used to provide the digital geologic framework used in a helicopter electromagnetic (HEM) geophysical survey of the area as well as for ongoing fracture and three-dimensional (3-D) EarthVision™ (EV) modeling.

One of the primary goals of the project is to produce infiltration-potential assessment maps for critical parts of the Edwards recharge area. An infiltration-potential assessment model for Comal County, which includes a 10-meter Digital Elevation Model (DEM) grid and numerical values for hydrostratigraphic units, faults and fractures, karst features, soils, vegetation, fracture density, and basin accumulation indices, is ongoing.

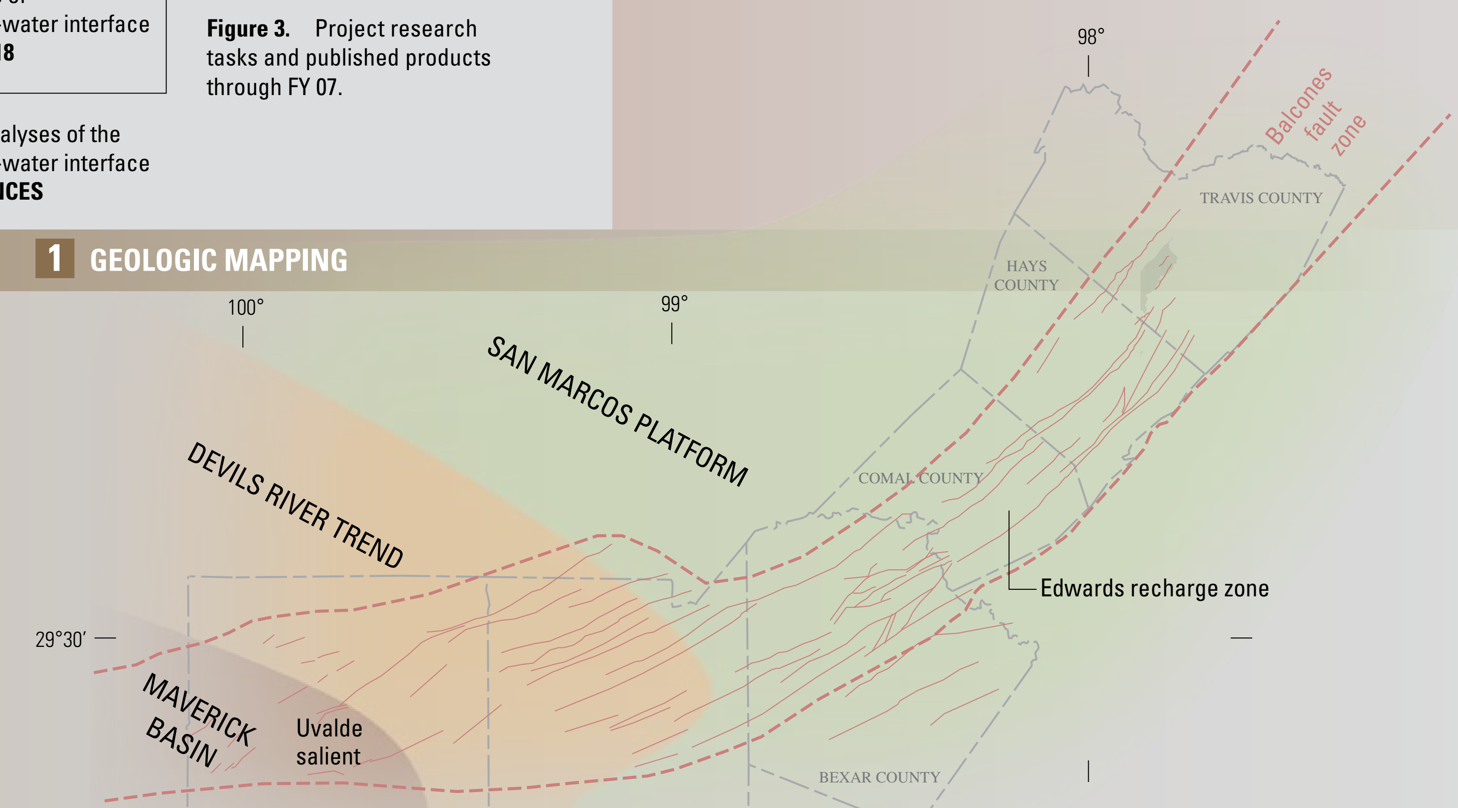

Figure 4. Distribution of depositional facies across the Edwards aquifer.

The HEM data were processed to produce apparent resistivities for each of the six electromagnetic and magnetic coil pairs and frequencies. The higher frequencies have the least depth of penetration. A map of the 100 kHz apparent resistivity shows that the catchment area and recharge and confined zones all have numerous linear features that likely represent faults and fractures. The maximum depth of penetration for this band is 3-5 meters. From this frequency, the warmer colors (reds, orange and purples, fig. 6) denote more resistive rocks (limestone and dolostone) and the cooler colors (blues) denote conductive rocks (shale and mudstone). The reds and purples are indicative of the Devils River Formation and Buda Limestone. The dark blues denote the Del Rio Clay and the Eagle Ford Shale. The intermediate colors (greens and light blue) represent the Glen Rose Limestone and the Austin Chalk.

A similar HEM geophysical survey of northern Bexar County (Camps Bullis and Stanley) was flown in December of 2003 (http://pubs.usgs.gov/of/2005/1158). This survey reflects the complexity of the Cretaceous rocks comprising the Trinity aquifer and, in particular, the Glen Rose Limestone. The Edwards recharge zone at the southern end of the survey is characterized by resistive limestones versus the more conductive siltstones and mudstones of the Trinity aquifer.

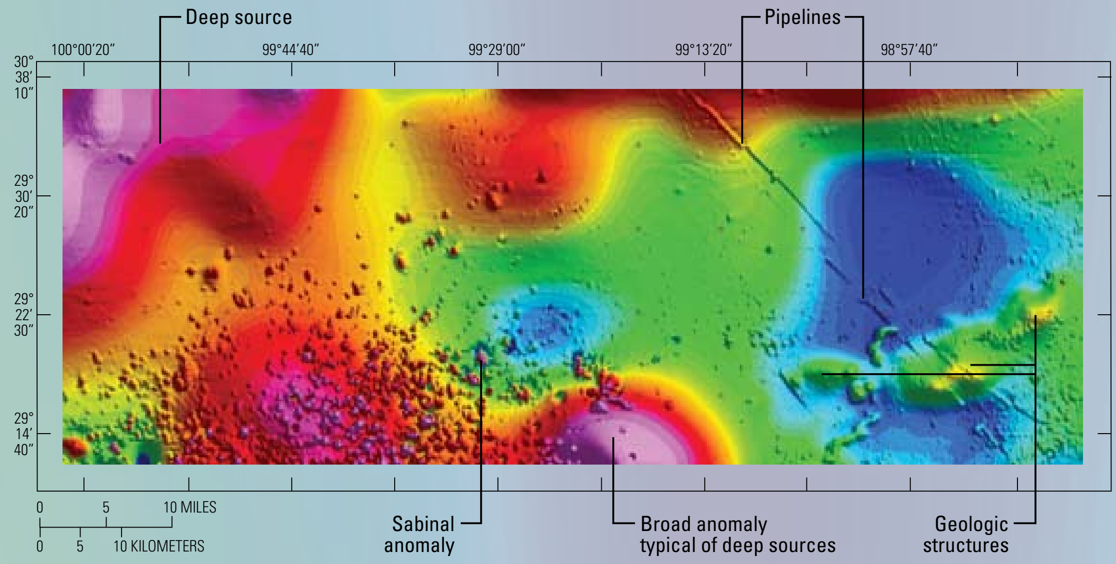

Figure 5. The total magnetic field (reduced to pole) of the geomagnetic survey area, Uvalde igneous field, Uvalde and Medina Counties. Magnetic intensities increase from blue (lowest) through shades of green, yellow, red, and purple (highest). *See figure 3 for location of this map area (OFR 2002-0049).*

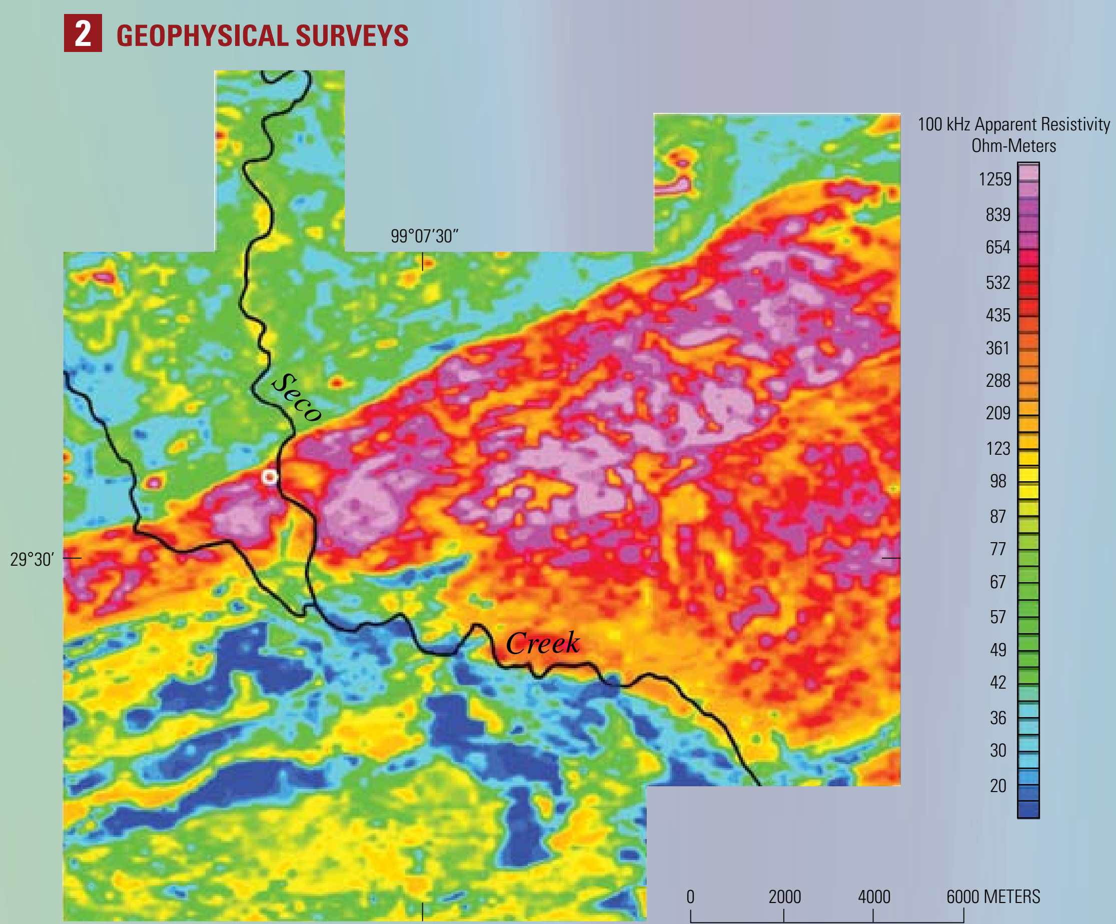

Figure 6. Upper Seco Creek HEM (helicopter electromagnetic and magnetic) survey. The highest frequency used is 100 kHz, and it defines the geoelectric signatures of near-surface strata. See text for descriptions of the rock units in this area. *See figure 3 for location of this map area (OFR 2003-0226).* The white circle indicates the location of Woodard Cave.

3 Geochronology

3 GEOCHRONOLOGY

The Uvalde igneous field consists of fine- to coarse-grained ultramafic and hypabyssal rocks that exist as dikes, plugs, and shallow intrusions. The five rock types identified in this field include alkali basalt, melilite-olivine nephelinite, olivine nephelinite, nepheline basanite, and phonolite.

A 2001 aeromagnetic survey (*http://pubs.usgs.gov/of/2002/ofr-02-0049/*) detected over 200 shallow, igneous intrusive bodies; fewer than 20 had previously been mapped. The apparent random distribution of these igneous bodies raised questions as to whether they represent a single intrusive episode or multiple episodes.

A preliminary $^{40}Ar/^{39}Ar$ geochronologic study (*http://pubs.usgs.gov/of/2004/1031/*) of various mineral separates and groundmass concentrates from a variety of rock types exposed in Uvalde County revealed two distinct age groups, one at approximately 82 to 80 Ma (million years ago) and the other at 74 to 72 Ma. Previous K/Ar ages had suggested that igneous activity spanned a range in age from 90 to 60 Ma.

Figure 7. Columnar joints in 80 to 82 million-year-old melilite-olivine nephelinite exposed at the Knippa Traprock Quarry east of Uvalde. *USGS photograph.*

4 Three-Dimensional Modeling

4 THREE-DIMENSIONAL MODELING

Three-dimensional (3-D) geologic modeling of aquifers can help to quantitatively evaluate the connectedness of hydrostratigraphic units across fault and fracture zones and to estimate the distribution of geologic units and structures in the subsurface. Geologic 3-D framework modeling is also useful for visualizing features within fault zones and the interactions of *en echelon* fault strands and flexed, relay ramps. All of these parameters are complex variables that reflect original depositional conditions and subsequent alteration and dislocation. The following 3-D models have helped project staff to evaluate some of the geologic processes controlling the Edwards and Trinity aquifers.

An interactive 3-D EarthVision™ (EV) model of the northern Bexar County area (*http://pubs.usgs.gov/sir/2004/5226/*) reveals the subsurface geology of the Edwards and Trinity aquifers where water wells are 200-1,000 feet or more in depth. This model is based on mapped geologic relationships that reflect the: (1) Balcones fault-zone structures, (2) detailed interpretations of 40 principal wells, and (3) geometry of the Edwards Group hydrostratigraphic units.

A similar 3-D EV model of the north Seco Creek area (Medina and Uvalde Counties) is ongoing. This model (fig. 8) is being built using a variety of digital datasets, including: (1) the current geologic map (*http://pubs.usgs.gov/of/2004/1430/*), (2) detailed lithologic descriptions and interpretations from 40 drill holes, and (3) helicopter electromagnetic geophysical data.

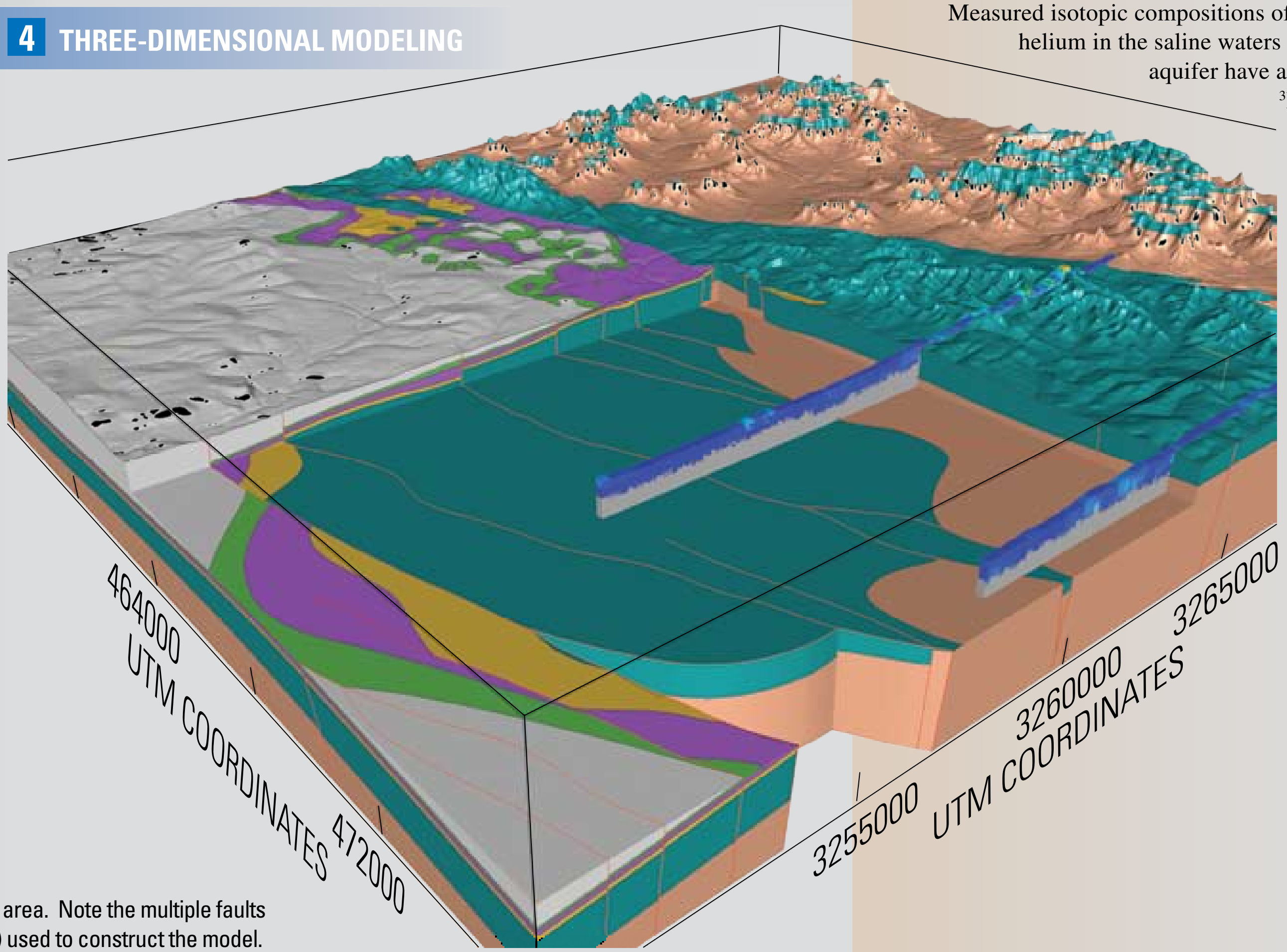

Figure 8. Three-dimensional EarthVision™ model of the North Seco Creek area. Note the multiple faults (shown in red) and the electromagnetic geophysical profiles (shown in blue) used to construct the model.

5 Noble Gas Geochemistry

5 NOBLE GAS GEOCHEMISTRY

Noble gases have proven to be excellent tracers for ground-water studies, and they can help to recognize ground-water origins and water/rock processes. The very rapid ground-water movement through the Edwards aquifer is controlled by two major flow paths: the western Medina flow path and the eastern flow path. Within both flow paths, the fresh-water zone of the aquifer is bounded to the south and southeast by the transitional downdip saline zone. This interface (fig 3), locally referred to as the "bad-water line," is arbitrarily defined where aquifer waters exceed 1,000 mg/L of total dissolved solids (TDS).

Fluid logging and discrete isotope and noble gas sampling were conducted in four transect wells across the fresh-/saline-water interface in Uvalde, Medina, Bexar, Guadalupe, and Hays Counties (Lambert and others, 2003). The fluid logs obtained from the monitoring transect wells show a distinct interface in the eastern part of the study area, such as near Kyle (fig. 9). In the western transect wells, the interface appears to be more gradational. The dissolved gas samples also indicate that the saline-zone water is much older than previously thought.

The helium isotopic (^3He and ^4He) data from the Kyle transect wells tell an interesting story. Measured isotopic compositions of the excess helium in the saline waters of the Edwards aquifer have a composition of 0.22 ± 0.02 R/R_A (R/R_A is the sample ^3He to ^4He ratio normalized to the present-day atmospheric ratio of helium). This homogeneous isotopic composition suggests a uniform source reservoir of excess helium associated with the aquifer. Measured helium compositions from Kyle 3 and 4 wells are similar to those of the other saline samples of the Edwards aquifer (0.23 ± 0.01 R/R_A), but excess helium values from Kyle 1 and 2 wells (freshwater and fresh-/saline-water transition zone) are on the order of 0.14 R/R_A (Hunt and others, 2003). This difference in isotopic composition suggests that the waters have a different origin and may be attributed to subsurface discharge of groundwater from the underlying Trinity aquifer. Major ion and stable isotope data also corroborate the existence of a subsurface communication between the aquifers as well as dramatic salinity changes in the Kyle 2 well following a major recharge event in the spring of 2003.

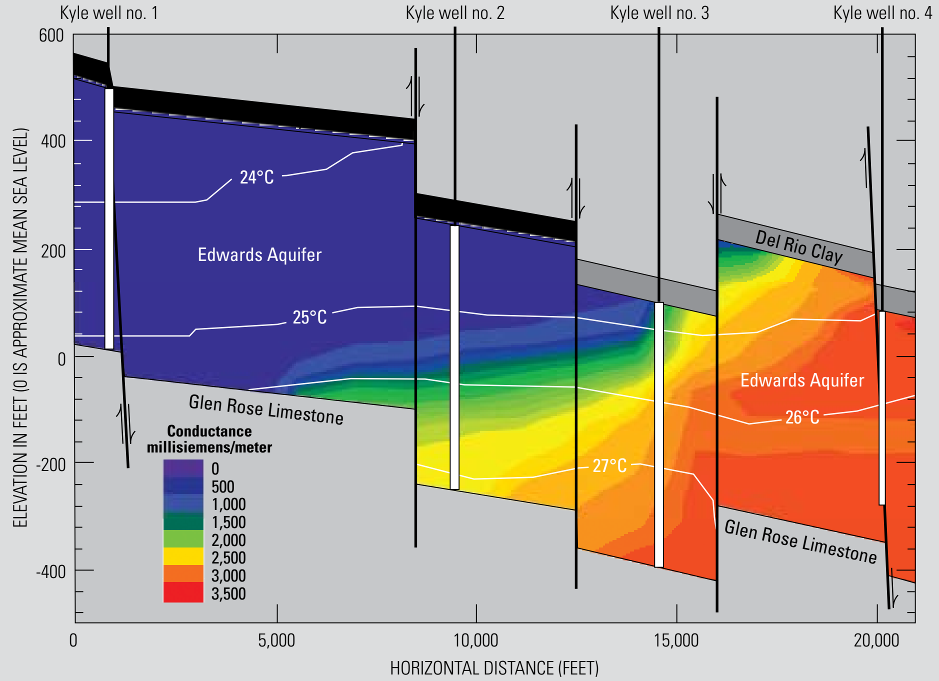

Figure 9. Diagram showing conductance (millisiemens/meter) and fault displacement near Kyle, Texas.

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References

Lambert, R.B., Hunt, A.G., Landis, G.P., and Waugh, J.R., 2003, Fluid logging and discrete sampling of the freshwater/saline-water interface of the Edwards aquifer, south-central Texas [abs.]: Implications for groundwater flow and origin of salinity (Part 1—Fluid logging): Geological Society of America, Abstracts with Programs, v. 35, no. 6, p. 280.

Hunt, A.G., Lambert, R.B., Waugh, J.R., and Landis, G.P., 2003, Fluid logging and discrete sampling of the freshwater/saline-water interface of the Edwards aquifer, south-central Texas [abs.]: Implications for groundwater flow and origin of salinity (Part 2—Geochemistry): Geological Society of America, Abstracts with Programs, v. 35, no. 6, p. 280.

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