

Geologic Cross Sections of the Questa Area, Taos County, New Mexico

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PURPOSE AND SCOPE OF THE STUDY

In 2011, the authors were contacted by Mr. Ron Gardiner and Village of Questa Mayor Esther Garcia (see attached letter in Appendix 1) to discuss the existing and future groundwater supply for the Village of Questa. This meeting led to the development of a plan in 2013 to perform an integrated geologic/geophysical/hydrogeologic investigation of the Questa area by the New Mexico Bureau of Geology & Mineral Resources (NMBG), the U.S. Geological Survey (USGS), and New Mexico Tech (NMT). The original study proposals by the NMBG and the USGS are attached in Appendix 1.

The NMBG was responsible for development of the geologic map and geologic cross sections. The USGS was responsible for developing a detailed geophysical model to be incorporated into the NMBG products. NMT was responsible for providing a graduate student to develop a geochemical and groundwater flow model. This report represents the final products for the geologic/geophysical investigation by the NMBG and the USGS. The USGS final products have been incorporated directly into the geologic cross sections attached, and therefore the Village of Questa will not receive a separate product from the USGS.

The objective of the study was to characterize and interpret the shallow three-dimensional geology and preliminary hydrogeology of the Questa area. The focus of this report is to compile existing geologic and geophysical data, integrate new geophysical data, and interpret it in a geologic context in order to draw three, detailed geologic cross sections across the Questa area. These cross sections can be used by the Village of Questa to make decisions about municipal water-well development, and can be used in the future to help in the development of a conceptual model of groundwater flow for the Questa area. This report consists of a table of water wells used in the study, a 1:24,000 scale geologic map of the study area, and three detailed hydrogeologic cross sections. The locations of the cross sections are shown in Figure 1.

FUNDING

Funding for the NMBG study was provided by the Healy Foundation and the New Mexico Bureau of Geology & Mineral Resources. Because the USGS work was essential to the project goals, funding was needed to support the USGS component. For that purpose, Mayor Esther Garcia procured \$24,000 (\$12,000 from the Village of Questa and \$12,000 from Chevron) and Peggy Johnson provided \$2000 (from Healy Foundation project funds) to fund the USGS to develop the geophysical model. Funding for NMT graduate student Kylian Robinson is provided by the Aquifer Mapping Program at the NMBG.

DATA USED

Prior to beginning the tasks that represented our scope of work, it was necessary to develop the following two data sets:

1. A database of select water wells in the Questa area (Table 1), including wells owned by Chevron, Inc. Most of this task was performed by Kylian Robinson and Kitty Pokorny (NMBG). The database was developed from a variety of sources, including: NMOSE well records, consultant reports, Chevron reports, NMED data, and NMBG data. Although most of the wells have some useful records (such as drillers logs, geologists logs, geophysical logs,

pump tests, water quality analyses, etc.), no records (or incomplete records) exist for a number of the wells. It is possible that these records are preserved somewhere, but they could not be located during this study.

2. An inventory and map of springs in the Questa area (Table 2). The springs inventory was developed during multiple field visits over several years by NMBG and NMED staff and field assistants. Springs were visited during field surveys along the Red River. Their locations were determined using a handheld GPS. Water-quality field parameters and samples were taken on select springs, and discharges were estimated where possible. These data — along with existing spring data from the Rio Grande gorge (Bauer and others, 2007) — were entered into a database, and a digital map of the field stations was created.

The data sets used in this investigation include:

1. Geologic map of the Guadalupe Mountain and Questa quadrangles developed by the NMBG STATEMAP program in partnership with Dr. Ren Thompson of the USGS (Plate 1);
2. Existing subsurface geologic and geophysical data from water-well records, lithologic logs, and borehole geophysics;
3. New and existing geophysical data and interpretations by the USGS;
4. Depth-to-water measurements and spring locations collected by the NMBGMR in 2013 and 2014 (Tables 1 and 2);
5. Historic depth-to-water data from a variety of published and unpublished sources (Table 1).

GEOLOGIC MAP AND GEOLOGIC CROSS SECTIONS

We developed three new geologic cross sections for this study (Plate 2). The locations of sections were chosen to optimize hydrogeologic understanding, maximize the number of useful wells that could be incorporated into the section lines, and utilize the geophysical insights provided by T. Grauch and B. Drenth (USGS). The topographic profiles were generated by ArcGIS software. Cross sections were drawn as vertically exaggerated by a factor of five to better illustrate the shallow hydrologic and geologic details. On the cross-section sheet, all three of the sections are also shown with no vertical exaggeration.

Data Sources

The geologic units shown in the cross sections were established from three principal data sources:

- 1) Local and regional geologic maps;
- 2) Interpretations from borehole geology and borehole geophysics; and
- 3) Interpretations from three geophysical data sets (high-resolution aeromagnetic survey, ground-magnetic surveys, and gravity modeling).

Each of these three data sets is briefly summarized below.

1. **Geologic map.** The principal geologic map used in this study is a digital version compiled from the Questa and Guadalupe Mountain 7.5-minute quadrangles (Kelson and others, 2008; Kelson and others, 2013) produced by the NMBG STATEMAP program. This 1:24,000 scale map shows the distribution of rock units and unconsolidated, surficial, sand and gravel deposits, as well as the locations of known faults. Some of the geologic units shown in the cross sections are not exposed at the surface in the study area. However, these units are exposed in the nearby areas where they have been mapped and analyzed. In the three Questa cross sections, the physical characteristics of some of these units (such as composition, thickness, texture, and lateral extent) are based on work in these nearby areas.
2. **Boreholes.** The geologic and geophysical data attached to the drill holes in the study area ranged from wells with no data attached, to wells with extensive sets of detailed lithologic cutting analyses, different types of borehole geophysics, and a variety of aquifer and water-quality tests. Domestic well records in the study area are only marginally useful for defining the subsurface stratigraphy, as most well drillers do not record the detailed characteristics of well cuttings. In contrast, geologic logs developed by geologists who examined well cuttings (such as those logged by Chevron and its geotechnical consultants) are generally very helpful for defining the subsurface stratigraphy.
3. **Geophysics.** A number of existing and new geophysical studies in the Questa area were incorporated into this investigation. Each of these geophysical techniques can be used alone to

provide useful constraints on the subsurface geology, but the real value of these techniques is that when they are interpreted collectively by a geophysicist, they can provide immensely valuable, detailed information on the subsurface geology. Each of the geophysical studies used in the current study are summarized below.

- a) Existing high-resolution aeromagnetic survey (T. Grauch, USGS Denver). In 2003, Dr. Grauch began a regional aeromagnetic survey of the San Luis Basin (Bankey and others, 2006). For the current study, she reexamined parts of the existing data set in order to develop an aeromagnetic anomaly map of the Questa study area that shows buried faults and buried volcanic rocks. This method can be extremely effective at delineating hidden, large-scale, horizontal and vertical variations in rock type.
- b) New ground-magnetic surveys (T. Grauch, USGS Denver). In April 2014, Dr. Grauch ran select ground-based magnetic traverses across the Questa area. This method can precisely locate buried faults and other features that juxtapose materials with different magnetic properties.
- c) Gravity surveys and regional gravity model (B. Drenth, USGS Denver). In April 2014, Dr. Drenth collected detailed gravity traverse data, and incorporated these data into a regional interpretation of gravity data for the Questa area. His main goal was to improve understanding of the thickness of the basin-fill materials in this part of the Rio Grande rift. This method is especially useful for estimating the general depth to basement rocks and for locating large-offset basement faults.

The fault structures depicted in the cross sections were established from three data sources: 1) mapped faults from the geologic map; 2) inferred faults from the magnetic and gravity surveys; and 3) a conceptual model of the geometry and kinematics of the northern Rio Grande rift. Each of these three data sets is summarized below. Readers should note that imposing a vertical exaggeration of five on the cross sections results in the apparent steepening of faults. Based on measurements of faults exposed in the Sangre de Cristo Mountains, the average dip of faults in this area is probably around 60 to 70 degrees. On the exaggerated cross sections, these dips appear much steeper.

1. The geologic maps of Kelson and others (2008, 2013) show a large number of segmented normal fault splays along the Sangre de Cristo fault zone east of Questa, and other zones of faults within the rift basin. On the cross sections, such faults are labeled “mapped fault.”
2. Modern geophysical techniques using high-resolution magnetic data and gravity data are capable of defining buried faults in Rio Grande rift basins, such as in the Questa area. Dr. Grauch and Dr. Drenth have refined these techniques in the Rio Grande rift. They are currently capable of processing these data in ways that allow them to draw the locations of faults that create geophysical anomalies. On the cross sections, such faults are labeled “geophysical fault.” It is worth noting that there is good correspondence between the mapped faults and the geophysically defined faults. Such correspondence elevates our confidence in the delineation of buried faults by such geophysical techniques. Recent gravity modeling by Dr. Drenth provides an extremely useful tool for estimating the thickness of basin-fill deposits in the rift basin. This technique yields a depth-to-basement curve for the cross sections. As the basement deepens away from the edge of the rift, numerous buried faults must exist in order to deepen the basement. On the cross sections, such faults are labeled “inferred fault.”
3. The conceptual geologic model for the development of this part of the southern San Luis basin of the Rio Grande rift (Kelson and others, 2008, 2013), provides a framework for presenting the geometry and kinematics of the local rift structures. In the Questa area, the west-down normal faults of the Sangre de Cristo fault system are expected to be the dominant buried features. The Red River fault is an east-down, normal fault zone.

Development of the Cross Sections

The following list illustrates the general steps that were taken to create the geologic cross sections developed for this study:

1. **Geologic contacts are picked off of the geologic map.** The surface geology is taken from the geologic map and placed on the topographic profile of the cross section. Geologic contacts that

are buried by thin surficial deposits were estimated. Some of the thinnest Quaternary surficial deposits are not shown on the cross sections.

2. **The gravity model is used to define the depth to basement rocks in the cross section.** The base of the cross section is constrained by the depth-to-basement curve derived from the USGS gravity model. The depth-to-basement curve depicts a highly smoothed contact between basin-fill sediments and bedrock. In the model, both Tertiary plutonic rocks of the Questa caldera and Proterozoic crystalline rocks are considered to be bedrock.
3. **Geologic information derived from the wells is added to the cross section.** Poorly studied wells have limited value for developing cross-section stratigraphy, especially for the basin-fill sediments. However, expertly studied wells can help control the regional thicknesses and depths of key stratigraphic formations, including some of the basin-fill units such as the Lama Formation and thick clay horizons. Most of the basin-fill stratigraphy (Santa Fe Group (Tsf) and Lama Formation (QT_L)) consists of poorly sorted, clay-to-boulder sized, alluvial material that was eroded from the nearby mountains. Unless the compositions and proportions of rock clasts and the color of the sediment is well described, it is not possible to tell them apart in drill holes. Although the depictions of these two units on the cross sections are based principally on borehole data, local stratigraphic relationships, and an understanding of the sedimentary systems and geologic processes of the area, it is possible that the thicknesses of the various basin-fill units are not accurately represented. For example, in many areas where there is no Servilleta Basalt in the subsurface, it is not possible to confidently place the contact between the Santa Fe Group and the Lama Formation.
4. **Mapped and inferred faults are drawn onto the cross section.** For the purposes of this study, the dips of the inferred faults were estimated to be between 60 and 70 degrees westward, unless evidence existed for some other orientation. In all cases, the geometries of the normal faults drawn in the cross sections are intentionally simplified as single inclined planes, when in fact all of the mapped normal faults in this area have much more complex geometries. They are typically curved, segmented, branched, and composed of multiple overlapping fault planes. Where exposed, faults in bedrock typically display wide fracture

zones with high permeabilities, whereas faults in basin-fill sediments commonly display narrow, clay-rich cores with lower permeabilities.

5. **Interpretations from geophysics is added to cross section.** With consultations from the USGS geophysicists, any additional information gleaned from the geophysics is added to the cross section. For example, this could include evidence for buried volcanic rocks or for dividing buried volcanic rocks into separate volcanoes.
6. **Conceptual models of volcanic and sedimentary processes are incorporated into cross section.** This phase of work was principally done by Dr. Thompson, who used his extensive knowledge of the Taos Plateau Volcanic Field to draw realistic configurations of the buried volcanoes and their surroundings.
7. **Information from the hydrology is added to the cross section.** Hydrologic information such as the locations of spring zones, water levels in wells, the locations of streams and acequias, and variations in field parameters such as groundwater temperature, may be included on the cross sections. Where we have studied the hydrogeology of springs elsewhere in Taos County, we have found that the location and characteristics of springs are strongly influenced by the geology. Specifically, springs tend to occur where contrasts in hydraulic permeability exist. Such contrasts can be created by faulting, by original variations in rock properties, and by post-depositional effects such as cementation.
8. **Formation contacts are drawn onto the cross section.** Due to a lack of stratigraphic markers in the Questa area, the dips of the geologic units are unknown. Therefore, unless evidence exists for depicting local dips, contacts have been drawn as sub-horizontal. In most areas of the study area, thicknesses of buried basin-fill units are unknown. As a general rule, most basin-fill units must thin from west to east, from the deepest part of the basin to the bedrock of the Sangre de Cristo Mountains.
9. **The cross section is checked against the geophysical models.** After the cross section has been drawn, it is checked by our USGS colleagues against the geophysical models from the aeromagnetic and gravity surveys. If the geophysical model is robust, this is an excellent way to fine-tune the geologic model. For example, the aeromagnetic model might suggest that a

volcanic layer shown in a cross section should be thicker or thinner, or that a fault must juxtapose materials with more-different magnetic properties. This iterative process between geologist and geophysicist is a powerful tool for developing well-constrained geologic models.

CONCLUSIONS DRAWN FROM THE CROSS SECTIONS

1. **Volcanoes.** Exposed volcanoes, such as Guadalupe Mountain, are underlain by buried roots that extend laterally in the basin-fill sand and gravel deposits. In the Questa area, the buried flank of Guadalupe Mountain volcano extends eastward in the subsurface nearly to the NM-522 highway. These buried volcanic rocks are typically strongly fractured, and therefore highly permeable to groundwater flow.
2. **Faults.** The basin below the Questa area contains large numbers of buried faults whose exact locations can not be determined. Although they are shown as simple planes in the cross sections, in reality, they are certainly extremely complex, with multiple segments, branches, and curved shapes. The permeability contrasts between such faults and adjacent material are known to influence the movement of groundwater, and depending on their characteristics, they can either enhance or restrict groundwater flow. It is possible that any water well in the Questa area could intersect such faults, and it is probable that deep wells in the area will be influenced by such structures.
3. **The Basin.** The deepest part of the basin is along the eastern edge of Guadalupe Mountain, where the basin-fill sand and gravel deposits extend to depths of approximately 4000 feet. The basin shallows rapidly to the east and the west. Certain types of sand and gravel deposits in such basins are known to form high-quality aquifers. The bedrock below the basin-fill sand and gravel deposits is most likely a complex combination of older Tertiary volcanic rocks (such as seen in Brushy Mountain west of the Rio Grande, and in the mountains east of Questa) and Precambrian crystalline rocks (such as the gneisses seen in the mountains east of Questa). These bedrock units typically make poor aquifers.

4. **Clays.** Thick clay layers appear to be common in the subsurface of the sedimentary basin in the Questa area. Such clays were most likely deposited in short-lived lakes that developed behind lava dams. However, without better well control, the thicknesses and lateral extents of these clays can only be estimated. Such clays can greatly affect the characteristics of groundwater flow systems, and are capable of “perching” water above the regional water table.
5. **The Regional Water Table.** Preliminary data indicate that the overall flow of the shallow groundwater system is westerly, from the Sangre de Cristo Mountains toward the Rio Grande gorge and the Red River. However, a preliminary water table map (K. Robinson, personal communication, 2015) shows many permutations in the flow pattern, probably related to a combination of factors such as permeability contrasts in the subsurface geology, topography, water exchanged with Red River and Cabresto Creek, acequia and irrigation recharge, and leakage from the tailings ponds. Preliminary data show a dramatic deepening of the regional water table as it encounters the highly fractured rocks of the Guadalupe Mountain volcanics to the west of Questa. This is a common hydrogeologic phenomena in the rift basin where buried volcanic rocks are adjacent to basin-fill sediments (Johnson and others, 2009; Johnson and Bauer, 2012).
6. **Questa Municipal Well #1.** The location of Questa Municipal Well #1 (QU-001) is ideally sited for development of a deeper well at the same location. The existing well is about 400 feet deep. As shown in cross section B-B’, the thickness of the basin-fill sand and gravel deposits at that location is estimated at 1600 feet. Neither buried volcanic rocks nor buried bedrock were detected in the vicinity of the well. The shallow aquifer in this area is likely recharged by infiltration along Cabresto Creek and the acequia systems and fields that lie east of the well. A deeper well at the same location could be highly productive if suitable aquifer units exist below 400 feet depth, although the possible existence of buried faults and clay layers complicates the geologic setting at this location.

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Figure 1. Map Showing Locations of Cross Sections

