10th Annual Española Basin Workshop

Espanola Basin Surface and Groundwater Quality

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ESPAÑOLA BASIN SURFACE AND GROUNDWATER QUALITY

10th Annual Española Basin Workshop

Wednesday, February 23, 2011

Jemez Rooms, Santa Fe Community College, Santa Fe, New Mexico

WORKSHOP PROGRAM

7:45-8:30 am **Registration —** Pick up badges, programs and sign-in; poster setup and viewing

8:30-8:45 am **Welcome and Introductory Remarks: Who is EBTAG and why the annual Española Basin workshops? –** *Claudia Borchert, Chair of Española Basin Technical Advisory Group*

8:45-9:15 am **Water Quality in New Mexico—A Program Perspective –** *Marcy Leavitt, New Mexico Environment Department*

9:15-10:00 am **Occurrence and Geochemistry of Drinking-Water Contaminants, Southern Española Basin** – *Stephen Wiman, Good Water Company and Pat Longmire, Los Alamos National Laboratory*

10:00-10:15 am **Coffee Break**

10:15-11:15 am **Geology, Hydrology, and Groundwater Geochemistry of the City of Santa Fe's 2,663-foot Exploratory Well—Geologic Logging and Aquifer Testing Results from the City of Santa Fe's 2,663 foot Exploratory Well –** *Claudia Borchert, City of Santa Fe; Steve Finch, John Shomaker and Associates; and Pat Longmire, Los Alamos National Laboratory*

11:15-12:00 am **In-situ Bioremediation at the North Railroad Avenue Plume Superfund Site –** *Steve Jetter, NM Environment Department and Dino Chavarria, Santa Clara Pueblo*

12:00-1:15 pm **Lunch Break** (food available for purchase in the cafeteria next door)

1:15-2:30 pm **Surface Water Quality in the Rio Grande through the Española Basin –** *Gretchen Oelsner, US Geological Survey*
Los Alamos Canyon Watershed Stormwater Monitoring from 2003 to 2008; Contaminant Transport Assessment – *Dave Englert, NM Environment Dept.*
River to Tap: Buckman Direct Diversion Project Water Quality - *Rick Carpenter, Buckman Direct Diversion Project Manager*

2:30-4:00 pm **Poster Session**

<u>**FIELD TRIP PROGRAM :**</u> ***Thursday, February 24, 2011***

9:00-5:00 pm **Uranium Sources, Mobility, and Occurrence in Groundwater in the Eastern Española Basin** *Dennis McQuillan, Virginia McLemore,Dave Vaniman, Pat Longmire, Ardyth Simmons, and Dan Koning*

Seismic Investigations of an Accommodation Zone in the Northern Rio Grande Rift, New Mexico, USA

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Seismic reflection and refraction data acquired in the Rio Grande rift near Santa Fe, New Mexico, in 2009 and 2010 by the SAGE (*Summer of Applied Geophysical Experience*) program imaged the La Bajada fault (LBF) and strata offset across the associated, perpendicular Budagher fault (BF). The LBF is a major basin-bounding normal fault, offset down to the west; the smaller BF is an extensional fault that breaks the hanging wall ramp of the LBF. We chose this area because it is in a structurally complex region of the rift, comprising a small sub-basin and plunging ramps, where north-trending, *en echelon* basin-bounding faults (including the LBF) transfer crustal extension laterally between the larger Española (to north) and Albuquerque rift basins. Our data help determine the precise location and geometry of the poorly exposed LBF, which, near the survey location, offsets the rift margin vertically about 3,000 m. When integrated with industry reflection data and other SAGE seismic, gravity, and magnetotelluric surveys, we are able to map differences in offset and extension laterally (especially southward) along the fault. We interpret only about 200 m of normal offset across the BF.

Our continuing work helps define multiple structural elements, partly buried by syn-rift basin-filling sedimentary rocks, of a complex intra-rift accommodation zone. We are also able to discriminate pre-Eocene (Laramide) from post-Miocene (rift) structures. Our data help determine the amount of vertical offset of pre-rift strata across structural elements of the accommodation zone, and depth and geometry of basin fill. A goal is to infer the kinematic development of this margin of the rift, linkages among faults, growth history, and possible pre-rift structural controls. This information will be potentially useful for evaluation of resources, including oil and/or gas in pre-rift strata and groundwater in Late Miocene to Holocene rift-filling units.

Geologic Logging and Aquifer Testing Results from the City of Santa Fe's 2,663 foot Exploratory Well

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The City of Santa Fe (City) drilled, completed, developed, and tested the 2,663-foot Exploratory Cañada Well between March 31 and September 10, 2010. The majority of the drilling and construction hours were restricted to 7am -7pm, as the well is located in the heart of the City in the Barrio La Cañada neighborhood on the site of the Agua Fria production well. The well was drilled under New Mexico Office of the State Engineer exploratory well permit RG-91855-Expl. The purpose of drilling RG-91855-Expl is to gain a greater understanding of geology, hydrogeology, and geochemistry of the Tesuque Formation regional aquifer from 1,000 to 2,500 feet below ground surface, depths greater than existing supply wells within the City. Characterization of the deeper aquifer will help the City understand the aquifer capacity and how to manage the City well field for maintaining future water demands. In the future, the City may drill production wells to replace aging existing wells and increase the well field's capacity with supplemental wells to reach the permitted 4,865 acre-feet per year water right. The 14¾-inch borehole pierced the Tesuque Formation from ground surface to 2,540 feet below ground surface (Tts and Tta). A 10-foot interfingered section of the Bishop's Lodge Member of the Espinaso Formation (Te) was encountered at 2,420 feet before encountering the Espinosa Formation for 100 feet from 2,540 to 2,663 feet below ground surface. The majority of the borehole penetrated the reddish brown gravelly, silty sand interbedded with clay and gravel typical of Lithosome S of the Tesuque Formation, deposits formed by a Miocene fluvial system flowing from east to west. The sand and gravel grains were moderately well rounded with a paucity of limestone clasts. Field geologists identified the deepest 220 feet of the Tesuque Formation (2,310–2,420 and 2,430–2,540 ft bgs) as Lithosome A, because the unit was poorly sorted, contained a greater percent of fine-grained clays, silts, and limestone clasts.

The $6^{5}/8$-inch diameter well casing has eight distinct screened intervals: 277–800 feet bgs, 860–940 feet bgs, 1,120–1,200 feet bgs, 1,500–1,580 feet bgs, 1,770–1,850 feet bgs, 1,920–2,000 feet bgs, 2,120–2,200 feet bgs, and 2,420–2,500 feet bgs. Bentonite grout seals isolated the screened intervals. Aquifer pumping tests were conducted on each of the screened intervals. Packers were inflated above and below each zone tested (screen interval), and pressure transducers were installed in the well above the zone and in the pumping assembly representative of the zone in order to test the aquifer production capability and water quality at distinct depth intervals. Constant-rate pumping tests were performed on each zone tested. Water levels were allowed to recover prior to starting the testing of the next zone. Hydraulic conductivity estimates ranged from 1.8 (most shallow) to 0.33 (deepest) feet per day. Transmissivity of the entire Tesuque Formation aquifer at the Cañada Exploratory well was estimated at 2,154 ft^2/day.

River to Tap: Buckman Direct Diversion Project Water Quality

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The Buckman Direct Diversion is a $221 million drinking water project that treats Rio Grande water for delivery to the greater Santa Fe, New Mexico area. River water in the Rio Grande has presented many significant water quality challenges for this regional drinking water project. This presentation will discuss the primary contaminants of concern in this reach of the Rio Grande, the concentrations at which they have been found to occur, and likely sources of those contaminants. Likewise, this presentation will also discuss associated radiological water quality issues, with particular focus on storm flow runoff from Los Alamos National Laboratory to the Rio Grande upstream of the Buckman Direct Diversion river intake facility.

Radiocarbon Dating and Paleohydrology of Regional Aquifer Groundwater Beneath the Pajarito Plateau, New Mexico

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The regional aquifer beneath the Pajarito Plateau offers a unique opportunity to investigate groundwater age and its relationship to climate change during the Holocene. Regional aquifer material, including the Puye Formation, typically does not contain calcium carbonate (calcite), making radiocarbon in dissolved inorganic carbon an ideal age tracer. From 2005 through 2010, 132 groundwater samples from 71 regional aquifer wells and springs were collected and analyzed for radiocarbon and other dissolved constituents including tritium, major ions, trace elements, and stable isotopes of hydrogen and oxygen. Wells and springs exhibiting background conditions do not contain tritium above 0.3 tritium units, suggesting that no post-1943 recharge has occurred at these sampling locations. Carbon-14 results indicate that groundwater ages increase west to east-southeast from approximately 500 years along the mountain-front recharge zone to 10,000 years in the discharge zone within White Rock Canyon. Distributions of average age (radiocarbon) and modern age (tritium) confirm active recharge and mixing of pre-1943 groundwater occurs beneath perennially wet canyon bottoms dissecting the Pajarito Plateau. Groundwater flow velocities calculated from points along the regional flow path and outside the areas of active recharge range from 1 to 3 m/year. Through the 10,000-year radiocarbon record, the more climate-sensitive ions such as chloride and sulfate tend to increase with groundwater age. δ^2H and $\delta^{18}O$ values correlate with groundwater age and are more positive in older groundwaters, suggesting that the climate in northern New Mexico during the Holocene was warmer than in recent times.

Hydrogeochemical and Stable Isotope Characteristics of the Upper Confined Aquifer, Buckman Well Field, New Mexico

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Chemical and isotopic tracer data were obtained at the artesian piezometer SF-5B during 2010. The piezometer is located at the western boundary of the Buckman well field at the confluence of Cañada Ancha and the Rio Grande. The piezometer penetrates the upper confined aquifer at a depth of about 46 m below ground surface (bgs). The thickness of this aquifer at SF-5B is approximately 30 m. Groundwater from SF-5B discharges at a rate of 1 to 2 L/min. The Buckman production wells pump from the deeper confined aquifer at a depth interval of about 76 to 256 m bgs. Water-level monitoring by the United States Geological Survey and the City of Santa Fe reveals that the upper aquifer shows no pressure response to pumping from Buckman 1 or Buckman 8 wells, located approximately 0.4 km equidistance from SF-5B. The upper and lower confined aquifers in this area are composed of fluvial deposits (silts and sands) of the Tesuque Formation.

For this investigation, data were analyzed with the purpose of determining the: a) hydrogeochemical nature of the groundwater in comparison to adjacent aquifers; b) recharge source(s); c) groundwater age or residence time; and d) presence of contamination from human activity. Specifically, samples were analyzed for major ions, trace elements, low-level tritium, low-level perchlorate, $\delta^{2}H$, $\delta^{18}O$, $\delta^{34}S$ and $\delta^{18}O$ (SO_4^{2-}), $\delta^{13}C$, ^{14}C, and other anthropogenic and natural radioactive elements. Additionally, pH, temperature, specific conductance (SC), oxidation-reduction potential, and dissolved oxygen measurements were made through a flow-through cell at the point of discharge.

The groundwater consists of a sodium-bicarbonate composition with a calculated total dissolved solids ranging from 105 to 136 mg/L. Average concentrations of chloride, nitrate, sulfate, bicarbonate, and carbonate are 1.82 mg/L, 0.40 mg/L, 3.18 mg/L, 64.5 mg/L, and 19.5 mg/L, respectively. Perchlorate was measured at 0.30 µg/L, within the range of background. Average concentrations of calcium, magnesium, potassium, and sodium are 1.55 mg/L, 0.11 mg/L, 0.40 mg/L, and 37.5 mg/L, respectively. Low-level tritium was measured at 0.12 tritium unit (0.39 pCi/L), suggesting that a portion of the the groundwater is younger than 60 years. $\delta^{2}H$ and $\delta^{18}O$ values at SF-5B are more positive compared to the deeper confined aquifer and slightly more negative compared to regional groundwater discharging at the White Rock Canyon springs. The major-ion chemical compositions at SF-5B do not match the deeper confined aquifer at Buckman wells 1 or 8 or the White Rock Canyon springs. The SF-5B piezometer does not show any indication of contamination.

Chromium Speciation and Distribution in the Vadose Zone and Regional Aquifer Materials beneath the Pajarito Plateau, Los Alamos, New Mexico

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Routine groundwater monitoring conducted in 2005 led to the identification of substantial chromium (Cr) contamination in regional groundwater at Los Alamos. To obtain site-specific sorption distribution coefficients of hexavalent chromium on vadose zone and regional aquifer materials beneath the Pajarito Plateau, and to reveal underlying mechanisms for retardation of chromium in the flow trajectory within and outside of the plume we conducted batch sorption, column flow-through transport experiments, and X-ray absorption spectroscopy measurements for speciation and oxidation-state determination of surface complexes of Cr(VI) reacted with geomedia from Sandia Canyon.

The results of batch sorption and flow-through experiments suggest that the vadose zone and regional aquifer materials show differential retention capacities for Cr(VI), reflecting large variations of measured sorption coefficient (K_d) values. Higher K_d values tend to be associated with crushed rocks and reduced particle size samples. Our XANES (X-ray Absorption Near Edge Spectroscopy) measurements suggest that reduction of Cr(VI) to Cr(III) occurred after the Cr(VI)-containing solution was exposed to these rock and sediment materials, suggesting that natural attenuation of anthropgenic Cr on the vadose zone and regional aquifer materials has occurred and shown a range of reduction capacities for Cr(VI), from strong reduction potential within wetlands to moderate within vadose zone basalts and regional aquifer sediments.

Los Alamos Canyon Watershed Stormwater Monitoring from 2003 to 2008; Contaminant Transport Assessment

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During 2003 to 2008, the Department of Energy Oversight Bureau of the New Mexico Environment Department collected stormwater samples from the Los Alamos watershed. The Los Alamos National Laboratory (LANL) discharged radioactive and industrial effluents into the watershed during the 1940's through the 1980's that have spread throughout the canyon channel systems to the Rio Grande. Commercial analytical laboratories analyzed the samples for radiochemical, metal and physical characteristics. The New Mexico Environment Department has produced a report that evaluates the chemical and hydrological data and estimates mass transport of sediments and LANL legacy plutonium$^{239/240}$ in stormwater runoff, develops coefficients that help identify changing watershed functions, describes spatial and temporal trends in suspended sediment loads and contaminant levels, and compares results to applicable water quality criteria.

The sediment and plutonium$^{239/240}$ transport estimates were made from assumptions developed by observation and empirical measurements in stormwater since the Cerro Grande fire of May 2000. General assumptions we found true were that suspended sediment concentrations in stormwater increase and decrease proportionately with flow rates, that plutonium$^{239/240}$ concentrations in suspended sediments were fairly consistent at individual stations, and total plutonium$^{239/240}$ measurements in water increased uniformly with increasing suspended sediment concentrations. Based on these assumptions and the correlations between multiple suspended sediment and plutonium$^{239/240}$ concentrations and paired stormwater flow rates, we estimated sediment and plutonium$^{239/240}$ contaminant transport in individual storm events. We also found that relationships developed between the sediment and plutonium$^{239/240}$ transport estimates and corresponding peak flows at each station. Using these relationships and the annual hydrograph records, we developed transport estimates for storm events not sampled.

Sediment and plutonium$^{239/240}$ transport estimates for the period of 2003 through 2008 are reported at six stations within the watershed. Coefficients are also developed and presented that identify stream function, relative channel stability, and sediment and contaminant availability at stations monitored during this period. Use of these coefficients in future stormwater assessments may identify changes in the watershed. These changes may reflect potential destabilization of the water courses or watershed improvements made by LANL to reduce off-site contaminant migration.

State Lead Remediation Services, Santa Fe County Judicial Complex, Santa Fe, New Mexico

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Under contract to the New Mexico Environment Department, Daniel B. Stephens and Associates (DBS&A) constructed a grout barrier around the Santa Fe County Judicial Complex property and installed a soil vapor extraction (SVE) system for remediation of gasoline-contaminated soil. The project was challenging owing to the presence of free-phase contamination, multiple sources, and limited access due to surrounding businesses. To accomplish the remedial action objectives, DBS&A implemented a number of engineered solutions that, in combination, provide for the safety of workers, local businesses, and the environment. This project is a unique application of a grouted barrier to keep otherwise inaccessible free-phase contamination available for SVE with standard and horizontal wells. This combination of remedial alternatives substantially expedited remediation timeframes, allowing the Judicial Complex construction to proceed. As of January 31, 2011, the remediation system has removed more than 75,000 pounds of petroleum hydrocarbons, and DBS&A is completing the second quarter of operations and maintenance.

The Española Basin 3-D Geologic Framework Model

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Understanding flow paths for water draining through the Española Basin is an important component of subsurface flow and transport models. In 1999, Keating et al. at Los Alamos National Laboratory (LANL) created a basin-scale model to define flow and boundary conditions for the regional aquifer. The latest update to this model was completed in 2005. In the last fifteen years, new geologic mapping in the Española Basin as part of STATEMAP, an initiative supported through a matching-funds grant program between the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) and the USGS, has updated many contacts and important relationships between units. The model presented here updates the geologic framework of the 2005 Keating et al. model by redefining basin boundaries and incorporating the latest geologic map data. Boundaries for the new basin-scale model are designed to include the watershed for the basin and incorporate possible subsurface flow coming from the Jemez Mountains.

Ten geologic map units are used in the model. These units were chosen based on their hydrogeologic properties and the ability to connect them to other LANL geologic framework models. The number of units was kept small to limit processing time and complexity. The Santa Fe Group and older sedimentary units are included as separate units in order to separate flow within the Santa Fe Group from deeper flow. Proterozoic crystalline rocks provide the bedrock surface.

Geologic contact lines were sampled at a 4000-foot spacing to provide point data for drawing structure contours. Structure contours were drawn freehand and then digitized. Surfaces were created using the ArcInfo (© ESRI) Grid interpolation tool 'TopoGrid'. Input data for this tool included the unit boundary, the structure contours, and the surface data points for each geologic surface. The gravity surface at the base of 'Tsfnvs' and the surface topography where units outcrop at the surface were considered to be the main controls for creation of the remainder of the model units.

In-situ Bioremediation at the North Railroad Avenue Plume Superfund Site

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The North Railroad Avenue Plume Superfund Site (the Site) is a groundwater contamination plume located in Española, New Mexico. The groundwater contamination was discovered in 1989 after tetrachloroethylene (PCE) and trichloroethylene (TCE) were detected in two municipal drinking water supply wells. The groundwater contamination was a result of releases from a dry cleaning facility which operated from the early 1970s until 2007. The groundwater plume is divided into two zones. The shallow plume extends approximately ¾ of a mile downgradient of the dry cleaning facility. A second deeper plume extends approximately 1200 feet downgradient of the source and to a depth of 260 feet below ground surface. An estimated 25 gallons (or 300 pounds) of residual dense non-aqueous phase liquid, or DNAPL, occurs in the source area and acts as a continual source of contamination through slow dissolution into the groundwater. The total volume of contaminated groundwater is estimated at 280 million gallons. Historical PCE contaminant concentrations of up to 81,000 ug/L and 1200 ug/L have been recorded in the source area and deep zone, respectively.

The Site was added to the US EPA National Priorities List in January 1999. The New Mexico Environment Department, through funding from the US EPA, constructed a groundwater remediation system in 2005 with full-scale operations beginning in April 2008. The selected treatment technology, enhanced in situ anaerobic bioremediation or enhanced reductive dechlorination (ERD), uses an electron donor solution (emulsified vegetable oil [EVO]) as an organic substrate to provide carbon and energy for indigenous microorganisms to facilitate the ERD process. The ERD process occurs as the microorganisms sequentially replace chlorine atoms with hydrogen-forming reduced dechlorination byproducts ie. PCE → TCE → DCE → VC → ethene. The ERD treatment has resulted in nearly complete degradation of PCE within the shallow treatment areas.

Geologic Map and Cross Sections of the Southern Española Basin

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We present the recently completed geologic map and eight cross sections of the southern Española Basin, all of which are available to the public as Open-file Report 531 from the New Mexico Bureau of Geology and Mineral Resources. The area covered by this map extends from the Rio Grande eastward to the upper western slope of the Sangre de Cristo Mountains, and from the southern limits of the town of Pojoaque southward to just north of Galisteo. The map area was expanded east-west from an earlier version of this map (OFR 481) to include newly interpreted structures under the Cerros del Rio volcanic field and the Cañoncito area. All of the Ancha Formation north of the Rio Galisteo is depicted. The expanded western area incorporates the Tetilla Peak and Montosa Peak quadrangles (from U.S.G.S. Professional Paper 1720, with fault revisions from Ren Thompson and Scott Minor of the U.S. Geological Survey, pers. commun.), the White Rock quadrangle, (NMBGMR Open-file Geologic Map 149), and the northern half of the Madrid quadrangle (NMBGMR OFGM-40). The eastern extent of the map has been expanded to include the western third of the Aspen Peak quadrangle (this study) as well as the McClure Reservoir and Glorieta quadrangles (NMBGMR OFGM 7 & 11, respectively). The northwest corner of the Bull Canyon quadrangle (this study and U.S.G.S. MF 823) was also added.

Eight cross sections illustrate the stratigraphy and structure of the southern Española Basin. Most of the basin fill belongs to the Tesuque Formation of the Santa Fe Group, which is subdivided into units based on interpreted paleogeographic position during basin aggradation in the late Oligocene through middle Miocene: western alluvial slope, basin-floor, eastern alluvial slope, and ancestral Santa Fe River deposits. The structure of the basin north of Interstate 25 corresponds to a west-tilted half-graben called the Cañada Ancha graben. The master fault of this half-graben is inferred to lie under the eastern Caja del Rio Plateau, based on geophysical modeling of gravity and seismic data by Tien Grauch and others (U.S.G.S. Professional Paper 1761). The base of the Santa Fe Group in the deepest part of this half-graben is as much as 1000 m (3300 ft) below sea level. The half-graben is bounded on the west by a west-down flexure called the Barrancos monocline and on the south by the Rancho Viejo hinge zone. South of Interstate 25, the southern Española Basin is a structural platform that has been slightly folded into a north-plunging syncline. Newly interpreted faults from aeromagnetic and gravity data were added to the map in the poorly exposed uplands between Buckman and Santa Fe and under the Ancha Formation between Santa Fe and Eldorado (using data from U.S.G.S. Professional Paper 1761).

The GIS data for the geologic map utilizes a new geodatabase schema (see: http://geoinfo.nmt.edu/statemap/datamodel) that allows much more detailed attribution of geologic units, structures, and contacts as well as feature-level metadata. For instance, fault attributes in the geodatabase now include the interpretative basis, scientific confidence, exposure, and data source. This detailed feature attribution, and the more granular geodatabase structure, will allow GIS users to display and interpret the data in novel ways and should facilitate integration with other rapidly evolving geoscience datasets in the Española Basin.

Water Quality in New Mexico – A Program Perspective

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In New Mexico, an arid state, water is our lifeline. Clean water is essential to people, our economy, and our ecology. Many of the state and federal programs that protect water quality have been in place for decades and address the obvious sources of pollution that discharge directly into our rivers, streams, lakes and aquifers. But there is more that can be done.

- Of the surface waters monitored and assessed by the Environment Department, approximately 39% of stream miles and 64% of lake/reservoir acres have been identified as impaired (i.e. do not meet water quality standards).
- Most impairments result from degraded watersheds and nonpoint or diffuse sources of pollutants caused by grazing, degraded forests and rangeland, malfunctioning septic systems, construction activities, stream bank degradation, roads, recreational activities, urban storm water run-off, and resource extraction.
- The State of New Mexico has issued fish consumption advisories for twenty-eight lakes and reservoirs and three rivers due to elevated concentrations of various contaminants including mercury, dichlorodiphenyltrichloroethane (DDT), and polychlorinated biphenyls (PCBs).
- In the section of the Rio Grande that runs through the Espanola Basin, PCBs in fish tissue have resulted in public fish consumption advisories and associated water quality impairment listings. Water quality impairments for turbidity have also been documented and have the potential to affect aquatic life.

The River Ecosystem Restoration Initiative, Outstanding National Resource Waters designations, refinements to the Clean Water Act Section 319 nonpoint source control program, and development of a new hydrology protocol are a few of the recent state initiatives that have been undertaken to address water quality concerns.

At the federal level, recent Supreme Court decisions have cast uncertainty regarding the scope of waters protected under the Clean Water Act, especially with regard to non-perennial and closed basin waters. In a state where ninety-two percent of our waters are non-perennial, we have a strong interest in the outcome of federal legislation, rules or policies that seek to expand or contract the universe of federally protected waters. State assumption of Clean Water Act surface water quality permitting programs is an option that warrants consideration.

These initiatives are examples of ways that New Mexico can protect its water quality programs for use by future generations.

Hydrogeochemical Characterization of the Cañada Well, Santa Fe, New Mexico

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The Cañada monitoring well drilled near the Agua Fria production well in Santa Fe, NM provides a unique opportunity to sample regional aquifer groundwater within the Tesuque and Espinaso Formations. Chemical variations in inorganic solute chemistry, stable isotope ratios, and unadjusted carbon-14 ages suggest that groundwater flow paths and residences times are complex within the regional aquifer. Groundwater samples were collected from seven zones in the well including the lowermost zone 1 (2500–2420 ft depth), zone 2 (2200–2120 ft depth), zone 3 (2000–1920 ft depth), zone 4 (1850–1770 ft depth), zone 5 (1580–1500 ft depth), zone 6 (1200–1120 ft depth), and uppermost zone 7 (940–860 ft depth). Groundwater varies from calcium-sodium-bicarbonate to sodium-bicarbonate composition with increasing sample depth. Groundwater samples were basic with pH values ranging from 8.95 to 9.58, most likely resulting from dissolution of disodium carbonate used during drilling. Sodium, bicarbonate, and carbonate concentrations in samples collected from the well most likely result from both natural geochemical processes and dissolution of this drilling additive. Concentrations of arsenic, nitrate(N), and uranium varied from 2.1 to 14.5 μg/L, from 0.08 to 1.94 mg/L, and from 1.3 to 17.1 μg/L, respectively. Iron and natural uranium concentrations show a strong correlation (r^2 = 0.968), suggesting that natural uranium is associated with colloidal iron particles through adsorption processes. Variations in δ^2H and $\delta^{18}O$ values at the well suggest that recharge to the regional aquifer occurs at different elevations within the Sangre de Cristo mountain front and basin-fill sediments. Unadjusted carbon-14 ages varied from 6056 (zone 6) years before present to 17,753 (zone 1) years before present. $\delta^{13}C$-HCO_3 values varied from -12.9 to -10.0 per mil, suggesting that dilution of carbon-14 by bicarbonate-carbonate released from calcite dissolution is not occurring to a significant extent at the Cañada well. Concentrations of tritium were less than 0.28 pCi/L (0.09 tritium units) in groundwater samples collected from the seven zones. This suggests that direct recharge from precipitation to the regional water table, based on measurable tritium, has not occurred at the well site since the early to mid 1950s. It is possible, however, that extensive groundwater mixing at the regional water table has diluted out any measurable tritium. $\delta^{15}N$-NO_3 values varied from +5.83 to +9.84 per mil, suggesting that enrichment of nitrogen-15 in groundwater samples collected from zones 6 and 7 result from past sewage releases from septic tanks/sewage lines in the area. $\delta^{18}O$-NO_3 values varied from -5.44 to -0.86 per mil, also suggesting that nitrate-N concentrations in zone 6 (1.16 ppm) and zone 7 (1.94 ppm) are derived from sewage and not from fertilizer enriched in oxygen-18.

Uranium Deposits in the Española Basin, Santa Fe County, New Mexico

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Uranium mineralization in the Española Basin is not of sufficient quantity and quality to justify mining. However, many private water wells in the region produce water with concentrations of uranium (up to 1,820 μg/L) that exceed the safe drinking-water standard of 30 μg/L. Therefore, it is important to understand the source of the uranium in the groundwater and the processes involved. Potential sources for uranium in the groundwater include 1) uranium occurrences in the Tesuque Formation (San Jose mining district); 2) veins, replacements, and pegmatites in Proterozoic rocks (San Jose and Nambé mining districts); 3) Proterozoic granitic rocks in the Sangre de Cristo Formation; and 4) rhyolitic ash beds interbedded within the Tesuque Formation.

Three types of sandstone uranium deposits are found in the San Jose district: 1) medium-grained sandstone with uranium associated with clay galls and carbonaceous material, 2) poorly consolidated fine- to medium-grained sandstone with disseminated uranium and little carbonaceous material, and 3) coarse-grained sandstone to conglomerate with abundant uranium associated with carbonaceous material. Carnotite, schroeckingerite, and meta-autunite coat fractures and bedding surfaces in sandstone, siltstone, and shale within the Tesuque Formation, especially near clay galls and carbonaceous material. Uranium also occurs as coatings around opal and chert grains, with organic debris, and in clay zones. One property, the San Jose No. 13 (NMSF0033), produced 12 lbs (5 kg) of U_3O_8 at a grade of 0.05% U_3O_8 in 1957.

The uranium occurrences in the Tesuque Formation probably represent natural precipitation and concentration from uraniferous groundwaters, likely derived from 1) the Sangre de Cristo Mountains to the east, 2) ash beds within the Tesuque Formation, and/or 3) the alteration of granitic and/or volcanic detritus in the sedimentary host rocks. The uranium in the waters in this area is most likely a result of weathering of uranium from rocks in the adjoining mountains and subsequent migration of uranium and radon in the groundwater. Uranium then precipitated from the waters to form the geochemical anomalies found in the stream sediments and prospects.

Sources, Mobility, and Groundwater Occurrence of Uranium in the Eastern Española Basin Region

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Water wells completed in basin-fill deposits in the metropolitan Santa Fe area typically produce water with uranium concentrations less than 5 μg/L, while 22% of the wells drilled into Precambrian aquifers in the mountain area east of Santa Fe contain uranium exceeding the drinking-water standard of 30 μg/L, with maximum concentrations in the range of 100 μg/L. North of Santa Fe, however, in the vicinity of Pojoaque, Nambé and Arroyo Seco, approximately half of the basin-fill wells tested contain uranium exceeding 30 μg/L, with many concentrations greater than 100 μg/L and some exceeding 1,000 μg/L. Most of the wells with high uranium are drilled to depths of 200 feet or less. These extraordinary uranium concentrations result from a combination of geologic, geochemical, and hydrologic conditions.

Uranium mineralization occurs in both Precambrian rock and in basin-fill sediment. Some deposits have been prospected, but the low uranium concentrations (<0.01 weight percent) and small volumes of mineralized rock are not economical for mining.

Uraniferous minerals including uraninite and coffinite occur in pegmatites, along local shear zones, and disseminated in Precambrian rocks in the Sangre de Cristo Mountains. Precambrian rocks north of Santa Fe contain relatively high concentrations of uraniferous minerals. Soluble uranium (VI) may be leached into groundwater from the weathering of these rocks, as well as reworked fromPrecambrian rocks that were washed into the basin-fill sediments.

Clastic basin-fill sediments are interbedded with volcanic ash-fall deposits, many of which have been reworked into ash-rich fluvial deposits. Vitric volcanic ash is relatively soluble and unstable when in contact with oxidizing groundwater. Glass in the ash can undergo devitrification, a chemical transformation from glass to clay minerals such as smectite. Smectites and zeolites have been detected in some clay deposits that appear to be devitrified ash. Devitrification can release heavy metals, including soluble uranium (VI), into groundwater.

Fault zones, where upwelling of deep groundwater has transported elevated concentrations of arsenic, boron and lithium into shallower aquifers, do not appear to be associated with high levels of uranium in groundwater in this region.

Aqueous uranium (VI) released from weathered Precambrian rocks and from devitrified ash migrates westward with the hydraulic gradient of the aquifer. A northwest-southeast trending belt of uranium mineralization in basin-fill sediment results, in large part, from roll-front precipitation of uranium (IV) minerals in a paleo-aquifer where organic-rich sediments created reducing conditions. Some of the aqueous uranium also may have been adsorbed onto ferric oxide and clay minerals, and eventually precipitated. Basin-fill sediment in the Española area has undergone relatively rapid incision and erosion in the past 300 ka, which has lowered groundwater levels and subjected many uranium deposits to oxidization. The latter results in leaching uranium back into groundwater. Reducing conditions currently occur in some shallow groundwater, such as along the Pojoaque River, but the extent to which aqueous uranium (VI) may be flowing into these areas and undergoing reduction and precipitation has not been defined.

Surface Water Quality in the Rio Grande through the Española Basin

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In arid regions, water quality and quantity are tightly linked and respond dramatically to rapid changes in climate or demand. This situation is exemplified along the Rio Grande, where communities within the growing urban areas are turning to water quantity solutions such as grey-water recycling, water banking and use of surface river water rather than groundwater. We conducted synoptic sampling of a 1200 km reach of the Upper Rio Grande from January 2001 to August 2006 to develop seasonal relationships between discharge, land use, and major water quality-parameters.

Within the Española Basin, water quality in terms of both salinity and nutrient concentrations, is generally good. Between Taos and Otowi, total dissolved nitrogen (TDN) concentrations are similar in summer and winter, while nitrate concentrations are lower in the summer than in the winter. Conversely, dissolved organic carbon (DOC) concentrations are higher in the summer than in the winter. Interestingly, we did not observe significant increases in nitrogen concentrations downstream of agricultural areas or wastewater inputs. The Rio Chama can be a significant source of solutes to the Rio Grande, particularly in the summer when it significantly augments Rio Grande flow. Data from a storm event in August 2006 show dilution of some solutes like sulfate and DOC, but increased transport of nitrate to the river. Similar to the Rio Grande downstream of Albuquerque, the river does not have much capacity to retain nitrogen within the Española Basin. Results from a chloride mixing model suggest that both TDN and DOC concentrations behave conservatively between Taos and Otowi, while there is biological processing of nitrate within the reach. River geomorphology within this reach provides favorable conditions for nutrient cycling.

This work was supported by SAHRA (Sustainability of Semi-Arid Hydrology and Riparian Areas) under the STC Program of the National Science Foundation, Agreement No. EAR-9876800. The majority of the data collection and analysis presented here was performed by G.P. Oelsner as part of her doctoral research at the University of Arizona.

Three-Dimensional Geologic Model of the Southeastern Española Basin, Santa Fe County, New Mexico

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We developed this multimedia model to digital three-dimensional faulted surfaces and volumes of lithologic units that confine and constrain the basin-fill aquifers within the Española Basin of north-central New Mexico. These aquifers are the primary groundwater resource for the cities of Santa Fe and Española, six Pueblo nations, and the surrounding areas. The model is a synthesis of geologic information that includes (1) aeromagnetic and gravity data and seismic cross sections; (2) lithologic descriptions, interpretations, and geophysical logs from selected drill holes; (3) geologic maps, geologic cross sections, and interpretations; and (4) mapped faults and interpreted faults from geophysical data. Modeled faults individually or collectively affect the continuity of the rocks that contain the basin aquifers; they also help define the form of this rift basin. Structure, trend, and dip data not previously published were added; these structures are derived from interpretations of geophysical information and recent field observations. Where possible, data were compared and validated and reflect the complex relations of structures in this part of the Rio Grande rift.

This interactive geologic framework model can be used as a tool to visually explore and study geologic structures within the Española Basin, to show the connectivity of geologic units of high and low permeability between and across faults, and to show approximate dips of the lithologic units. The viewing software can be used to display other data and information, such as drill-hole data, within this geologic framework model in three-dimensional space.

Computed Streamflow Gains and Losses in the Lower Santa Fe River

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Few recent studies estimate the gains and losses to the lower Santa Fe River between the City of Santa Fe Wastewater Treatment Plant (WWTP) and the USGS gage, Santa Fe River above Cochiti Lake, NM. Under the direction of the New Mexico Office of the State Engineer, a field investigation was undertaken in March 2010 to measure streamflow in the lower Santa Fe River and tributaries for the purpose of estimating gains and losses under baseflow conditions for several reaches of the river.

We computed or acquired streamflow data at four sites on the Santa Fe River between March 26 and March 31, 2010: 1) the WWTP; 2) a site about 4,000 feet downstream from Calle Debrah bridge in the La Cieneguilla area (Site A); 3) a site upstream of the confluence with Cienega Creek (Site B1); and 4) the USGS gage, Santa Fe River above Cochiti Lake, NM. In addition, streamflow was computed on Cienega and Alamo Creeks. Flows at the WWTP were based on outflow data provided by the City of Santa Fe. For Sites A and B1, staff gages were installed, rating curves were developed for each site, and gage heights were measured and recorded every five minutes to compute streamflow. Streamflow data at the USGS gage, Santa Fe River above Cochiti Lake, NM, were obtained from the USGS. Streamflow data were compiled for several days at each of the sites, since flow from the WWTP varies considerably during the day. Flows on the Santa Fe River were averaged for several 24-hour periods at each site and compared to the next site upstream or downstream to estimate average gains or losses for each stream reach.

In general, the results indicate that there are streamflow losses in the Santa Fe River between the WWTP and Cieneguilla, there are streamflow gains in the Santa Fe River between Cieneguilla and the confluence with Cienega Creek, and there may be some streamflow losses between the confluence with Cienega Creek and the USGS gage, Santa Fe River above Cochiti, Lake, NM. The results represent a step towards improving our understanding of present-day gains and losses to the lower Santa Fe River. Additional streamflow studies to estimate gains and losses to the lower Santa Fe River and tributaries in the La Cienega area are planned for 2011.

Occurrence and Geochemistry of Drinking-Water Contaminants, Southern Española Basin

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With the generous support of the New Mexico Small Business Assistance Program and the Earth and Environmental Sciences Division wet chemistry laboratory at Los Alamos National Laboratory (LANL), a regional water-testing program was conducted in the summer and fall of 2009. The diverse technical team included Good Water Company, LANL, the NM Environment Department, the City of Santa Fe, and Santa Fe County. The objective of the testing program was to determine the geographic distribution of drinking water constituents believed to be of potential human health risk (arsenic, fluoride, nitrate, and uranium) as well as other constituents such as total dissolved solids (TDS), hardness, iron, and manganese. Analytical results for major anions and cations, trace elements, fluoride, and nitrate were provided to over 475 participating private well owners in the greater Santa Fe area. The 2009 test results were compared with U.S. Environmental Protection Agency (EPA) Maximum Contaminant Levels (MCLs) for public drinking-water systems, and with NM Water Quality Control Commission (WQCC) groundwater standards. Well owners were provided test results along with interpretive letters including, when necessary, information on potential health risks and options for water treatment.

Eighty-two percent of all private wells tested in 2009 did not contain any constituents at concentrations exceeding human health standards set by EPA or WQCC. Six percent of the wells tested contained sulfate, chloride, and/or TDS at concentrations exceeding WQCC aesthetic standards, but did not contain any other constituents at concentrations posing health hazards. Potentially hazardous concentrations of arsenic, uranium, fluoride, and nitrate, however, were detected in 48, 29, 11, and 9 individual wells, respectively. Arsenic exceeding the EPA MCL of 0.01 mg/L was detected in 10% of the wells tested (20% in western Santa Fe, and 15% in Eldorado). Upwelling of deep mineralized groundwater along fractures and faults in western Santa Fe transports soluble arsenic into shallower aquifers. Arsenic in the form of arsenite species also may be released during desorption reactions with clay minerals and hydrous ferric oxide occurring along flow paths in shallow aquifers. Arsenic was positively correlated with pH, sodium, fluoride, lithium, and boron. Numerous volcanic glass deposits in various stages of alteration contain roll-front uranium(VI) ore bodies or mineralized zones east of the Rio Grande between the cities of Santa Fe and Española. Uranium is also leached from Precambrian granite and other rocks comprising the Sangre de Cristo mountain front and mountain block. Natural distributions of total dissolved uranium are hypothesized to be controlled by precipitation of uranium(VI) minerals, specific adsorption of uranium(VI) complexes onto hydrous ferric oxide, and cation exchange of uranyl cation with calcium in smectite. Fluoride exceeding the WQCC groundwater health standard of 1.6 mg/L was detected in groundwater with low concentrations of calcium in isolated areas throughout the study area. Calcium can control fluoride concentrations by precipitation of fluorite and by cation exchange. Nitrate(N) detections exceeding the EPA MCL of 10 mg/L appear to be associated with localized contamination from onsite septic systems, particularly in the fractured bedrock terrain of the mountain front. With the exception of arsenic removal, for which speciation is essential for complete treatment success, concentration reduction of all these contaminants is straightforward, once the complete water chemistry is determined.

EBTAG Field Trip – February 24, 2011

Sources, Mobility, and Groundwater Occurrence of Uranium in the Eastern Española Basin

Field Trip Leaders: Dennis McQuillan, Virginia McLemore, Dave Vaniman, Pat Longmire, Dan Koning, and Ardyth Simmons

From Santa Fe:

- Travel north on HW 285 to Pojoaque
- (0 mi) Turn east on HW 503, pass through Nambé towards Chimayó
- (2.7 mi) Where the road bends northward in the town of Nambé, a thick white ash bed is seen to the right by the fire station (**Figure 1**). The ash appears to be relatively fresh. It was assigned to White Ash No. 1 by Galusha and Blick (1971) and to the Middle Ash of the Nambé Member by Koning et al. (2002). The ash is interbedded with pinkish siltstone and silty, very fine- to fine-grained sandstone. The relatively unaltered ash is mined by local potters to mix into the clay used to make ceramics. The ash reportedly imparts a beneficial quality to the ceramic products.
- (4.7 mi) Two miles north of the fire station, the road winds through badlands developed on the upper Nambé Member of the Tesuque Formation, whose age is 16.0–16.5 Ma (Galusha and Blick, 1971; Tedford and Barghoorn, 1993; Izett and Obradovich, 2001). These strata were deposited on the distal part of an alluvial slope, and consist of tan to pink, arkosic siltstone and fine sandstone in tabular beds. Interspersed in this fine sediment are minor channel-fills composed of coarser sand and granitic pebbles.
- (6.2 mi) 3.5 miles north of the fire station, the road is still on distal alluvial slope sediment.
- (6.7 mi) 0.5 mile to the west, the alluvial slope sediment laterally grades westward into fine-grained, basin-floor deposits with freshwater limestone beds.
- (6.7 mi) 4.2 miles north of the junction of CR 98 and HW 503, the road bends eastward in Arroyo Seco. Just to left is a windmill marking the location of Uranium Spring. This spring is 500 ft east of the White Operation fault zone (discussed in Stop 2). This fault may locally act as a groundwater flow barrier by cutting off and sealing west-trending channel fills in the Santa Fe Group, thereby creating a local groundwater high (**Figure 2**). Just 1 mile to the southeast, another spring discharges on this fault trace and is probably formed by the same hydrogeological process. In the main drainage of Arroyo Seco, Quaternary alluvium may be too thick to manifest a high groundwater table. The sandy-gravelly nature of the Quaternary alluvium results in high hydraulic conductivities (Koning et al., 2007).
- (7.4 mi) 0.5 mile north beyond Uranium Spring is a good exposure of an east-down normal fault in the roadcut to the north (**Figure 3**).
- (7.7 mi) Turn left (north) onto CR 98 (Juan Medina Road) toward Chimayó. Well-exposed badlands are north of the CR 98-HW 503 intersection. These badlands are developed in fine-grained sandstones (minor siltstone and conglomerate beds) of the middle Nambé Member and are probably 16.5–17.5 Ma.
- (10.1 mi) Turn right (east) onto CR 92 to Santa Cruz Dam (**Figure 4**). Santa Fe Group strata near this turnoff are gravelly and were deposited by an ancestral Santa Cruz River ca. 17–19 Ma. This river carried subordinate Paleozoic detritus in predominantly arkosic sand and granitic gravel. The Chimayó fault is crossed 0.3 miles east of the turnoff, where the road makes a slight bend to the right. This west-down fault has down-dropped gravelly, lower Nambé Member strata against Proterozoic bedrock. It probably has accumulated over 100 m of throw. East of the fault, the basal contact of the Nambé Member can be readily observed overlying Proterozoic bedrock. Coarse-grained, basal

Nambé Member strata immediately overlying this contact are commonly strongly cemented by calcium carbonate.

- (10.6 mi) Shaw no. 2 prospect across creek and up slope. Park at the end of the road 0.8 miles east of the intersection of County Roads 98 and 92.

FIGURE 1. View of Nambé ash, looking to the east.

FIGURE 2. Cemented White operation fault zone exposed in road cut east of Uranium Spring.

FIGURE 3. Detail of cemented fault zone (calcite) exposed on highway between Nambé and stop 1. LANL XRD sample here (see Table A-1 in Appendix A).

9:30 a.m. – (10.9 mi) Stop 1 and field trip starting point – uranium mineralization in Precambrian granite and pegmatite

A variety of Proterozoic rocks are exposed in the gorge just west of the Santa Cruz Reservoir. Immediately west of the dam is coarse-grained, non-foliated granite that locally contains pegmatites. The granite has been interpreted as Paleoproterozoic or Mesoproterozoic in age. Amphibolite and biotite schist are more common in the middle of the gorge and have been assigned a Paleoproterozoic age (Koning et al., 2002). Some of the larger pegmatites (up to 100 ft wide) occur in the amphibolite.

The Shaw 2 prospect (New Mexico Mines Database Number NMSF0034) also is known as the Santa Rita, Hubbard, Cordova, Big Buck, and Salmar prospect and is located in section 7, T20N, R10E (35.9827424°N 105.9221679°W), north of Santa Cruz Dam on the north side of Santa Cruz River (**Figures 5, 6**). Pits and two short adits expose Precambrian vein and replacement deposits consisting of secondary uranium minerals disseminated along a shear zone (N20°E), approximately 1 m thick, in Proterozoic amphibolite schist intruded by simple quartz-feldspar-biotite pegmatites and granite. The uranium minerals are reported associated with secondary copper minerals. Hematite, quartz, biotite, feldspar, and unknown uranium minerals are found along fractures within the shear zone. Radioactivity was approximately 50 times background reading (background 30 cps, high 1500 cps). Reid et al. (1982) reported a sample contained 47 ppm uranium. Chemical analyses of samples collected for this report are shown in **Table 1**. There is no economic resource potential because of the prospect's small size and low grade. The shear zone as seen from the parking area is shown in **Figure 7**. The Shaw 2 prospect adit is shown in **Figure 8** and a closeup of the shear zone is shown in **Figure 9**. **Figure 10** shows the location of uranium mines and prospects in the San Jose and eastern Nambé mining districts.

TABLE 1. Chemical analyses of samples collected from shear zone and analyzed by portable X-ray fluorescence instrument (Bruker model Tracer III).

Sample	La ppm	Ce ppm	Cr ppm	Ni ppm	Cu ppm	Zn ppm	Th ppm	U ppm	Y ppm
Shaw1	124	226	203	115	60	99	6	48	45
Shaw2	Not detected?	Not detected?	163	45	65	81	Not detected?		36

FIGURE 4. Santa Cruz Dam, view from southeast.

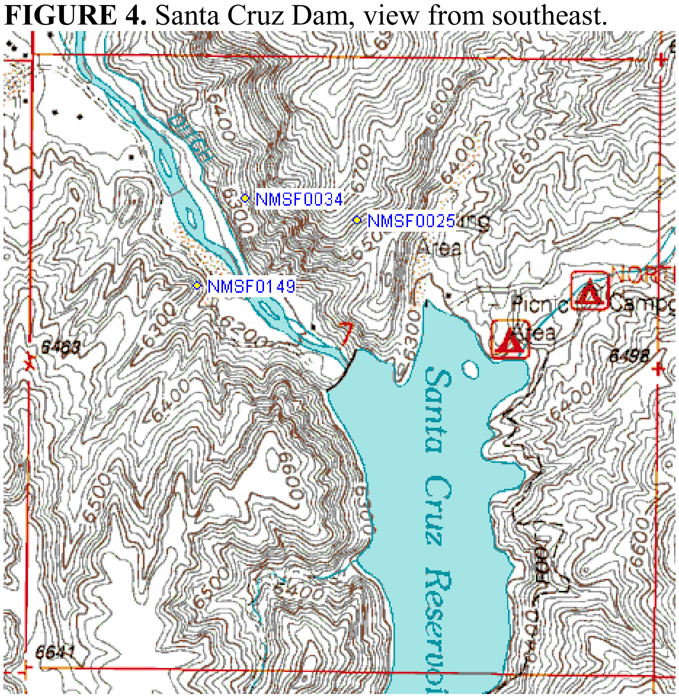


FIGURE 5. Location of Shaw 2 (NMSF0034), unknown (NMSF0149), and Marion (NMSF0025) prospects in section 7, T20N R10E, Cundiyo quadrangle, Santa Fe, New Mexico.

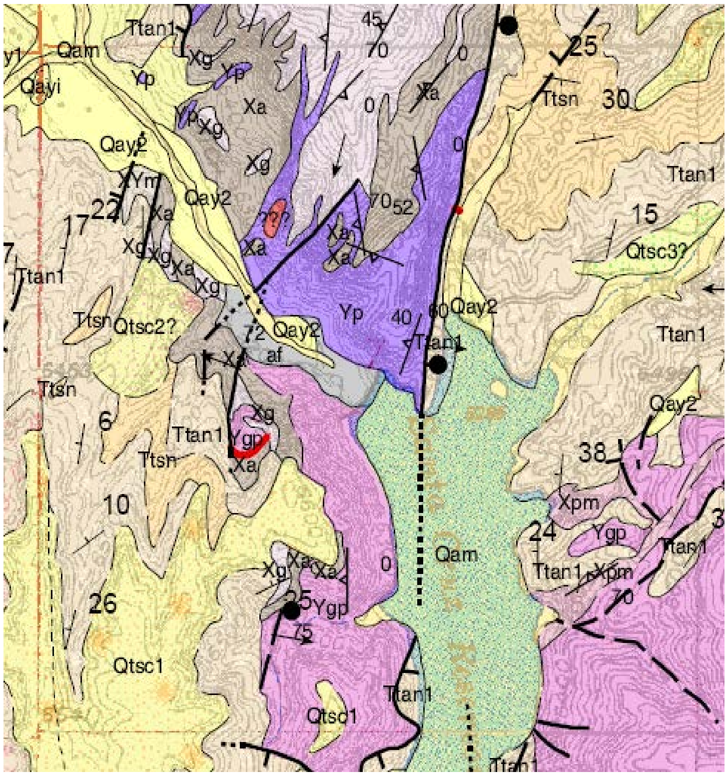
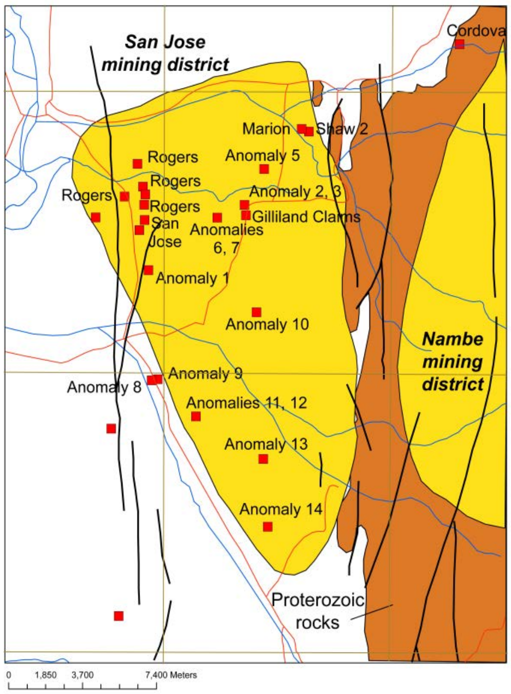


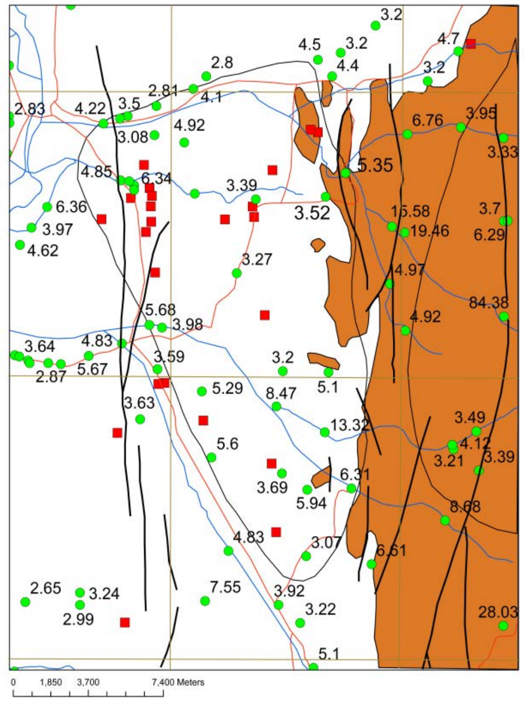
FIGURE 6. Geologic map of the section 7, T20N R10E, Cundiyo quadrangle, Santa Fe, New Mexico (from Koning et al., 2002). Xa=amphibolite, Yp=pegmatite. The reservoir is in Qam. See Koning et al. (2002) for description of other geologic units.

FIGURE 7. Closeup view of adit and cuts in shear zone, looking west, Shaw prospect. The parallel black lines show the extent of the shar zone, and the arrows denote the location of the adit and cuts.

FIGURE 8. Short adit in shear zone in amphibolite schist, Shaw prospect.

FIGURE 9. Shear zone, Shaw prospect.





a) Mines, prospects (red squares) and mining districts (yellow). Brown is Proterozoic rocks.

b) stream sediments (green circles). (U in ppm).

c) water samples (blue circles, below left). Numbers are uranium concentrations in parts per million

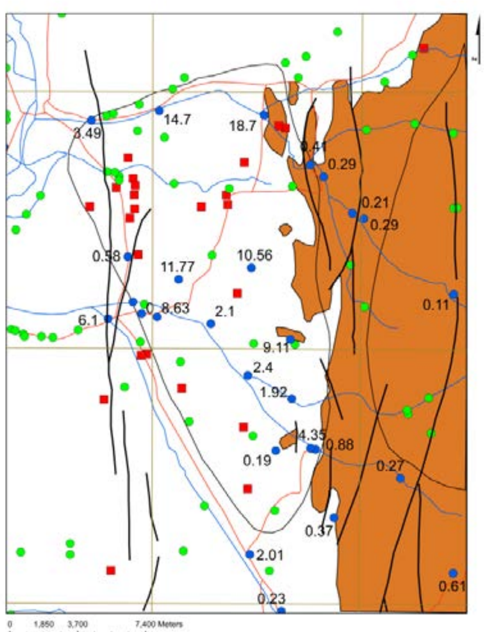


FIGURE 10. Location of uranium mines, prospects, mining districts, stream-sediment samples, and water samples in the San Jose and eastern Nambe mining districts, Santa Fe County, New Mexico (T19-21N, R8, 9E). Note that high uranium concentrations also are found in the Proterozoic terrain (Nambe district), which are related to radioactive pegmatites that intruded Proterozoic granitic and metamorphic rocks. Location of San Jose mine is latitude 35.938417°, longitude 106.013496°. Stream-sediment samples containing greater than 12 ppm U are considered anomalously high (McLemore, 2010a, b).

- (11.7 mi) Return to CR 98 (turn right, north) and continue north toward Chimayó
- (11.8 mi) Santuario de Chimayó
- (13,0 mi) Turn west (left) onto CR 76, pass through Chimayó towards Española
- (15.9 mi) Santa Fe County Line
- (16.9 mi) Turn left (south) onto CR 88D, Placita Road
- (17.7 mi) Turn left (east) onto CR 88C, Loma Vista
- (17.9 mi) Drive to where Loma Vista bends north. Pull off road on right (south) in parking area with trailhead. Easy to moderate hike into badlands to south, ~ 1 mile round trip.

11:00 a.m. – Stop 2 – Lithosomes A and B of the Tesuque Formation, ash beds, and fault (Lunch will be at Stop 2 – bring your own food and beverage)

At Stop 2, we will hike about ½ mile southeast along a trail into badlands exposing the Skull Ridge Member of the Tesuque Formation. Between here and Stop 1, these strata have been extensively disrupted by faulting and tilted to the west. Most of the faults are east-down normal faults. One relatively long, west-down fault has been called the White Operation fault zone, which locally acts as a groundwater barrier (see notes in road log preceding Stop 1). The amount of westward tilt in fault blocks bounded by east-down faults varies. On this hike, we will observe strata in a relatively non-faulted, gently west-dipping structural block called the Arroyo Seco homocline (Koning et al., in review). Strata here strike northeast and dip 5–8^{o} to the northwest. We will end the hike at a large east-down fault. East of this fault, strata strike more northerly, dip 9–12^{o} west, and contain several normal faults spaced 500–2000 ft apart. This east-down fault serves as a structural boundary between two structural domains within the Española Basin.

The Tesuque Formation of the Santa Fe Group is the term applied to most of the sedimentary fill of the Española Basin. The other Santa Fe Group unit, the Chamita Formation, is overall coarser-grained than the Tesuque Formation and is mostly found west of the Rio Grande, although a coarse-grained equivalent caps the mesa to the north of the Santa Cruz River. In the area covered by this field trip, all groundwater flow is in the Tesuque Formation.

The Tesuque Formation southeast of Española has been subdivided into the Nambé, Skull Ridge, and Pojoaque Members, in ascending order (Galusha and Blick, 1971). An exposure of a prominent ash in the Nambé Member is shown in **Figure 11.** These members were envisioned as "layer-cake units." The contact between the Nambé and Skull Ridge Members corresponds to a laterally extensive ash called White Ash No. 1, conveniently chosen to be very close to the boundary separating collected fossils of Hemingfordian "age" and fossils of Barstovian "age" (North American land mammal "ages"). The contact between the Skull Ridge and Pojoaque Members corresponds to the base of a grayish, thick channel-fill sand interval with greenish pebbles. Fossils collected above this contact were interpreted as late Barstovian and fossils collected below this contact were interpreted as early Barstovian. In essence, the Nambé, Skull Ridge, and Pojoaque Members were created to coincide with North American land mammal "ages."

Another way of differentiating the Tesuque Formation is by lithologic characteristics, such as composition and color of the sediment, and the general trend of the Miocene streams that deposited these strata. Such an approach was undertaken by Cavazza (1986), who recognized that two Miocene drainage systems deposited the Tesuque Formation southeast of Española. The first of these drainage systems, called Province A (Cavazza, 1986), was sourced in the Sangre de Cristo Mountains and carried arkosic sand and granite-dominated gravel (with minor quartzite and pegmatitic detritus). The second of these drainage systems, called Province B (Cavazza, 1986), represents larger streams (or rivers) that flowed southwest and carried abundant clasts of Paleozoic sedimentary rocks (greenish sandstone and siltstone and gray limestone) in addition to quartzite and felsic-intermediate volcanic rocks. The sand fraction of Province B contains less potassium feldspar and more Paleozoic/volcanic detritus than sand in Province A. Koning has tried to incorporate the stratigraphic scheme of both Cavazza (1986) and Galusha and Blick (1971) in his mapping of the Española area, but opines that the scheme of Cavazza (1986) is more lithologically orientated and better follows the North American stratigraphic code.

Figure 12 illustrates depositional environments of the Tesuque Formation. The environments are of importance to the uranium mineralization because most of the deposits are in lithosome B, near the boundary with lithosome A.

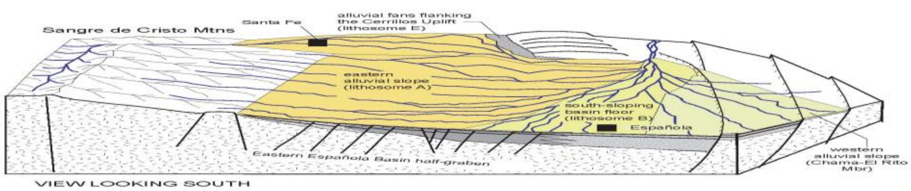


FIGURE 12. Schematic block diagram illustrating Santa Fe Group depositional environments during the middle Miocene. View is to the south. The locations of the modern-day cities of Española and Santa Fe are shown by the two black squares.

In Koning's mapping, Cavazza's Province A and Province B are referred to as lithosome A and lithosome B, respectively. Lithosome A represents deposition by a plethora of west-trending, likely ephemeral streams on an alluvial slope (see Kuhle and Smith [2001] and Smith [2000] for discussion of alluvial slope sediment in the Skull Ridge Member). Lithosome B deposits were deposited by two converging rivers, one draining the San Luis Basin (where the volcanic sand and gravel were derived) and one draining the Peñasco embayment. Reflecting the relative sizes of their associated rivers or streams, the channel-fills of lithosome B tend to be relatively wide whereas those of lithosome A are more ribbon-like. The smaller, narrower channel-fills of lithosome A appear to be more susceptible to a high degree of cementation by calcium carbonate. Based on cementation and channel-fill geometry considerations, one probably has a better chance of contacting a thick, laterally continuous, transmissive channel-fill sandstone if he/she drills into lithosome B, as opposed to lithosome A, deposited on the distal (western) alluvial slope. Lithosome A becomes coarser-grained eastward (towards the mountains) and channel-fills are more connected, so the proximal parts of the alluvial slope represented by lithosome A likely make a better aquifer than the distal parts. On our hike today, we have the opportunity to examine both lithosome A and lithosome B sediment.

In the Skull Ridge Member are about 30 named ash beds (Galusha and Blick, 1971). Because strata dip west and most faults are down-to-the-east, there is much repetition of the stratigraphy. These ashes have proven very useful in correlating strata from one fault block to another. The fine-grained texture of all the ashes indicates a distal source.

A scenic view of Stop 2 is shown in **Figure 13** and an aerial photograph of ash in the basin is shown in **Figure 14.** We will visit three distinct ashes on our hike. For the highest ash (Ash Gamma), chemical analyses by the U.S. Geological Survey are consistent with a source in the Snake River Plain volcanic field (Idaho) or southern Nevada volcanic field. Exact sources for the other two ashes are still uncertain.

The lowest ash is called White Ash No. 4. It has been dated at 15.45 Ma and 15.3 Ma using $^{40}Ar/^{39}Ar$ methods (McIntosh and Quade, 1995, and Izett and Obradovich, 2001, respectively). This ash lacks mafic minerals, has a silty texture, and contains a high content of glass shards. It is 70–170 cm thick. The lower 10–30 cm of this ash is generally massive and interpreted as an ash fall. The middle and upper parts of the ash are commonly very thinly bedded and slightly wavy; this part of the ash bed is interpreted to be fluvially reworked. The ash is overlain and underlain by very pale brown to pink to pinkish gray siltstone and very fine- to fine-grained sandstone that belong to lithosome B. About 15–20 ft above this ash lies the base of a tongue of lithosome A sandstone (whose strata are pink-orange and more arkosic than lithosome B).

The middle ash lies 40–60 ft above White Ash No. 4, and is called Ash Gamma (Galusha and Blick, 1971; Koning et al., 2002). This ash is light gray to white and horizontal-planar laminated. It may be shard-rich and silty textured, or reworked with 5–7% very fine- to fine-grained, detrital sand. The ash is 20–60 cm-thick. It is overlain and underlain by pink to light brown, silty, very fine- to fine-grained sandstone in medium, tabular beds.

The upper ash lies 40–60 ft above Ash Gamma. It may correlate with Ash Zeta of Galusha and Blick (1971). This ash is light gray, relatively non-altered, shard-rich, and silty-textured. It is commonly 30–50 cm thick and internally horizontal-planar laminated. Surrounding strata are pink, light brown, or reddish-yellow siltstone and very fine- to fine-grained sandstone that are in medium to thick, tabular beds.

Our first inspected outcrop on this hike is a small gully exposure of lithosome A sediment, where we can see granitic granules and pebbles in an arkosic sandstone channel-fill. This is located 500 ft south of the parking area. We then walk ~800 ft to the southeast, just beyond a small ridge, to visit Ash Gamma, the contact separating lithosomes A and B, and White Ash No. 4. After walking over another small ridge, we hike southward down an arroyo to inspect outcrops of lithosome B. These illustrative outcrops exhibit broad, sandy channel-fill facies and clayey floodplain facies, and serve as an outcrop analog to the aquifer screened by many wells in the Española area. We end the hike at the fault bounding the east side of the Arroyo Seco homocline. A map of the area of Stop 2 is shown in **Figure 15**.

FIGURE 13. Stop 2 scenic view looking east from trail.

FIGURE 14. Aerial photograph of White Ash No. 3 of the Skull Ridge Member, Tesuque Formation. View is to the east.

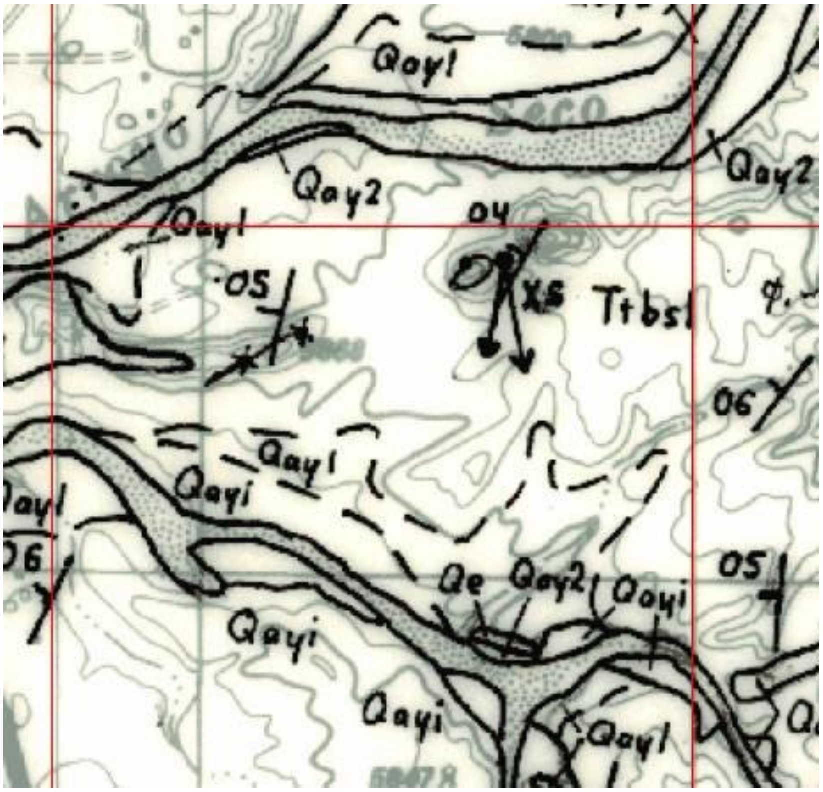


FIGURE 15. Geologic map of the section 17, T20N, R9E, Española quadrangle, Santa Fe, New Mexico (from Koning, 2002). See Koning (2002) for description of geologic units. Ttbs=Tesuque Formation.

- Turn around and head back west on Loma Vista
- (18.2 mi) Bear right onto Firehouse Road (John Gonzales Fire Station)
- (18.6 mi) Turn left (south) onto La Puebla Road, CR 88
- On the east-west ridge mid-way between Highways 76 and 285 are exposures of the base of the Pojoaque Member. The contact caps the butte 500 ft to the east and is found within 200 ft of the highway to the west. Paleoflow data indicate a southwest flow direction for the river depositing the gray sandstones at the base of the Pojoaque Member. These sandstones correspond to lithosome B, and the underlying, pinkish fine sandstone and siltstone correspond to lithosome A.
- 19.9 mi) Stop 3. Pull off road and park on left (south) side with lead vehicles. Cross fence. Walk up hill.

1:00 p.m. – Stop 3. La Puebla Road – devitrified ash in Tesuque Formation

Stop 3 provides an opportunity to observe devitrified ash and alteration byproducts at a stop that is similar to, and more accessible than, Cowboy Lane, a nearby site which is described in **Appendix A.** A view of the reworked ash and green clay at Stop 3 is provided in **Figure 16**. **Figure 17** provides a closeup view of the reworked ash and **Figure 18** shows a closeup of the green clay at Stop 3. For comparison, **Figures 19 and 20** show green clay and reworked ash, respectively, at Cowboy Lane. The green clay at Cowboy

Lane is much thicker and is associated with basal alteration that includes the zeolite mineral phillipsite **(Appendix A**). Typically, zeolites are rare in the Española Basin and, where they do occur, the more siliceous zeolite clinoptilolite is generally present.

FIGURE 16. Stop 3. Reworked ash is on top of ridge a bit left of center (just left of tree). The green clay is below the ash about 2/3 of the way up from the base of the slope.

FIGURE 17. Reworked ash at stop 3.

FIGURE 18. Green clay at stop 3.

FIGURE 19a (left). Green clay at Cowboy Lane (see 'Cowboy Lane clay' analysis in Appendix A). 19b (right). Reworked ash at Cowboy Lane.

FIGURE 20. Reworked ash at Cowboy Lane.

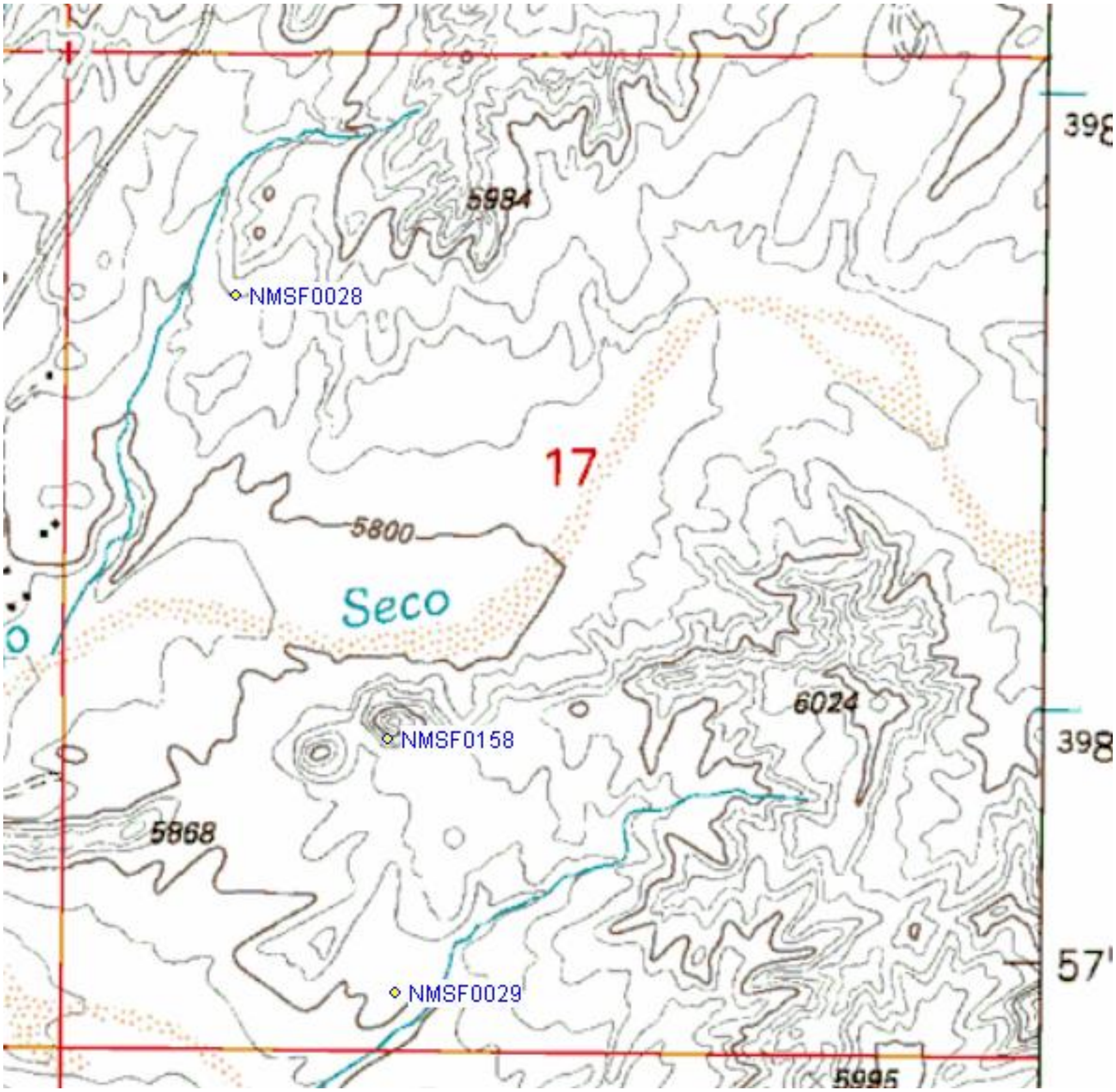


FIGURE 21. Location of (NMSF0158) prospects in section 17, T20N, R9E, Española quadrangle, Santa Fe, New Mexico.

- Continue west on La Puebla Road
- (20.9 mi) Just before HW 285 turn left (south) on unnamed road
- (21.2 mi) Bear left
- (21.5 mi) Bear right
- (21.6 mi) Enter private property
- (21.7 mi) Pass through gate and be sure to c lose gate after entering
- (22.0 mi) Stop 4. Park on side of road, hike to twobuttes to north, return to La Puebla Road

2:30 p.m. – Stop 4 – uranium mineralization in Tesuque Formation at "Oxide Buttes"

Three types of sandstone uranium deposits are found in the San Jose district: 1) medium-grained sandstone with uranium associated with clay galls and carbonaceous material, 2) poorly consolidated fine-to medium-grained sandstone with disseminated uranium and little carbonaceous material, and 3) coarse-grained sandstone to conglomerate with abundant uranium associated with carbonaceous material. Carnotite ($K_2(UO_2)_2V_2O_8 \cdot 3H_2O$), schröckingerite ($NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$), and metaautunite ($Ca(UO_2)_2(PO_4)_2 \cdot 2\text{-}6H_2O$) coat fractures and bedding surfaces in sandstone, siltstone and shale within the Tesuque Formation, especially near clay galls and carbonaceous material in several areas (Chenoweth, 1979). Uranium also occurs as surface coatings around opal and chert grains, with organic debris, and in clay zones. One property south of Stop 4, the San Jose no. 13 (NMSF0033), in section 29 T20N R9E 35.932059°N 106.012266°W UTM 408685E 3976686N zone 13 (NAD 27), yielded 12 lbs (5 kg) of U_3O_8 at a grade of 0.05% U_3O_8 in 1957 (U.S. Atomic Energy Commission file data; McLemore, 1983). The location of unknown uranium prospects in the Arroyo Seco area is shown in **Figure 21.**

We have informally named Stop 4 "Oxide Buttes" (**Figure 22**). **Figure 23** shows a volcanic ash bed in the western butte. The unknown prospect (New Mexico Mines Database Number NMSF0158) at Stop 4 is an example of the first type of sandstone deposit found in the San Jose district and is located in section 17 T20N R9E 35.961536°N 106.011777°W UTM 408763E 3979955N zone 13 (NAD 27), on the eastern butte (**Figures 24, 25)**. Several horizons occur with orange-brown, poorly consolidated fine- to medium-grained sandstone with disseminated uranium and little carbonaceous material. Locally, uranium is associated with greenish-gray clay galls and lenses **(Figures 26, 27, 28)**. Numerous mineralized areas are discontinuous and scattered throughout the area. There is no economic resource potential because of small size and low grade.

These natural uranium occurrences in the Tesuque Formation result from initial concentration followed by precipitation from uraniferous groundwaters, likely derived from weathering and oxidation of 1) the Proterozoic granitic rocks in the Sangre de Cristo Mountains to the east (such as from the Shaw 2 prospect at Stop 1), 2) volcanic ash beds within the Española Basin (seen at Stops 2 and 3), and/or 3) the alteration of granitic and/or volcanic detritus in the sedimentary host rocks. The uranium was leached from the Proterozoic and/or volcanic rocks and then precipitated from the waters to form the uranium occurrences found throughout the San Jose district. Adsorption onto clay minerals and ferric (oxy)hydroxide and precipitation of uranium(VI) minerals most likely are the primary modes of uranium occurrence in the area. These processes are still active today as evidenced from uranium anomalies in both NURE water and stream-sediment samples (**Figure 10,** see also McLemore, 2010a, b), and local high concentrations of uranium and radon in residential drinking water.

FIGURE 22. West (Left) and east (right) “Oxide Buttes”.

FIGURE 23. Volcanic ash bed along western butte, section 17, T20N, R9E. White Ash No. 4 of the Skull Ridge Member of the Tesuque Formation. This ash is 15.3-15.4 Ma (Izett and Obradovich, 2001; McIntosh and Quade, 1995).

Fine-grained, grayish sediment below the ash belongs to lithosome B. This grayish sediment consists of interbedded floodplain sediment and sandy channel-fills associated with a southwest-flowing river on the basin floor (Koning, 2002).

FIGURE 24. Orange-brown uranium-bearing layer along eastern butte, section 17, T20N, R9E (NMSF0158).

FIGURE 25. Orange-brown uranium-bearing layer along eastern butte, section 17, T20N, R9E (NMSF0158).

FIGURE 26. Orange-brown uranium-bearing layer along eastern butte, section 17, T20N, R9E (NMSF0158). Note gray clay lens underlying the oxidized zone and the clay galls within the oxidized zone.

FIGURE 27. Orange-brown uranium-bearing layer along eastern butte, section 17, T20N, R9E (NMSF0158). Note gray clay lens underlying the oxidized zone and the clay galls within the oxidized zone.

FIGURE 28. Orange-brown uranium-bearing layer along eastern butte, section 17, T20N, R9E (NMSF0158). Note the clay galls within the oxidized zone.

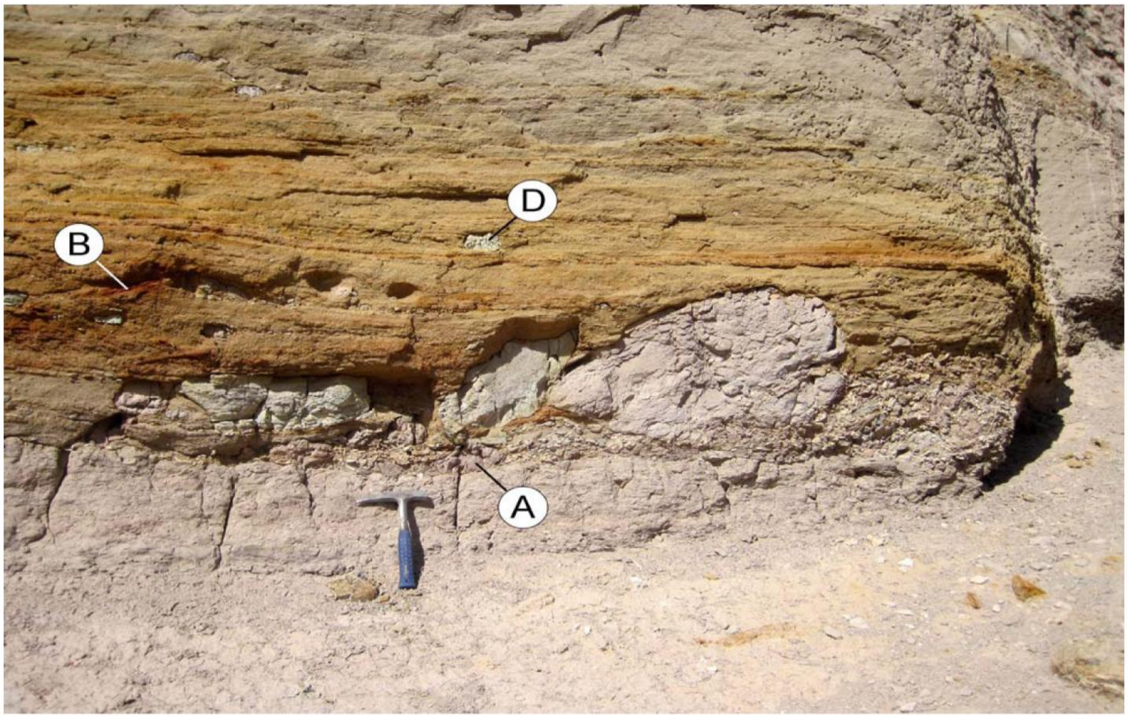


Figure 29. Locations of samples collected at eastern butte for XRD analysis (Table 2). Sample 11A, basal clay horizon; sample 11B, dark reddish-brown sandstone; sample 11D, pale clay ball of micaceous silt (section 17, T20N, R9E; NMSF0158).

Figure 29 shows the locations of samples collected for XRD analysis of uraniferous sands and clay-rich portions of the eastern butte (section 17, T20N, R9E; NMSF0158). Samples were disaggregated in deionized water with a sonic probe and size fractions were collected based on settling rate (>40 μm and 40–0.7 μm). For sample 29B centrifuge separation (0.7–0.1 μm) and evaporation of suspended particles (<0.1 μm) was also used to concentrate the small amount of fine colloidal clay. For samples 29A and 29D there were no clays in suspension after settling of all particulates >0.7 μm, but salt minerals were collected as a leachate and analyzed after drying. Results of XRD analysis are listed in **Table 2**.

The basal clay horizon (sample 11A) is a relatively continuous deposit of purple-brown silty smectite with traces of kaolinite and some calcite cement. The dark reddish-brown sandstone (sample 29B) has only a small amount of smectite but a significant proportion of the smectite present occurs as orange colloidal clay of <0.1 μm. The small 7-cm body of pale gray micaceous clay (sample 29D) has significantly more calcite cement than the surrounding sandstone; this clay body flocculated on suspension in DI water, producing clusters of silt and clay that accumulated as the >40 μm size fraction.

The salt leachates from clay-rich samples 29A and 29D had no equivalent in the sandstone sample 29B. The leachate salts included calcite, halite and the anhydrous sulfate phase aphthitalite [$(K,Na)_3Na(SO_4)_2$]. Because these salts were collected by drying at 40 °C, they do not necessarily represent the salt phases originally present, which could, particularly for the sulfate component, occur as other salt phases including hydrates. Nevertheless, the salt leachates listed in **Table 2** represent the amount and chemical composition of soluble material present in the clay-rich samples analyzed.

Preliminary data on oriented and glycolated clay separates from samples 29B and 29D indicate that the clay minerals dispersed in the sandstone matrix (29B) are relatively simple smectites that expand to 17.1 Å on glycolation. In contrast, the clay mineral component of clay ball 29D has a very poorly developed

001 peak that separates on glycolation into an 18.0 Å smectite, an illitic clay or severely altered mica, and a 10.5 Å phase tentatively identified as palygorskite. The varieties of clay in this outcrop that occur in ball form or as galls, along with altered micas, suggest a complex range of clay minerals, some of which may act as hosts for uranium accumulation.

TABLE 2. Size-fraction proportions (wt%) and X-ray diffraction data (minerals abundances in wt%[a]) for samples illustrated in Figure 29

	proportion (wt%)	smectite	kaolinite	chlorite	zeolite[b]	mica/illite	quartz	plagioclase	microcline	calcite	aphthitalite	halite
11A (>40 μm)	0.31	6	tr	-	tr	4	40	28	19	2	-	-
11A (40-0.7 μm)	99.65	50	1	-	-	8	26	6	-	9	-	-
11A leach salt	0.04	-	-	-	-	-	-	-	-	51	47	2
11B (>40 μm)	94.05	tr	-	-	-	2	59	39	-	-	-	-
11B (40-0.7 μm)	4.50	55	1	-	-	10	20	14	-	-	-	-
11B (0.7-0.1 μm)	1.20	99	-	-	-	-	tr	-	-	-	-	-
11B (<0.1 μm)	0.25	98	-	-	-	-	-	-	-	2	-	-
11D (>40 μm)	99.47	16	tr	12	2	27	19	6	-	18	-	-
11D (40-0.7 μm)	0.44	29	tr	tr	-	tr	21	-	-	50	-	-
11D leach salt	0.09	-	-	-	-	-	-	-	-	66	24	10

[a]tr = trace (<1%); [b]the zeolite is likely clinoptilolite.

FIGURE 30. San Jose clay.

FIGURE 31. San Jose iron concretions.

FIGURE 32. San Jose iron oxidation.

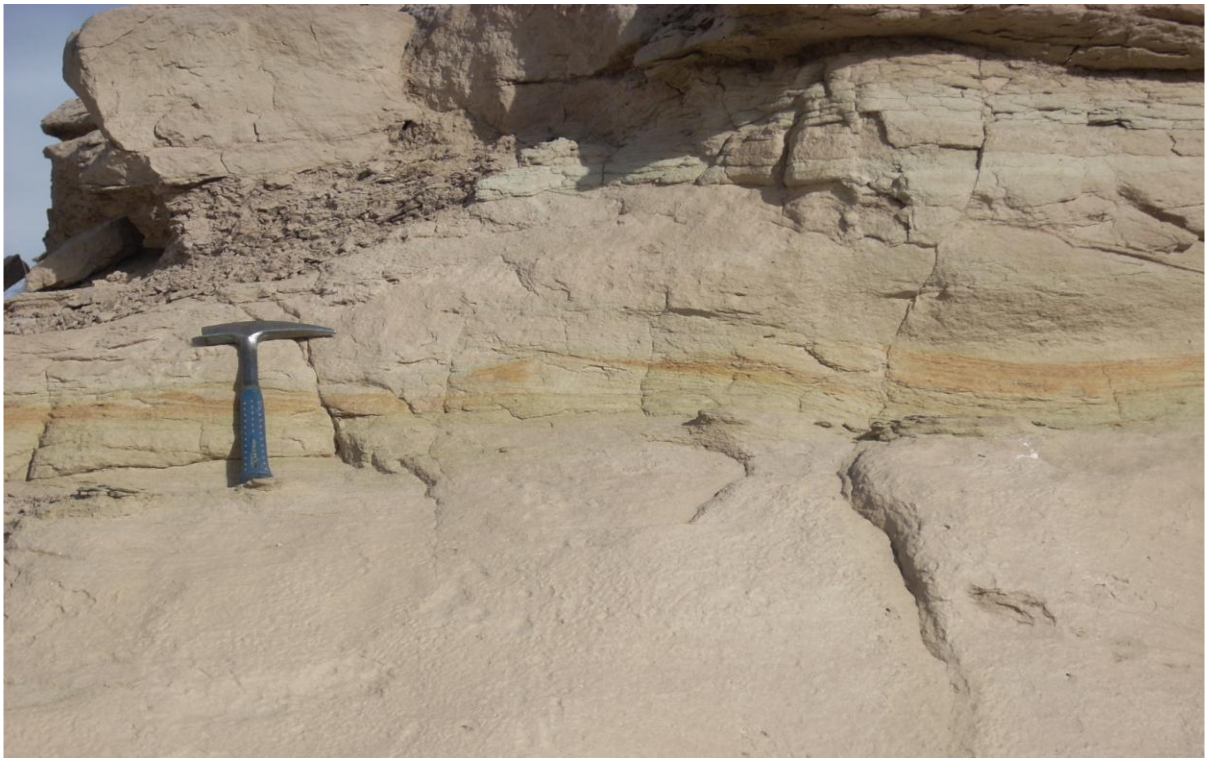


FIGURE 33. Another example of San Jose iron oxidation.
Figures 30–33 show other examples in the San Jose area near "Oxide Buttes" that display iron oxidation, iron concretions, and clay galls, which all factor into the uranium sequestration story.

- (23.4 mi) Turn left (west) back onto La Puebla Road
- (23.5 mi) Turn right (north) onto HW 285
- (24.8 mi) Turn left (west) onto 399 heading into Mesilla
- (27.9 mi) Stop 5. Turn left (east) into Mobile Home Park

4 p.m. – Stop 5 – Ion-exchange treatment system to reduce uranium in a public water supply

This mobile home park has 75 public drinking-water service connections and is supplied by two wells, both of which produce water containing up to approximately 100 μg/L of uranium. The Maximum Contaminant Level (MCL) for uranium in public drinking-water systems is set at 30 μg/L. In 1996, more than a decade before compliance with the uranium MCL became mandatory, the mobile home park owner hired an engineer to design and install an ion-exchange system to decrease uranium concentrations in his public water supply.

Figure 34 shows the anion exchange system at Stop 5. The treatment vessel is the yellow one on the right. It uses proprietary resins that exchange uranyl carbonates dissolved in the well water with chloride. Uranyl carbonates are believed to be the most common uranium species in natural water under oxidizing conditions above pH values of 6. It is regenerated with KCl brine just like a water softener. Treated water entering the public distribution system decreases uranium concentrations from about 100 ug/L in raw (pretreated) water to about 5 ug/L. Treated water entering the public distribution system typically contains uranium concentrations of 5 μg/L or less, well within the MCL of 30 μg/L.

FIGURE 34. Uranium ion-exchanger at stop 5.

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Appendix A. Influence of Tephra Alteration Byproducts on Ground-Water Quality, North-Central Española Basin (excerpted and modified from Clay Minerals Society June 2007 Field Trip Log)

McQuillan, Dennis[1], Vaniman, David[2], Longmire, Patrick[2], Chipera, Steve[2], Koning, Dan[3], Broxton, David[2], and Moore, Duane[4]
[1]N.M. Environment Department, [2]Los Alamos National Laboratory, [3]N.M. Bureau of Geology and Mineral Resources, [4]University of New Mexico

The occurrence of high uranium content in groundwater of the Española Basin has not yet been linked to an explicit source. However, we do know that the isotopic signatures are consistent with natural uranium, not depleted or enriched by anthropogenic processes. The question of the source and control of uranium can be approached by combined mineralogical and geochemical analysis of sediments and alteration products from units that host groundwater. Only preliminary data are available, but the results provide some directions for future research. The first two rows in Table A-1 compare a fault filling near Chimayo (~4.5 miles northeast) with the adjacent wall rock (1.5 m from the fault, in the foot wall; see Figures 2 and 3 in the main text). Carbonate distributions are of interest in light of the carbonate complexation of uranium(VI) in groundwater. The high abundance of fault-filling calcite with only minor abundance in the wall rock suggests that carbonate-rich solutions can migrate along faults in the Santa Fe Group without permeating adjacent sediments. The other rows of Table A-1 are discussed below.

TABLE A-1: Quantitative XRD Analyses

Sample	Smectite	Zeolite (Clinoptilolite)?	Phillipsite	Opal-CT	Quartz	K-Feldspar	Plagioclase	Amorphous	Hematite	Hornblende	Calcite	Chlorite / Kaolinite	Mica	Total
Chimayo fault fill	6.6	---	---	---	5.1	1.0	1.2	---	---	---	86.9	---	---	100.7
Chimayo wall rock	9.2	0.2	---	---	36.5	10.8	37.5	---	0.6	---	0.3	---	3.8	98.9
Tsf 70 µR/hr	4.5	0.8	---	20.5	28.6	4.0	31.3	---	---	0.3	0.5	0.1	5.9	96.6
Tsf ~20 µR/hr	8.4	2.4	---	7.0	34.0	6.2	36.2	---	0.4	0.2	0.3	---	7.1	102.1
Nambé ash	17.3	---	---	---	0.8	2.8	4.1	70.4	---	0.1	---	---	3.0	98.5
Tsf below ash	30.9	0.8	---	---	32.9	5.1	16.4	5.2	0.3	0.3	1.2	0.2	6.4	99.8
Cowboy Lane upper Tsf	18.8	1.0	---	---	43.1	7.6	18.4	---	0.2	---	7.6	---	0.8	97.5
Cowboy Lane clay	93.5	---	---	---	2.0	0.5	0.1	---	---	---	3.8	---	---	99.8
Cowboy L. basal zeolitic	17.4	11.0	53.8	---	4.0	3.9	8.9	---	---	---	1.0	---	---	100.0
Cowboy Lane lower Tsf	14.4	4.5	---	---	41.6	7.4	15.0	---	0.2	0.1	13.4	0.1	1.3	98.0

--- = Not Detected
Phillipsite abundance in sample DV 11/4/04 #4C was determined as the difference from 100%.

In nearby sediments at Uranium Spring (farther west on the left side of this road), detectable radioactivity is localized in sediments that have significantly elevated amounts of opaline cement **(sample "Tsf 70 µR/hr" in Table A-1, compared to sample "Tsf ~20 µR/hr").** Elsewhere uranium mineralization of the Tesuque Formation is attributed to carnotite [$K_2(UO_2)_2(VO_4)_2.3H_2O$], possibly present in these samples at an abundance below detection by XRD. However, the possibility of uraniferous opal and other uranium hosts may broaden the scope of uranium origins, migration, and leachability within the Santa Fe Group.

We identify three possible sources of uranium: 1) it is present in the ash as delivered from its volcanic source; 2) it has come from the detritus of the weathering of the Precambrian rocks of the Sangre de Cristo Mountains; and 3) it has risen along the faults that mark the eastern boundary of the Rio Grande Rift along with other inorganic volatiles from the mantle.

Beds of silicic ash provide a variably altered and potentially leachable uranium source. Typical rhyolitic ashes have uranium content in the 10–20 ppm range. The Tesuque Formation in this area contains numerous tephra or volcanic ash layers. Some of the volcanic ash has been devitrified by reaction with groundwater to smectites and zeolites (clinoptilolite and, less commonly, phillipsite). Devitrification of the ash may release metals including uranium (VI) into solution. Uranium most commonly occurs and migrates in groundwater as uranyl carbonates most commonly as $UO_2(CO_3)^0$ for pH 5–6.5; $UO_2(CO_3)_2^{2-}$ in a neutral pH environment; and $UO_2(CO_3)_3^{4-}$ for basic pH. Tesuque sediments in this area contain numerous small, laterally discontinuous, roll-front uranium ore bodies (Fig. A-1) consisting of grain coatings of carnotite [$K_2(UO_2)_2(VO_4)_2.3H_2O$] and other uranyl minerals. In addition to ash devitrification, other potential uranium sources include

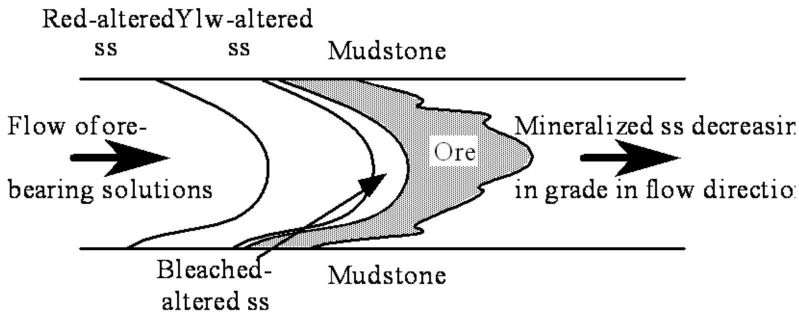

FIGURE A-1. Roll-front uranium deposits. See: Finch (1997).

leaching of the detritus weathered from the crystalline Precambrian rocks in the nearby mountains, then leached from the detritus and selectively fixed in the ash beds. A third possibility is that the U is only one of several elements (e.g., CO_2, F, He) carried in gases and fluids escaping form the mantle through the fault systems that mark the margins of the Rio Grande Rift (Crossey et al., 2007). The chief signature indicating material from the mantle is the ratio of $^3He/^4He$. The lighter isotope, ^3He, is almost exclusively primordial and its presence at the surface indicates mantle degassing. The currently accepted value for the $^3He/^4He$ isotope ratio in the Earth's atmosphere is 1.384×10^{-6}. To maintain this ratio, the heavier ^4He isotope is continually replenished by the radioactive breakdown of uranium and thorium. Anything much higher than this indicates contamination with ^3He isotopes from the mantle. Kennedy and van Soest (2004) observed, on the basis of their measurements within the Basin and Range province, that high $^3He/^4He$ ratios are confined to the range front normal faults characteristic of the extensional regime, suggesting that such faults can be permeable pathways for deep fluid circulation. Measuring the $^3He/^4He$ ratio in groundwaters of the Española Basin should be continued, following the work of Manning (2008) and Longmire et al. (2007).

Uranium has been detected in approximately 50% of the water supply wells in this area at concentrations exceeding the drinking water standard of 30 μg/L. At least 27 wells serving 19 public water systems and 209 private domestic wells produce water with excessive uranium. Concentrations range from less than 1 μg/L to a maximum of 1820 μg/L.

High uranium in concentrations in drinking water can cause kidney toxicity. Some area residents have installed anion exchange and reverse osmosis treatment units to decrease uranium in their water supply. Anion exchange units installed on two wells serving a mobile home park decrease uranium from ~100 μg/L to less than 5 μg/L (see Figure 34 in the main text). The units use proprietary resins to exchange uranyl carbonate anions with chloride, and are regenerated with potassium chloride brine. Disposal of waste generated by drinking-water treatment systems is an emerging issue. The amount of waste that will need to be treated will increase as public water systems are required to comply with the drinking-water standard. In this region, treatment waste is presently discharged to on-site septic systems.

There are two additional and related problems. One concerns radon, a uranium decay byproduct, which is ubiquitous in groundwater in this area. High levels of indoor radon are widespread in this region. EPA's recommended action level for indoor radon is 4 pCi/L to protect against lung cancer. Radon concentrations in excess of 20 pCi/L have been measured in buildings in the area, and abatement measures have been taken at many locations. The other problem is smectitic and zeolitic devitrification byproducts that are responsible for extensive cation exchange in this region with sodium often being the predominant groundwater cation. In some cases, and particularly in deep wells under artesian pressure, calcium concentrations are very low or not detectable. Not having Ca^{2+} with which to combine, there is high fluoride (up to 13 mg/L) present in some areas, which can manifest itself in dental and skeletal fluorosis. The very modest positive aspect of all this is that the locals have naturally softened water.

The outcrop at the Cowboy Lane site is small, but significant. In contrast with the Nambé ash in Table A-1, the ash bed here no longer contains any glass. Traces of clinoptiloilte are commonly found throughout the Santa Fe Group, but phillipsite has so far only been found in this altered ash. The phillipsite occurrence might reflect exceptionally high Na, K activity in groundwater associated with the ash alteration. The ash at Cowboy Lane belongs to the Pojoaque white ash zone, given its stratigraphic relation to nearby mapped ashes of this zone, which contains as many as eight ashes within a 150−157 m-thick stratigraphic interval (Koning, 2002). These ashes are mostly white (some are gray or locally grade from gray to white), altered to non-altered, powdery to silty-textured, generally hard and ledge-formers, and internally massive or planar- to wavy-laminated. The ashes contain various proportions of biotite and may be up to about 100 cm thick. Many of these ashes were differentiated and correlated over 6-7 km distance with the aid of geochemical comparisons conducted by Andrei Sarna-Wojcicki of the U.S. Geological Survey (unpublished data by Andrei Sarna-Wojcicki). The Pojoaque white ash zone is interpreted to be 13.2−14.0 Ma based on interpretations of Koning et al. (2005) and Koning (2002). These age interpretations consider the $^{40}Ar/^{39}Ar$ age of 13.7 ±0.18 Ma from biotite in an ash bed about 60 m above the base of the zone at the type section (Izett and Obradovich, 2001) in addition to magnetic polarity data of Barghoorn (1981), revised according to the geomagnetic polarity time scale of Cande and Kent (1995).

The clay-altered ash from Cowboy Lane is laced throughout by thin carbonate veins. A large portion of the 93.5% smectite + 3.8% calcite + 2% quartz sample was processed into three size separates and analyzed by X-ray diffraction and INAA. Results comparing calcite abundance against uranium content are shown in Figure A-2. Without further analyses, particularly of separated carbonate veins and of unaltered ash equivalents, these data are only suggestive but they are in line with the observation that uranium in groundwater of the Española Basin occurs as carbonate complexes. The Cowboy Lane locality may contain a "snapshot" of localized uranium derivation and mobilization through carbonate complexation.

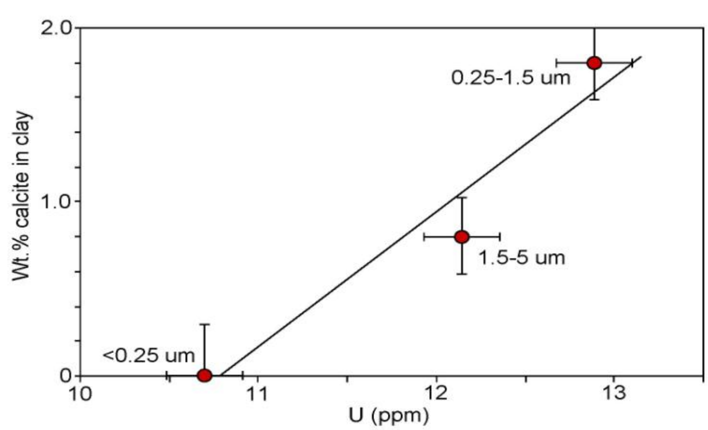

FIGURE A-2. Calcite versus uranium content in three different size fractions (μm) of the Cowboy Lane clay-altered ash.