Geologic and Hydrogeologic Framework of the Española Basin -- Proceedings of the 2nd Annual Española Basin Workshop, Santa Fe, New Mexico, March 4-5, 2003

Mark R. Hudson, editor

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INTRODUCTION

By Mark R. Hudson

This proceedings volume presents abstracts of technical studies that pertain to the hydrogeologic framework of the Española basin, a major subbasin of the Rio Grande rift. These technical studies were presented as poster exhibits at the second annual Española basin workshop, held during March of 2003 in Santa Fe, New Mexico. The workshop was sponsored by the U.S. Geological Survey, the New Mexico Bureau of Geology and Mineral Resources, and Los Alamos National Laboratory. Principal goals of the Española basin workshop were to share information from ongoing studies and to seek input on important topics for further study.

The abstracts are grouped within sections on (1) Geology and Geophysics and (2) Hydrology and Hydrogeology, but many of the studies are relevant to both sections. A number of studies present geologic maps at scales of 1:24,000 and larger that were recently completed for areas within or adjacent to the Española basin. The petrology of the Santa Fe Group as well as isotopic dates from interbedded volcanic rocks are described by several studies, providing important constraints on the provenance and age of the rift-filling sediments. Structural and hydrogeologic characteristics of faults in the Rio Grande rift are described for faults hosted in both sedimentary and volcanic rocks. Several studies present geophysical mapping and characterization using aeromagnetic, magnetotelluric, and gravity methods. Data from drill holes constrain the subsurface distribution and characterization of hydrogeologic units. Ground-water levels, ground-water chemistry, and subsidence related to ground-water withdrawal are presented for selected parts of the Española basin. Several abstracts consider surface and ground-water resources and options for their management, including ground-water models. Taken together, these abstracts provide a snapshot of the current status of hydrogeologic research within the Española basin.

GEOLOGIC MAPPING IN THE ESPAÑOLA BASIN BY THE NEW MEXICO BUREAU OF GEOLOGY AND MINERAL RESOURCES

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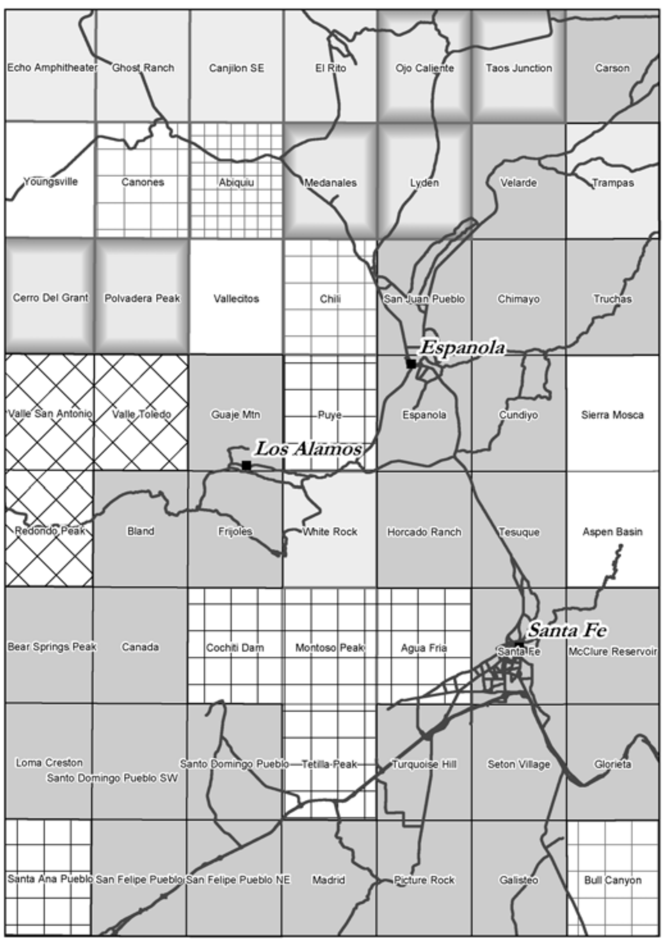
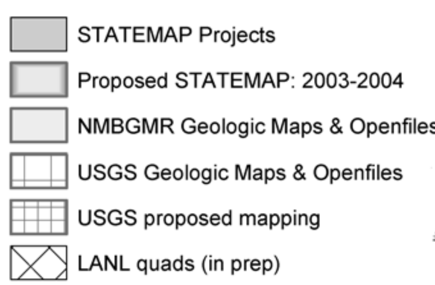
During the last few years, the Española basin has been a top priority for geologic quadrangle mapping by the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) STATEMAP program, mainly due to concern by local, state, tribal, and federal officials over the sustainability of potable ground water for a rapidly expanding population. Due to parallel mapping efforts by the NMBGMR and the USGS, by June 2003, the basin will be mapped at 1:24,000, except for a few quadrangles at the northern end of the basin that should be completed by summer 2004.

For every map, our objective is to produce digital (ArcGIS), detailed geologic maps (1:24,000), with accompanying explanation of units, cross sections, stratigraphic sections, and explanatory texts. In each quadrangle, the mappers emphasize bedrock lithologies and structures, surficial basin- and arroyo-valley-fill deposits and structures, and hydrostratigraphy. All quads are released as open-file reports at the end of the contract year, and posted on our Web site <http://geoinfo.nmt.edu/publications/maps> as freely downloadable PDFs. As time permits, the maps are digitized and released as color geologic maps.

At present, we are also compiling a southern Española basin map based on eight completed quadrangles (Horcado Ranch, Tesuque, Agua Fria, Santa Fe, Turquoise Hill, Seton Village, Picture Rock, Galisteo, plus the NE corner of White Rock) to support an ongoing NMBGMR hydrogeologic investigation.





DEFORMATION BANDS IN NON-WELDED IGNIMBRITES: PETROPHYSICAL CONTROLS ON THEIR OCCURRENCE AND IMPLICATIONS FOR FLUID FLOW

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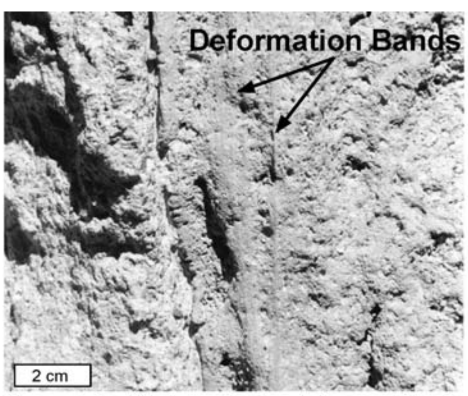
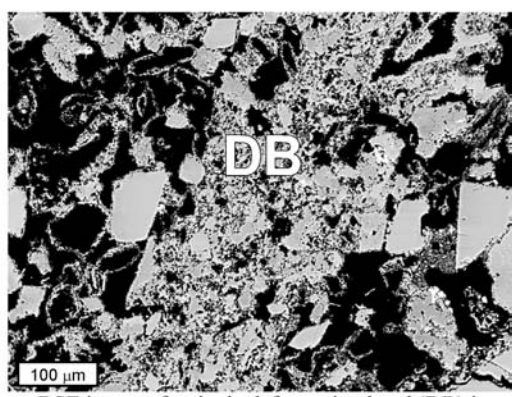
Faults in ignimbrite sequences are of interest for a variety of reasons, including their potential impact on fluid flow and transport through thick vadose zones in such places as Los Alamos, N.M., and Busted Butte, Nev. We have investigated petrophysical controls on deformation in small-displacement faults in these areas. Fractures and deformation bands are found at both sites. The primary control on which structure forms in a given ignimbrite unit is the number of clast contacts, which is inversely proportional to porosity and directly related to degree of welding and postdepositional crystallization. Low porosity, welded units deform by transgranular fracture; high porosity, glassy, non-welded units deform by cataclasis and pore collapse within deformation bands. Moderately high porosity, non-welded units that have undergone postdepositional crystallization deform by either cataclasis with associated pore collapse or by transgranular fracture, depending on local variations in porosity, clast size, and nature of crystallization (devitrification versus vapor-phase alteration).

Clast- and pore-size reduction in the deformation bands is significant, commonly producing indurated, tabular zones of clay-sized fault material. Preferential wetting, inferred to promote alteration and cementation, is locally observed in many of the deformation bands. Many of these bands are also locally rich in smectite and/or cemented by calcite. We therefore interpret variably altered fault-zone material as evidence of preferential fluid flow through deformation bands in the vadose zone, which we infer to be the result of enhanced unsaturated permeability due to porosity and pore-size reduction in deformation bands. This is especially significant for models of fluid flow and transport at Los Alamos and Busted Butte, since most assume matrix-dominated flow through non-welded ignimbrite units, disregarding any effect of small-displacement deformation-band faults. The magnitude of this effect and the density of deformation bands necessary to create significant flow paths for recharge and contaminant transport have not yet been determined.



Photograph of deformation bands in crystallized, non-welded Bandelier Tuff (Qbt3).



BSE image of a single deformation band (DB) in crystallized, non-welded Bandelier Tuff (Qbt3).

FAULT-ZONE PROPERTIES AND POTENTIAL FOR COMPARTMENTALIZATION OF GROUNDWATER AQUIFERS IN POORLY LITHIFIED, RIO GRANDE RIFT-RELATED, SANTA FE GROUP SEDIMENTS, NEW MEXICO

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Numerous well-exposed, extensional fault zones dissect gently dipping, Neogene clastic sedimentary rocks of the Santa Fe Group (SFG) throughout the Albuquerque and Española basins. However, many unexposed faults have also been identified in the subsurface through high-resolution aeromagnetic data. Because SFG rocks form the primary groundwater aquifer system for the region it is critical to understand the significant geological features that cause heterogeneity and anisotropy within the flow system.

Our field observations and mapping along the San Ysidro fault zone in the northern part of the Albuquerque basin, as well as previous work by other researchers, have shown that Santa Fe Group (SFG) fault zones are characterized by three distinct architectural components: (1) protolith (PL); (2) damage zones (DZ) typically marked by deformation bands, few open fractures, mesoscale slip surfaces, and entrained blocks of PL; and (3) a fault core (FC) where cataclasis and 'smearing' of clay-rich materials dominates. A significant feature of the San Ysidro fault zone is the persistent presence of a clay-rich fault core and varying degrees of carbonate cementation consistently observed in exposures along its ten-kilometer surface trace.

To understand the permeability (*k*) structure of the San Ysidro fault zone from the hand sample to outcrop scale, permeametry has been completed in representative samples of each fault-zone component. Large diameter (~6 cm) cores were drilled from PL and DZ samples and *k* was measured using deionized water in a hydrostatic confining cell. Small samples (~1 cm^3) of clay-rich FC materials were measured for *k* using the mercury injection capillary entry pressure method. Permeametry results indicate that relatively uncemented sandstone PL and DZ samples have *k* values on the order of 10^{-13} m^2, sandstone from the DZ / FC contact yields *k* values on the order of 10^{-15} m^2 parallel to the fault 'plane' and 10^{-16} m^2 perpendicular to the fault 'plane', and samples of clay-rich FC have *k* values ranging from 10^{-18} m^2 to $7x10^{-19}$ m^2. Additionally, these results and observations are consistent with existing work on other faults in the basins.

Field mapping and characterization studies in conjunction with permeametry results indicate that SFG fault zones are major structural and hydraulic heterogeneities in the subsurface due to several factors. These factors include varying combinations of (1) physical juxtaposition of sedimentary units with different hydraulic properties; (2) heterogeneous cementation and entrainment of lithologic bodies along the fault zone; and (3) the persistent presence of clay-rich fault cores that form at preferentially high angles to strata and that have as much as six orders of magnitude lower *k* than surrounding sandstone aquifer host rocks rocks.

The *k* contrasts and internal hydraulic heterogeneity of fault rocks relative to PL rocks, in combination with the geometry of the San Ysidro and other SFG fault zones, suggest that these structures act as partial barriers to lateral groundwater flow and thus compartmentalize the SFG aquifer system. Recent INSAR data also suggests that faults act as partial barriers that control patterns of groundwater drawdown and resulting aquifer-system deformation in the vicinity of pumped wells. These data and observations have significant implications for inter-compartment groundwater recharge, storage, and solute transport particularly when the aquifer system is stressed. Additionally, if the fault-rock characteristics are as persistent as they appear and the number of fault zones are more numerous than what is observed at the surface, as indicated from aeromagnetic data, then the degree of aquifer compartmentalization may be more significant than currently realized.

REGIONAL SURVEY OF FAULT-ZONE STRUCTURAL PROPERTIES AND CEMENTATION PATTERNS IN THE NORTHERN ALBUQUERQUE BASIN

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Motivated by the need to document and evaluate the types and variability of fault-zone structures and their potential impact on aquifer systems in basins of the middle Rio Grande rift, we systematically characterized physical and cementation properties of exposed fault zones at 170 sites in the northern Albuquerque region. A statistical analysis of measurements and observations was conducted on four fault zone characteristics: (1) attitudes and displacements; (2) cementation characteristics; (3) hostrock lithology; and (4) distinctive structural and hydraulic architectural components at the outcrop scale. Fault zone components observed at the outcrop scale include: (1) outer damage zones related to fault growth that typically contain strike-parallel deformation bands and open extensional and shear fractures that may enhance or impede groundwater flow along the faults; (2) "mixed" zones composed of entrained blocks of hostrock; and (3) centralized fault cores where most of the strain is accommodated and where low permeability clay-rich fault rocks likely impede cross-fault flow. There is a strong hostrock lithologic influence on fault zone architecture and component widths that can be attributed to strength contrasts between different hostrock grain-size distributions and degrees of induration, which result in variations in fracturing and other brittle-strain features. Also, hostrock lithology appears to exert an important control on fault zone cement distribution.

Most faults strike N to NNE and dip 55^{o} to 77^{o} east or west, towards the basin center. Faults mainly exhibit normal slip, and many of these faults have been reactivated by normal-oblique and strike slip. Although measured fault displacements have a broad range, from 0.9 to 4000 m, most are <100 m, and fault-zone deformation appears to have occurred mainly at depths less than 1000 m. Fault-zone widths do not exceed 40 m (median width = 15.5 m). Width measurements of the fault-zone components reveal that the mean width of fault cores (0.1 m) is nearly one order of magnitude less than that of mixed zones (0.75 m) and two orders of magnitude less than that of damage zones (9.7 m).

Cements, recognized as a proxy for concentrated paleo-groundwater flow, are common along fault zones in the basin. Silica cements are limited to faults that emanate from the Jemez volcanic field north of the basin, whereas carbonate fault cements are widely distributed. Coarse sediments (gravel and sand) host the greatest cement concentrations within fault zones. Also, cements are concentrated along open fractures and, to a lesser degree, along shear fractures and deformation bands within inner damage zones. Cements are commonly concentrated on one side of a fault, resulting in an asymmetric cement distribution within the fault zone, but there is no consistent concentration of cement on the basinward sides of faults as has been suggested in earlier studies. From observed spatial patterns of asymmetrically distributed fault zone cements we infer that intrabasin, fault-parallel, paleo-groundwater flow was common.

It is apparent from our study that there is a large density of faults in the Albuquerque basin, and that these fault zones have a geometry, internal structure, and cement distribution that has, and will continue to be, significant permeability heterogeneities within the basin aquifer. Also, the types and statistical range of fault zone features appear to be predictable and consistent basin wide, which has utility in groundwater flow simulations that consider the influence of faults.

MINERALOGIC DETERMINATION OF PRE-BANDELIER SEDIMENT SOURCES IN THE SOUTHWESTERN ESPAÑOLA BASIN

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New drilling on the Pajarito Plateau at Los Alamos National Laboratory provides the opportunity to improve understanding of lithologies beneath Bandelier Tuff in the southwestern Española basin. Cuttings from 14 new drill holes have been analyzed petrographically and chemically; in addition, quantitative X-ray diffraction (QXRD) was used to determine mineral and glass abundances. For consistent comparison most data were collected from 2-4 mm sieved cuttings, although hand-picked fragments of cemented sands and rare core samples were also analyzed.

Prior to the current drilling program, many drill holes at the Laboratory were thought to have penetrated through Puye Formation fanglomerates into Miocene sediments of the Santa Fe Group. Current data show that some of these deeper sediments differ from both the Santa Fe and the Puye. Petrographically they are more akin to the Puye in having proximal and relatively unaltered volcanic sources, rather than the distal plutonic and altered volcanic sources of the Santa Fe. The deeper sediments are characterized by abundant rhyolitic pumice interspersed with crystalline dacitic detritus. $^{40}Ar/^{39}Ar$ ages of 7.2 Ma and 7.5 Ma have been obtained on pumice separates from the deeper sediments, suggesting a possible relation to fan deposits of the Cochiti Formation. These deeper sediments indicate that Miocene Keres-Group volcanism contributed to volcaniclastic deposits similar to the thick Puye deposits that were later produced from Tschicoma volcanic sources. Sediments from recent drill holes that are attributable to the Puye Formation can be correlated with specific dacite centers in the Sierra de los Valles. Specific correlations of known Keres volcanic sources to the older sediments have not yet been made.

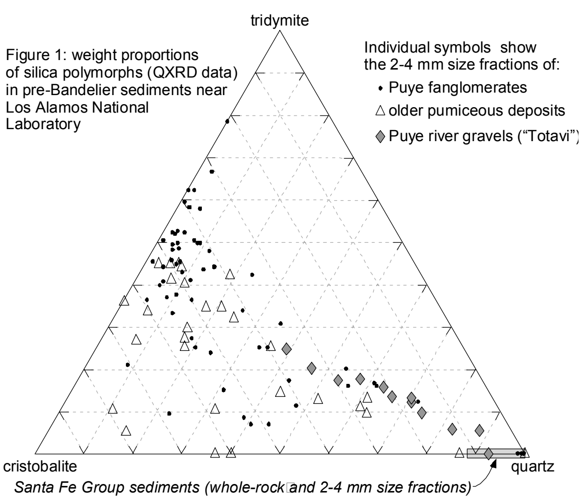

Figure 1: weight proportions of silica polymorphs (QXRD data) in pre-Bandelier sediments near Los Alamos National Laboratory

Stratigraphic assignment of the deeper volcaniclastic sediments remains problematic. However, these older sediments cannot be attributed to the Santa Fe Group. The content of silica polymorphs determined by QXRD supports this conclusion (Fig. 1). For comparison with the drill samples, 11 samples were collected from six outcrops representing variation within the Santa Fe Group in lower Los Alamos Canyon. These sediments are characterized by plutonic or altered volcanic sources and contain quartz, with traces of cristobalite at the top of the sampled sequence. Tridymite is absent. In contrast, most samples from the Puye Formation and the deeper pumiceous sediments contain significant amounts of both cristobalite and tridymite, reflecting relatively unaltered volcanic detritus. Some Puye or pumiceous samples with >95% quartz/(quartz + cristobalite + tridymite) do occur and include lakebed deposits, a few extensively clay-altered pumiceous sediments, and calcite-cemented sands beneath the northeast portion of the Laboratory.

PERIODICITY AND DISTRIBUTION OF VOLCANISM IN THE PAJARITO PLATEAU, RIO GRANDE RIFT, NORTH-CENTRAL NEW MEXICO

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Recent $^{40}Ar/^{39}Ar$ age determinations of samples from major mafic, intermediate, and rhyolitic lava flows and tephra from the Pajarito Plateau and adjacent areas provide temporal information on at least six episodes of volcanism. The Pajarito Plateau is located along the southwestern part of the Española basin of the Rio Grande Rift in north central New Mexico. The plateau represents a series of east-dipping mesa tops blanketed by ignimbrite deposits of the Quaternary Bandelier Tuff. It is separated from the Jemez Mountains volcanic field by the NNE-trending Pajarito fault system on the west and is bounded by the Rio Grande to the east.

The earliest volcanism in the Pajarito Plateau of the Española basin began in the late Oligocene (25 Ma) and continued to the early Miocene time (18-20 Ma). The flows are represented by at least three basanite flows that are interbedded within the lower part of the Santa Fe Group sedimentary deposits at the southwestern end of the plateau, directly southeast of St. Peters Dome.

The next major volcanic activity occurred during the middle Miocene. The most voluminous eruptions at this time marked the onset of mafic and intermediate to silicic volcanism in the Jemez volcanic field. However, contemporaneous mafic lavas of the Guaje Canyon Basalt (11.5-13.1 Ma) occur in outcrop and in deep boreholes in the central and northern part of the Pajarito Plateau.

Late Miocene tholeiitic, alkali, and evolved mafic flows of the Bayo Canyon Basalt (7.0-10.0 Ma) occur as outcrops and in the subsurface throughout the Pajarito Plateau. Outcrops in Santa Clara Pueblo, Bayo, and Ancho Canyons represent the northern, central, and southern exposures of the late Miocene lavas, respectively. These outcrops are correlated to some of the subsurface units, using age and chemical data.

Late Miocene mafic eruptions of the Pajarito Plateau were followed by voluminous eruptions of mostly dacitic lavas and tephra of the Tschicoma Formation (3.77-7.3 Ma); large overlapping domes of Tschicoma lavas make up the eastern part of the Jemez Mountains directly west of the plateau. Post-eruption faulting along the Pajarito fault zone dropped the dacitic flows of the Tschicoma Formation eastward, resulting in outcrops and subsurface units on the west side of the Pajarito Plateau.

During the Pliocene, the central and eastern parts of the Pajarito Plateau and the adjacent Cerros del Rio area experienced widespread mafic volcanism. Collectively, these mafic flows make up the Cerros del Rio volcanic field (2.3-4.0 Ma). Phreatomagmatic deposits are commonly associated with lava flows close to clustered vents along White Rock Canyon. The last episode of volcanism was represented by the caldera-forming rhyolitic eruptions of the Bandelier Tuff and related silicic rocks.

The volcanic rocks of the Pajarito Plateau are interbedded with basin-filling sedimentary rocks in the western part of the Española basin and form important stratigraphic markers for determining basin evolution and for correlating complex lithostratigraphic units. The stratigraphic sequence in the western part of the Española basin is well constrained as a result of these new geochemical and age analyses and through new subsurface information gathered as part of the LANL hydrogeological investigations on the Pajarito Plateau.

GEOLOGIC MAP AND STRUCTURE OF THE FRIJOLES QUADRANGLE, LOS ALAMOS AND SANDOVAL COUNTIES, NEW MEXICO

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The Frijoles 1:24,000 quadrangle map encompasses the greater part of Los Alamos National Laboratory (LANL) and Bandelier National Monument (BNM) on the southern Pajarito Plateau. The map provides structural and stratigraphic boundary conditions for environmental and hydrologic programs of LANL, furnishes archeological and volcanic information for the BNM and the Valles Caldera National Preserve, and contributes to the geologic quadrangle mapping program of the New Mexico Bureau of Geology and Mineral Resources in cooperation with the U.S. Geological Survey. The geology of the quadrangle was mapped primarily during the spring and summer months of 2001, supplemented by previous published and unpublished mapping. Four cross sections interpreting subsurface geology utilize exposures along fault zones and canyons as well as intercepts from 10 drill holes varying from 213 to 855 m deep. Mapped rock units include (from bottom to top) Eocene Galisteo Formation, Miocene Santa Fe Group, Miocene Keres Group, Miocene to Pliocene Polvadera Group, Pleistocene Tewa Group, and Pleistocene to Holocene older alluvium, fan, landslide, and surficial deposits.

The most important structural feature of the geologic map is the Pajarito fault zone (PFZ), which is located on the west side of LANL and BNM and consists of fault strands and segments of gouged, brecciated, rotated and offset rocks in a north to southeast belt that is 0.2 to 1.2 km wide. Our mapping indicates that minor offset has occurred in probable Holocene time along short segments of the PFZ. The El Cajete Pumice, which erupted from Valles caldera ca. 55 ka, forms an eroded sheet that thins dramatically from WSW to ENE on mesa tops in the southwestern Pajarito Plateau. The distribution of the pumice correlates with ancestral Pueblo or Anasazi archeological sites, suggesting that ancient cultures farmed the pumice because of its water retention and easy cultivation properties. Using stratigraphic interpretations provided from a series of recent LANL drilling reports and our own reinterpretations of some older LANL drilling reports, we show that the Puye Formation (Polvadera Group) is considerably thicker and more extensive than previously recognized. We now correlate older Puye Formation fanglomerates ($\leq$9 Ma) with the upper Santa Fe Group of Griggs (1964) and the Chaquehui Formation of Purtymun (1995).

DEPOSITIONAL TRENDS OF THE UPPER TESUQUE FORMATION, ESPAÑOLA BASIN, N.M., AND INFERRED TECTONIC AND CLIMATIC INFLUENCES ON AGGRADATION

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Geologic mapping and sedimentologic study of the upper Tesuque Formation refines interpretations regarding the influence of tectonics and climate in the aggradation of a Rio Grande rift basin in northern New Mexico. The upper Oligocene-upper Miocene Tesuque Formation is 1200-3000 m thick and is well exposed and well dated in the west-tilted Española basin half graben. The Tesuque Formation has been subdivided into Lithosome A, derived from the adjacent Sangre de Cristo Mountains to the east, and Lithosome B, derived from a more distant source across the Peñasco embayment to the northeast. Lithosome A represents piedmont deposition associated with drainages oriented transverse to the basin axis, and its gravel is dominated by granite from the Sangre de Cristo Mountains. Lithosome B represents a southwest flowing fluvial system whose gravels are dominated by Paleozoic carbonates, sandstone, and siltstone. New outcrop and well data indicate that Lithosome A has progressively prograded up to 19 km westward-northwestward over Lithosome B since approximately 15-16 Ma. Also, stratal thickness variations (taken in part from past studies) between White Ashes 2 and 4 indicate that, between 15.5 and 15.3 Ma, relative subsidence of the basin floor increased southward away from the Peñasco embayment and westward away from the Sangre de Cristo Mountains. The long-term basinward progradation of Lithosome A may be due to progressive westward tilting of the hanging-wall block of the Española basin and concomitant uplift of the Sangre de Cristo Mountains since the beginning of the middle Miocene. Significant upward-coarsening of sediment after 13-14 Ma, accompanied by a progressive decrease of dip magnitudes in late Miocene strata, probably indicate increased rates of rift tectonic activity. A temporary reversal of Lithosome A progradation occurred during faunal changes associated with the early/late Barstovian boundary (14-15 Ma), and may perhaps relate to geomorphic and hydrologic responses of the drainage basins to a climatic change.

SEDIMENTOLOGIC AND STRUCTURAL FRAMEWORK OF THE SOUTHERN AND CENTRAL ESPAÑOLA BASIN – INSIGHTS FROM RECENT STATEMAP AND EDMAP EFFORTS

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Geologic mapping conducted under the STATEMAP and USGS EDMAP programs has led to improved understanding of the sedimentologic and structural characteristics of the southern and central parts of the Española basin (east of the Rio Grande and south of Española). Mapping the Tesuque Formation using provenance and textural criteria has been successful where attempted; however, it is difficult to differentiate the Tesuque Formation into the Nambé, Skull Ridge, and Pojoaque Members south of the Pueblo of Tesuque. Three basic units that follow provenance criteria include: *Lithosome A* (representing a piedmont facies derived from the Sangre de Cristo Mountains south of the Peñasco Embayment, whose clast assemblage includes granite with none to subordinate quartzite), *Lithosome B* (representing a fluvial system derived from the Sangre de Cristo Mountains east and northeast of the Peñasco Embayment, whose clast assemblage contains Paleozoic sedimentary clasts, quartzite, felsic volcanic rocks, and only minor granite), and *volcanic-rich sediment* observed in the subsurface and probably correlative to the Chama-El Rito Member of the Tesuque Formation. Texturally, these three units become finer in their downstream directions (west for *Lithosome A*, southwest for *Lithosome B*, and probably south for the *volcanic-rich sediment*). The Tesuque Formation, however, also exhibits an overall coarsening-upward trend in middle to late Miocene strata. Concomitant with this coarsening trend, these three units have generally shifted to the west from the middle to late Miocene, albeit in an irregular manner, that has been hypothesized by the lead author to reflect westward basin floor tilting in response to an increase in rift tectonism during this time period. The overall basin structure in the central basin is consistent with a half-graben, with strata generally tilting to the west and a progressive, but irregular (due to numerous local structures), decrease in dip magnitudes from older to younger strata. A major north-south structure that is greater than 24 km long, called the Barrancos monocline, is located between Highway 285 and the Rio Grande. This structure forms the eastern boundary of a relatively deep, graben-like feature within the larger half-graben; the structure is bounded on the east by the Pojoaque-Road fault zone and includes the West- and East-Jacona faults and the Huerfano fault. There is also a 4-km-wide zone of significant faulting that extends from the town of Nambé northward to 3 km north of the Santa Cruz River. These two structures are manifested by a higher abundance of faults in zones up to 6 km wide and more steeply westward-tilted strata compared to adjoining areas. North of Rio Chupadero, we interpret a structure along the present-day mountain front that is marked by down-to-the-west monoclinal flexure and localized faulting. The overall basin geometry in the southern basin (south of Santa Fe) is a northward-plunging syncline in Miocene and older strata that are unconformably overlain by the essentially undeformed Ancha Formation. The geologic maps covering the central and southern Española basin are improving our understanding of the evolution of the basin, and are providing an essential framework for on-going, detailed hydrogeologic investigations as well as other studies.

GEOLOGY OF THE HORCADO RANCH 7.5-MINUTE QUADRANGLE, SANTA FE COUNTY, NORTH-CENTRAL NEW MEXICO

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The Horcado Ranch quadrangle is located approximately 10-23 km northwest of Santa Fe in the south-central part of the Española basin. The area is underlain by middle to late Miocene strata of the Tesuque Formation, but basaltic to andesitic lava flows of the Cerros del Rio volcanic field are present along part of the western border. Geologic mapping of the Horcado Ranch quadrangle has led to a better understanding of the stratigraphic, sedimentologic, geomorphic, and structural features of this part of the Española basin. First, it is not possible to accurately map the Skull Ridge – Pojoaque Member contact of the Tesuque Formation in the central and southern parts of the quadrangle. Instead, we have differentiated the exposed Tesuque Formation into six units based on texture and provenance. Second, the upper Tesuque Formation (units Tta3 and Ttm3) is significantly coarser than the underlying units and the clast assemblage generally consists of granite; the coarse texture tends to result in relatively high topography. This coarse, upper part of the Tesuque Formation probably has an age range of 12-8 Ma on the quadrangle, based on comparison with a similar unit mapped by the lead author to the north (in the Española , San Juan Pueblo, and Chimayo quadrangles) and $^{40}Ar/^{39}Ar$ data from two pumice beds. The exposed underlying finer and more hetereolithic strata have an age range of 15.3-11.5 Ma. Third, several terrace deposits are found in this area. The straths of the higher, ridge-capping terrace deposits (units Tga1 and Tga2) project at least 30 m above the scoured base of the Ancha Formation, so we interpret that they pre-date the Ancha Formation and have an age range of about 2.7-5 Ma. The straths of these two terrace deposits may show evidence of Pliocene-age, tectonic steepening near an unnamed, down-to-the-west fault and above a monoclinal structure in underlying strata. Near the northern quadrangle boundary, lower than the aforementioned terraces, are several prominent terrace deposits deposited by the Pojoaque River and Rio Tesuque. Three of these terraces, occupying heights of 70-85, 55-65, and 20-40 m above the Pojoaque River, respectively contain tephra beds correlative to the Cerro Toledo Rhyolite (~1.5 Ma), Tsankawi Pumice Bed (~1.2 Ma), and the El Cajete Pumice (probably late Pleistocene). Tesuque Formation strata in the area generally strike north-south, but in the southern part of the quadrangle the strikes are slightly more to the northeast. Stratal dips commonly range from 1-5 degrees in the coarse, upper part of the Tesuque Formation to 5-10 degrees in older, relatively finer strata. Attitude data and the terrace profiles of units Tga3 and Tga2 are consistent with the interpretation that there has been broad relative uplift near the southeast portion of the quadrangle since the middle Miocene.

SUBSURFACE MAPPING AND HYDROLOGIC CHARACTERISTICS OF BISHOP'S LODGE MEMBER OF THE TESUQUE FORMATION

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The Bishop's Lodge Member (BLM) of the Tesuque Formation crops out along the Sangre de Cristo Mountain front northeast of the Santa Fe area. Several domestic water wells in the Tesuque area have encountered the BLM at depths ranging from ground surface to 730 ft. The BLM interfingers with the Nambé Member of the Tesuque Fm (Read and others, 1999) and together comprise the basal Tesuque Fm. Encountering the BLM in these boreholes vertically constrains the basal portion of the Tesuque aquifer system along the Sangre de Cristo Mountain front near the village of Tesuque. In outcrop, the BLM consists of white and gray tuffaceous mudstone, sandstone, and pebble to cobble conglomerate. The portion of the BLM encountered in well borings is predominantly tuffaceous mudstone interfingered with Nambé Member arkosic sand, silt and clay. The BLM is generally a poor aquifer because it is composed of low-permeability, fine-grained volcaniclastic sediments. These low-permeability sediments also create a confining layer resulting in artesian flow in some wells that penetrate into the underlying, more permeable, sediments.

Olivine basalt of the Nambé Member of the Tesuque Fm was encountered in a 980-ft deep well boring (RG-77686) located approximately 2 mi north of Santa Fe. The basalt is directly overlain by a thick sequence of greenish gray mudstone with significant $CaCO_3$ and minor coarse arkosic sand. This clay layer is overlain by 49 ft of coarse arkosic, pink sand of the Nambé Member. This sequence is similar to descriptions of a nearby basalt outcrop along Bishop's Lodge Road. The top of the basalt in the borehole is at an elevation of approximately 6260 ft (above msl), which is approximately 820 ft lower than an outcrop of the basalt exposed on the west side of Bishop's Lodge Road approximately 1 mi southeast of the well. This difference suggests a total down-to-the-west throw of up to 820 ft across several fault splays mapped between the Bishop's Lodge Road outcrop and well RG-77686 (Read and others, 1999). While some of these splays indicate down-to-the-east motion, the majority of the faults in this area have down-to-the-west motion. The basalt in RG-77686 may correlate to the basalt of the outcrop, described by Read and others (1999) that contains one basalt flow of 1 – 1.7 m (~3 – 6 ft) thick. The basalt encountered in well RG-77686 has a minimum thickness of 25 ft (~7 m). The greater thickness of the basalt encountered in the well could be due to accumulation of flow(s) in a paleo-low. An outcrop exposure of the basalt in the Tesuque quadrangle (Borchert and others, 1998) contains five separate flows with a total thickness of 3 – 8 m (~9 – 24 ft). Due to the mixing of cuttings during mud-rotary drilling, separate basalt flows could not be identified in the drill cuttings from the well boring.

Pumping tests were conducted on three separate wells in the vicinity of RG-77686. The lithologic logs and pumping test data indicate a significant variation in aquifer characteristics in the area. Transmissivity ranges from 60 to 250 ft^2/day and appears to be mainly dependent on grain size. One limiting boundary was observed in pumping test data from RG-77686 and may be related to pinching out of coarser sand lenses into finer, clay-bearing sediments, rather than structural influences.

PRELIMINARY AEROMAGNETIC INTERPRETATIONS FOR UNDERSTANDING THE HYDROGEOLOGIC FRAMEWORK OF THE SOUTHERN ESPAÑOLA BASIN, NEW MEXICO

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High-resolution aeromagnetic data were flown over the southern Española basin in order to better understand the geologic controls on ground-water flow and storage. Preliminary interpretations of these data, with limited constraints provided from other geophysical and geologic information, depict the presence of and depth to many features that have hydrogeologic significance, including shallow faults, different types of igneous units, and Precambrian basement rocks. From these results, we can estimate the thickness of and types of rocks that are interlayered with or underlie Santa Fe Group sediments, which constitute the primary aquifer system for the basin.

Estimated and modeled depths to Oligocene volcanic rocks provide the greatest information on the thickness of the Santa Fe Group, because they directly underlie these sediments over a large part of the study area. The aeromagnetic depth estimates indicate the volcanic rocks are shallow (<250 ft) underneath the poorly consolidated deposits of the Ancha Formation in the southern part of the study area, including the western half of Eldorado subdivision. The uppermost volcanic surface appears faulted and irregular, consistent with an eroded surface, with isolated depressions up to 1¼ mi wide and 800 ft deep. Variations in aeromagnetic patterns suggest the volcanic rocks include many circular vents or small intrusions generally <1 mile wide and multiple, northeast-oriented elongated features, which may be basalt-filled paleochannels. Aeromagnetic patterns also indicate several broad areas where volcanic rocks are absent below the Ancha Formation in the eastern part of Eldorado, south of Eldorado, and southeast of La Cienega. In these areas, Ancha Formation probably directly rests on older clastic sedimentary rocks, likely the Galisteo Formation. East of La Cienega, the surface of the Oligocene volcanic rocks dips to the north into the Española basin as an asymmetric syncline, with depths ranging from 2000-4000 ft in the central part of the study area, west of Santa Fe. Several north-south trending, elongated aeromagnetic anomalies northwest of Santa Fe are interpreted as narrow (about 1 mi wide) structural highs that involve Precambrian through Oligocene rocks that may or may not have been associated with magmatic activity. This interpretation implies that the Santa Fe Group may thin to less than 2000 ft in these areas. In contrast to the Oligocene volcanic rocks that are commonly buried, aeromagnetic patterns indicate that most of the younger basalt flows on the western side of the study area are limited to the areas of exposure.

Aeromagnetic interpretations also infer intrabasin faults and address the configuration of the Precambrian basement surface at depth. Interpreted faults show generally north to northeast trends where they offset Santa Fe Group sediments in the central and northern parts of the study area; many of them locate possible major, buried faults. The basement surface generally dips 5-20° to the west from the mountain front, reaching depths greater than 7000 ft west and north of Santa Fe and 10,000 ft in the Española area. In the northeast part of the Eldorado subdivision, basement rises to the surface with an overall dip of 15° to the southwest. South of Eldorado, basement is generally 3000-4000 ft deep.

MAGNETOTELLURIC SURVEYS NEAR THE CERRILLOS UPLIFT AND LA BAJADA CONSTRICTION, FOR HYDROGEOLOGIC FRAMEWORK STUDIES IN THE ESPAÑOLA BASIN, RIO GRANDE RIFT, NEW MEXICO

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Sixteen magnetotelluric (MT) soundings were acquired in 2002 by the U.S. Geological Survey to investigate the subsurface distribution of sediments and volcanic rocks in support of hydrogeologic framework studies in the southern Española basin, Rio Grande Rift, New Mexico. The MT stations span the basin from the southeastern Jemez volcanic field in the footwall of the Pajarito fault zone to the eastern Cerrillos del Rio volcanic field terrane near the La Bajada constriction, and from the Santa Fe block near Española to the Cerrillos uplift near the Cerrillos Hills. The MT method is a surface electromagnetic (EM) geophysical technique that uses the Earth's natural EM fields to investigate the electrical resistivity structure of the subsurface.

The resistivity of geologic units is largely dependent upon their fluid content, porosity, fracturing, temperature, and conductive mineral content. Fluids, especially saline fluids, within the pore spaces and fracture openings can reduce resistivities in a resistive rock matrix. Resistivity can also be lowered by the presence of electrically conductive clay minerals, graphitic carbon, and metallic mineralization. It is common for altered volcanic rocks to contain replacement minerals that have resistivities ten times lower than those of the surrounding rocks. Clay-rich alluvium, shale deposited in marine environments, and mudstones are normally very conductive from a few ohm-m to a few tens of ohm-m. Unconsolidated terrestrial alluvial sediments are commonly moderately conductive (tens of ohm-m), with conglomerate and coarse, clean sand having higher resistivity, and impure sand and siltstone having lower resistivities. The dominant factor determining resistivity of unconsolidated sediment, saturated with fresh water at low temperature, is the relative proportion of clay minerals. Unaltered, unfractured igneous rocks and metamorphic rocks (non-graphitic) are normally moderately to highly resistive (hundreds to thousands of ohm-m). Carbonate rocks are also moderately to highly resistive resistive (hundreds to thousands of ohm-m) dependent upon their fluid content, porosity, fracturing, and impurities. Faults may exhibit low resistivity (less than 100 ohm-m) when they are comprised of rocks fractured enough to have hosted fluid transport and subsequent mineralogical alteration. Increased temperatures cause higher ionic mobility and mineral activation energy, reducing rock resistivities significantly.

We present preliminary resistivity model cross-sections that are related to lithologic variations important to the critical aquifers. In the footwall of the Pajarito fault zone, we model a thin layer of moderately resistive inferred volcanics underlain by a 3-km thick package of conductive sediments that have similar resistivities to the Galisteo Formation and Mancos Shale measured in the Pelto Ortiz #1 and Pelto Blackshare #1 wells. On the hanging wall of the Pajarito fault zone, we model an 800-m-thick layer of moderately resistive Santa Fe Group sediments (based on the Dome Road well) underlain by a 2-km-thick package of conductive sediments that are also similar to the Galisteo and Mancos. Near the La Bajada constriction, we model an 800-m offset, uplifted to the south, of a 300-m- to 1.3-km-thick package of conductive sediments that have similar resistivities to the Galisteo and Mancos.

HYDROGEOLOGY OF THE SANTA FE GROUP AQUIFER SYSTEM, SOUTHERN ESPAÑOLA BASIN, NEW MEXICO—REPORT ON RECENT DEEP TEST WELLS IN THE SANTA FE COMMUNITY COLLEGE DISTRICT

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Recent (2001-2002) sample and geophysical logging of a 1,500-ft exploration well in the "type" Santa Fe Group (SFG), and concurrent hydrogeologic studies throughout the Santa Fe embayment area are providing significant new insights on basin-fill aquifers of the southern Española basin, New Mexico. Primary study sites include stratigraphic and production test-wells near the Santa Fe Community College and adjacent parts of the Rancho Viejo de Santa Fe, Inc. development. As in other Rio Grande rift basins (e.g., Hawley and Kernodle, 2000, NMWRRI Rept. 312), our conceptual model of the area's hydrogeologic framework is here defined in terms of 1) *lithofacies assemblages* that are grouped into informal (lower, middle and upper) SFG *hydrostratigraphic units*, and 2) basin-boundary and intra-basin structural controls.

Our work confirms both the "type" Santa Fe Group lithostratigraphic model (Ancha Fm/ Tesuque Fm) of Spiegel and Baldwin (1963, USGS WSP 1575) and recent revisions proposed by Koning and others (2002, NM Geology, v. 24). Borehole logs of Community College District Exploratory Well #1 (CCDX1), however, provide a much clearer subsurface view of this previously unexplored part of the Santa Fe embayment. At the CCDX1 site, about 200 ft of the Pliocene Ancha Fm, with a veneer of arroyo deposits, are underlain by 1,300+ ft of the Miocene Tesuque Fm. The vadose zone is about 260 ft thick. The Upper Santa Fe–Ancha Fm is composed of arkosic (Sangre de Cristo-derived) piedmont alluvium, but this facies is a subordinate Tesuque Fm component. The dominant *lithofacies assemblage* in the main body of the Tesuque (middle SFG *hydrostratigraphic unit*) is a basin-floor sequence of sandy channel and silty overbank deposits. Hydraulic testing is consistent with a heterogeneous system of stacked channel deposits. This unit is about 1,100 ft thick at the CCDX1 site and has significant groundwater-production potential.

Well logs, early geophysical surveys (Winkler *in* Spiegel and Baldwin, 1963), and recent interpretations of aeromagnetic data by Sweeney and others (2002, USGS OFR 02-205) all indicate that the southern Santa Fe embayment is a narrow rift subbasin that expands to the north and narrows southward toward the Laramide Galisteo basin. About 2 mi east of the test-well site, a shallowly buried (N-trending) linear feature is here interpreted as the principal boundary fault of the embayment. The southern subbasin termination, marked by an abrupt pinch out of the Tesuque Fm, is located about 4 mi SSE of the well site near the western edge of the Eldorado Community.

HYDROGEOLOGIC STUDIES IN THE ESPAÑOLA BASIN BY THE NEW MEXICO BUREAU OF GEOLOGY AND MINERAL RESOURCES

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The New Mexico Bureau of Geology and Mineral Resources, in collaboration with the New Mexico Office of the State Engineer, is engaged in hydrogeologic studies of the Española basin and the Santa Fe embayment. The general objective is to integrate results of new geologic mapping with new and existing hydrologic data, into hydrogeologic interpretations of regional ground-water flow. The current studies are focused in the basin-fill deposits south of Española, north of Galisteo Creek, and east of the Rio Grande, and encompass the Tesuque, Horcado Ranch, Santa Fe, Agua Fria, Seton Village, and Turquoise Hill 7.5-minute quadrangles, and the northeast portion of the White Rock quadrangle in the vicinity of the Buckman well field. The studies will support water-resource management in areas that are most affected by ground-water withdrawal from the Santa Fe and Buckman well fields.

The NMBGMR/NMOSE studies will synthesize geologic and hydrologic data from a number of sources that have not previously been integrated and fully evaluated. New NMBGMR geologic, structural and hydrostratigraphic mapping of the Tesuque Formation (see Bauer and Read; Koning, Read and Borchert; this volume) is being compiled into a 1:50,000 surface geologic coverage that will be combined with subsurface geologic and geophysical data from new and existing wells. When the map data are integrated with outcrop analog studies of air permeability and grain size, and aquifer transmissivity data from Santa Fe County hydrologic reports, our anticipated new interpretation should advance understanding of the three-dimensional permeability structure in the Tesuque Formation and associated intrabasinal faults.

Collection of new water-level data, expansion of the ground-water observation network, and integration of existing head data from Santa Fe County hydrologic reports and other sources will support construction of updated hydraulic-head and water-level decline maps. New well locations that define hydraulic head patterns near key geologic structures and the Buckman-Santa Fe well fields are a priority. Aquifer test data from Santa Fe County and NMOSE files will be reinterpreted to identify boundary effects and the influence of geologic structures on regional ground-water flow.

Results of these studies will address the following hydrogeologic questions and issues:

1. What is the current hydraulic head distribution surrounding the Santa Fe and Buckman well fields, and how has it changed with historical development of the aquifer?
2. What are the three-dimensional sedimentary architecture and permeability structure of the Tesuque Formation?
3. What effects do faults and dipping strata have on regional ground-water flow, well field drawdowns, and stream-aquifer connections?
4. To what degree is the Tesuque aquifer system compartmentalized, what geologic structures or features are responsible for compartmentalization, and could regional ground-water models be improved by incorporating these key geologic elements?

GROUND-WATER FLOW NEAR TESUQUE VILLAGE, SANTA FE COUNTY, NEW MEXICO

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A ground-water study covering 40 km^2 within the Tesuque quadrangle determines ground-water characteristics and controls on flow in the Tesuque aquifer near the Village of Tesuque, Santa Fe County, New Mexico. Ground-water elevation data measured in the Fall of 1998 provide a degree of accuracy for interpolation of the ground-water-flow geometry not provided by the existing Office of New Mexico State Engineer Water Administration Technical Engineering Resource System (WATERS) data. The ground-water elevation map interpolated from the 1998 data delineates a gaining reach along the Rio Tesuque and establishes that the regional aquifer is hydrologically indistinguishable from the Rio Tesuque alluvial aquifer. Anomalous ground-water elevations, which do not conform to the interpolated water-table surface, may be the result of local gradients and variability in permeability. The map does not reveal barriers to ground-water flow such as faults. The density of the 1998 well data alone cannot resolve geologic controls that act on a hundreds-of-meters scale, such as the heterogeneity of permeability in the Tesuque aquifer. Additional insight into the geologic controls on ground-water flow was gained by combining the measured 1998 data with adjusted data from the Office of New Mexico State Engineer WATERS database to achieve greater data density. This combined data set reveals that arroyos and valleys are recharge zones.

USE OF REPEATED GRAVITY MEASUREMENTS TO ESTIMATE AQUIFER RECHARGE IN THE ESPAÑOLA BASIN

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We are beginning a three-year project to estimate how rapidly water is being depleted from the Española basin aquifer, which is the aquifer used by, for example, the City of Santa Fe, the County of Los Alamos, the City of Española, and several Pueblos. Our project requires that we measure gravity at many fixed locations in the Española Valley, as well as in the mountains ringing the valley. The gravity measurements will be extremely precise and repeated several times over a three-year period. The changes in measured gravity at these locations will permit us to measure the amount of water being withdrawn or added to the aquifer over the course of the project.

For the experiment we will establish survey markers, or monuments, at which the gravity measurements will be made. Such monuments will be placed on rock outcrops or pre-existing concrete pads where such are available; elsewhere, they will be installed on metal rods driven roughly 1 m into the ground. Once installed, these monuments will strongly resemble monuments (benchmarks) installed by survey organizations such as the U. S. Geological Survey. They will be nearly flush with the ground surface and about 60 cm^2. We plan to visit these monuments about twice a year for our project. Most of the gravity measurements will be made using absolute gravity meters manufactured by Micro-g Solutions, Inc. Such instruments have essentially no drift and thus permit one to measure precise gravity changes over long time periods, a task which is extremely difficult using relative gravity meters.

We have already established over 70 such monuments, primarily located within the major municipal well-fields in the basin. Specifically, monuments have been established at both the Buckman and the Santa Fe well fields (serving Santa Fe), the Pajarito well field (serving Los Alamos), the Española municipal wells, and wells located within and near San Juan and San Ildefonso Pueblos.

The horizontal and vertical coordinates of the monuments established will be known very precisely. At many locations, but particularly in areas of known subsidence, such as the Buckman well field, we will determine precise coordinates each time we measure gravity. At such locations we will be able to quantify the amount of subsidence over time, within the precision of our GPS observations (20 mm or better).

SUBSIDENCE AT THE BUCKMAN WELL FIELD OBSERVED BY INTERFEROMETRIC SYNTHETIC APERTURE RADAR

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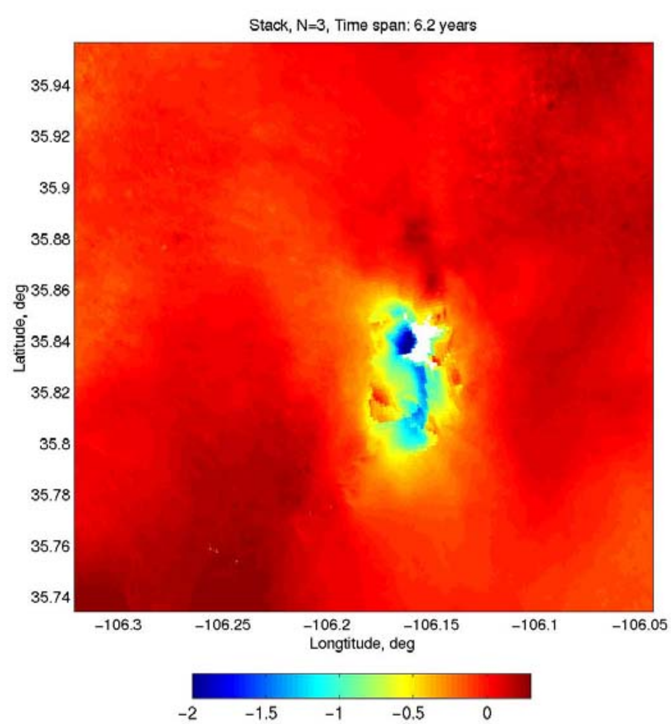
We use interferometric synthetic aperture radar (InSAR) to measure surface deformation at the Buckman well field near Española, New Mexico. Based on three interferometric pairs each spanning a three-year time period, we observe localized ground subsidence over a ~25 km^2 with a maximum line of sight displacement rate of ~2 cm/yr. The deformation pattern is elongated in the north-south direction with an aspect ratio of ~1:3. Based on the proximity of the signal to the Buckman well field, we infer that this deformation may be the result of the withdrawal of water from the underlying aquifer, sediment compaction, or some other mechanism. Interferometric synthetic aperture radar (InSAR) has been widely used to measure line-of-sight displacements due to crustal motion and can provide unique insight into subsurface deformation by measuring surface displacements over a large area at high spatial resolution. We use radar images acquired by the European Space Agency ERS spacecraft spanning the period between June 1993 and September 1997. While stacking only three pairs does not guarantee the removal of tropospheric effects, the same deformation signal is seen in each interferogram and is significantly large and persistent to indicate ground motion. Similar studies have revealed a seasonal trend in the subsidence/inflation associated with groundwater in the Los Angeles basin in California using a combination of InSAR and GPS. While the temporal coverage of this study is insufficient to measure any seasonal variability in the crustal deformation of the Buckman well field, we demonstrate significant overall subsidence over the time period spanned by our observations.



Line of sight displacement rate (cm/yr) based on three interferometric pairs. Negative numbers indicate displacement away (downwards). The look angle for these pairs was ~23 degrees from the descending track. The white region in the center is uncorrelated.

Track 277, Frame 711

DEVELOPING A GROUNDWATER FLOW MODEL TO EVALUATE HYDROLOGIC EFFECTS OF PUMPING FROM THE BUCKMAN WELLFIELD

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The City of Santa Fe is evaluating future water supply options that include use of its Buckman wellfield. The Buckman wellfield, which currently supplies over 40 percent of the City's demands, has excess capacity under its permit and may be called on to supply more than the 5200 acre-feet per year (AFY) that it has averaged in recent years.

A numerical flow model was developed to evaluate the timing, location, and extent of both aquifer drawdown and stream depletions associated with future pumping scenarios. Existing models of the region either were limited in their spatial extent, had grid spacing that were too coarse, or were insufficiently calibrated in the Buckman wellfield area, so a new model was developed. This model was based on the MODFLOW model by Frenzel (1995). A ninth layer representing the alluvial deposits was included. The grid spacing was decreased from a uniform square mile down to 500 ft^2 in the Buckman area up to 0.5 mi^2 at the outer edges of the model. The historic pumping data from the Los Alamos, City of Santa Fe, and Buckman wellfields were updated through the year 2000. Private, agricultural, and other pumping was estimated on an annual basis from County-scale water use and population projections.

The model was calibrated using a variety of criteria, including matching simulated heads to: (1) the mapped prepumping potentiometric surface, (2) water levels measured in the eight individual Buckman supply wells, (3) water levels measured in observation wells located near the Buckman wellfield, and (4) flows in the Rio Grande and Rio Pojoaque. In addition, a detailed sensitivity analysis was undertaken. Based on the calibration results and sensitivity analysis the model was deemed to be sufficiently calibrated in the vicinity of the Buckman wellfield to be used for evaluating the effects of a range of potential future pumping scenarios. The results of these modeling evaluations have given the City of Santa Fe insight into both near-term and long-term water supply strategies.

INVESTIGATION OF STREAMFLOW, INFILTRATION, AND RECHARGE PROCESSES IN THE ARROYO HONDO, NEW MEXICO

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Streambed infiltration along ephemeral channels may provide a substantial source of recharge to alluvial aquifers in the Rio Grande Valley. The ephemeral nature of streamflow in many southwestern streams has resulted in poor documentation of streamflow and streambed infiltration. Current research in the Arroyo Hondo is designed to improve understanding of streamflow and infiltration processes in mountain-front streams. The Arroyo Hondo, like many mountain-front streams in the Española basin, is a perennial stream above the mountain front and an ephemeral, losing stream below the mountain front.

Instrumentation and data collection began in October 1999 and will continue through September 2003. Three rain gages installed throughout the watershed provide precipitation data. Two streamflow-gaging stations, located at and approximately 1 mi below the mountain front, provide continuous streamflow data. Temporal variations in streambed-surface temperature are recorded at 30-min intervals every 0.3 to 1.2 mi along the channel. Five thermistor nests, located throughout the ephemeral reach of the Arroyo Hondo, record temporal variations in the vertical temperature profile (generally, to a depth of 7-9 ft). At two transects, continuous core samples were collected and analyzed for chloride concentration and water content.

Streamflow measurements used in conjunction with thermographs from streambed temperature probes provide information on temporal variations of the downstream extent and duration of streamflow. An inverse modeling technique, which fits simulated to measured temperatures, provides estimates of instantaneous infiltration rates at thermistor nests; these instantaneous infiltration rates may be scaled up to provide estimates of total infiltration during a given streamflow event. The chloride mass-balance method was used to estimate long-term recharge rates.

During the current study, precipitation has been below average and measured streamflow has been lower than estimates that are based on empirical equations. The most substantial streamflow event that extended into the ephemeral reach of the Arroyo Hondo occurred during the snowmelt period of March 2001; estimated instantaneous infiltration rates ranged from 4 to 14 ft per day during this event. Preliminary data indicate that snowmelt-induced streamflow events produce more cumulative streambed infiltration than events generated by summer thunderstorms because of the longer duration of the events and the larger size of the actively losing channel during snowmelt events. Long-term recharge rates estimated from the chloride mass-balance method range from 0 to 0.25 in/yr.

COMPARISON OF SEEPAGE INVESTIGATIONS IN THE RIO GRANDE REACH FROM OTOWI BRIDGE TO WHITE ROCK, NEW MEXICO

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The interaction of the Rio Grande and intersecting ground-water basins has become more important in the last few years since the supply of ground water and surface water is not enough to fill all demands. In the last two years of below-normal snowpack (winter of 1999-2000 and 2000-2001) and declining reservoir levels, surface water supplies have become insufficient to satisfy all needs in several basins in New Mexico including the Española basin. As an initial effort in the quantification of the interaction of surface water and ground water in the Española basin, the Rio Grande was measured at the location of two gages in the White Rock Canyon reach on November 21, 2002. This poster will compare the results of this seepage investigation in this reach of the river to several seepage investigations that were conducted prior to the establishment of the Buckman well field.

PRELIMINARY PRE-DEVELOPMENT WATER-LEVEL MAP IN THE SANTA FE AREA WITH WATER-LEVEL TRENDS AND PUMPING ZONES OF INFLUENCE

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This montage depicts pre-ground water development water levels, water-level trends in selected wells, and simplified model-estimated zones of influence due to major ground-water rights. An updated map is necessary for detailed studies of hydrologic effects of well diversions since the 1950's, and to assist in hydrologic interpretations. Constructed using GIS, this map differs locally from previous interpretations in using surface water body elevations as control points. Several databases from different sources were combined, edited and gridded using geostatistical analysis. Dominant features include regional flow from the Sangre de Cristo Mountains to the Rio Grande, steep dip across the La Bajada fault zone, and flattening in the La Cienega discharge area. Water level data collection underway by the NMBGMR is targeted at wells possessing historical data and wells in low data density areas, especially west and north of the city of Santa Fe. This study is part of ongoing Española basin hydrologic studies in cooperation with the NMOSE, the NM Bureau of Geology and Mineral Resources, and the U.S. Geological Survey.

GROUNDWATER CHEMISTRY IN THE ESPAÑOLA BASIN: RELATION TO GEOLOGIC AND HYDROLOGIC INFLUENCES

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We investigate the use of multiple naturally occurring tracers, both reactive and non-reactive, present in groundwater in the Española basin and evaluate their potential utility for discriminating between alternative conceptual models of flow and transport in the regional aquifer. To accomplish this, we present maps of major ion and stable isotope variation within groundwaters in the basin and discuss spatial trends. In addition, we present 3-D simulations of groundwater chemistry evolution within the basin, via coupling a basin-scale groundwater flow model to simple geochemical models.

The two most common types of waters are Ca-HCO_3 waters in the eastern basin and Ca-Na-HCO_3 waters on the Pajarito Plateau. Less common are Na-HCO_3 and Na-Cl waters found in some locations along the Rio Grande and waters enriched with SO_4 in the northwestern portions of the basin. Chemical equilibrium calculations illustrate the potential importance of reactions with calcite, plagioclase, several SiO_2 polymorphs and volcanic glass on groundwater chemistry.

Isotopes (^{3}H, ^{14}C, $\delta^{18}O$) have been used to infer groundwater flow paths by several authors (Anderholm 1994; Blake and others 1995; Rogers and others 1996; Keating and others 2000). We present simulated steady-state concentrations of these isotopes in three dimensions and discuss strengths and limitations of isotopes as tracers in this basin. We find that ^{14}C is a very useful tracer and provides information on large-scale effective porosity of the aquifer. Interpretation of trends in oxygen isotopes is less definitive; nevertheless oxygen isotope simulations provide useful illustrations of regional flowpaths and identification of potential areas of recharge.

Anderholm, S.K. (1994) Ground-water recharge near Santa Fe, north-central New Mexico. U.S. Geological Survey Water Resources Investigations Report, 94-4078.

Blake, W.D., Goff, F., Adams, A.I., and Counce, D. (1995) Environmental Geochemistry for surface and subsurface waters in the Pajarito Plateau and outlying areas, New Mexico. Los Alamos National Laboratory Report, LA-12912-MS.

Keating, E., Kwicklis, E., Vesselinov, V., Idar, A., Lu, Z., Zyvoloski, G., and Witkowski, M. (2000) A Regional Flow and Transport Model for Groundwater at Los Alamos National Laboratory. Los Alamos National Laboratory. A progress report submitted to the Hydrogeologic Characterization Program, LA-UR-01-2199, http://lib-www.lanl.gov/la-pubs/00818241.pdf.

Rogers, D.B., Stoker, A.K., McLin, S.G., and Gallaher, B.M. (1996) Recharge to the Pajarito Plateau regional aquifer system, NM Geol. Soc. Guidebook, 47th Field Conference, Jemez Mountains Region.

GROUND-WATER CONTAMINATION AT LOS ALAMOS NATIONAL LABORATORY (LANL)

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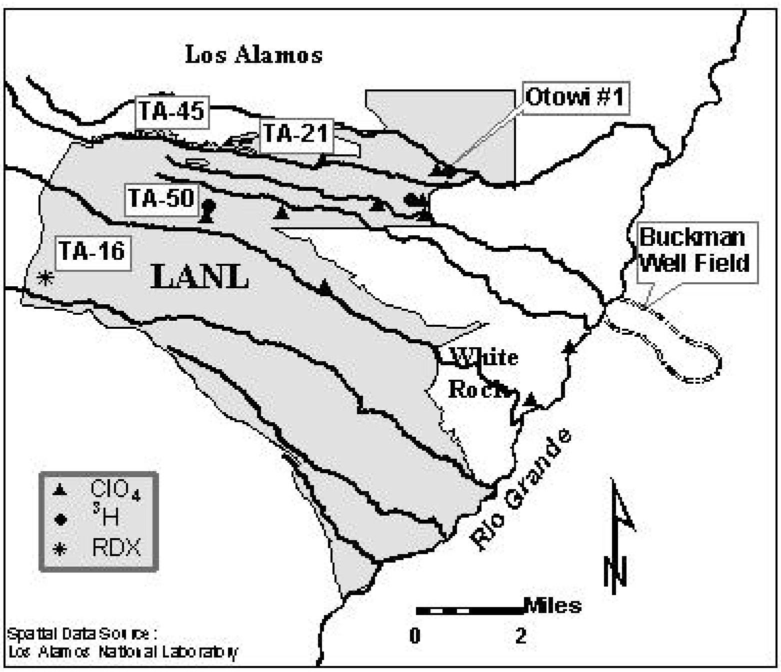
http://www.nmenv.state.nm.us/gwb/GWQ Atlas/GWQ_Atlas.html

LANL has discharged wastewater to surface watercourses since 1943. Untreated radioactive waste was released at TA-45 from 1943-51. Treated wastewater was discharged at TA-16, TA-45 (1951-64), TA-21 (1952-86), and at TA-50 (1963-present). These discharges contaminated alluvial ground water with chloride (Cl^-) nitrate (NO^{3-}), fluoride, perchlorate (ClO^{4-}), high explosives (e.g., RDX), and radioisotopes ^{241}Am, ^{137}Cs, ^{3}H, ^{238,239,240}Pu, ^{90}Sr, ^{99}Tc, and U. Alluvial aquifers recharge perched ground-water zones, which recharge the regional aquifer. These recharge pathways transport the highly mobile contaminants Cl^-, NO^{3-}, ClO^{4-}, and ^{3}H into the regional aquifer. LANL has greatly reduced contaminant levels in its wastewater discharges, and concentrations in alluvial aquifers have subsequently decreased. Contaminants that once created high levels in alluvial aquifers, however, have migrated deeper into the subsurface.



ClO^{4-} has emerged as a major issue because of widespread detections in ground water, sometimes at concentrations of human-health concern (e.g., up to 3180 µg/L in the alluvial aquifer). ClO^{4-} has been detected in Los Alamos supply wells Otowi #1 (up to 5 µg/L), and Pajarito #1, 2, 3 & 5 (up to 0.5 µg/L). Los Alamos tap water contained 0.2 µg/L ClO^{4-} on 11/25/02. ClO^{4-} also has been detected in White Rock Canyon springs (up to 0.5 µg/L) that intercept the regional aquifer. These springs also contain elevated Cl^- and NO^{3-}.

The regional direction of ground-water flow is to the southeast. LANL has suggested that the source of ClO^{4-} in Otowi #1, first detected in 1997, may be waste discharged at TA-45. Otowi #1 and the City of Santa Fe's Buckman well field are located approximately 25,000 ft and 50,000 ft down-gradient from TA-45, respectively. If TA-45 is the source of ClO^{4-} in Otowi #1, then ClO^{4-} has migrated (via surface water, vadose zone and/or ground water) approximately 5 mi, half the distance to Buckman, in 54 years or less. The specific source of ClO^{4-} in White Rock Canyon springs has not been determined. These trace-level detections, along with elevated Cl^- and NO^{3-}, represent the leading edge of LANL ground-water contamination. ClO^{4-} has not been detected in the Buckman well field, which captures about 1/3 of its production from west of the Rio Grande.

A SUMMARY OF WATER RESOURCES IN THE RIO CHAMA WATERSHED, NORTHERN REGION OF THE ESPAÑOLA BASIN

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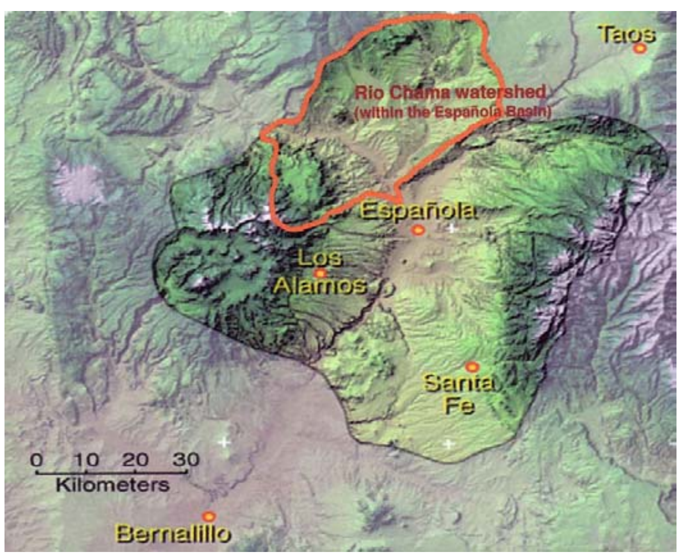
The Española basin is a geologically and hydrologically complex and heterogeneous structural basin. It is situated within three New Mexico Interstate Stream Commission water-planning regions: the Rio Chama, Taos, and Jemez y Sangre regions. The Rio Chama region, which is the subject of this presentation, is outlined on the basin map below. Water resources, and demands on resources, are quite varied within the different regions of the basin. While numerous geologic studies have been conducted throughout the Española basin, few water resource assessments have been conducted, especially in the northern portion of the basin. Water resources in the Rio Chama watershed have been assessed as part of regional water planning efforts. Ground water is the primary resource for domestic uses (as is true for the entire Española basin). However in the Rio Chama region of the basin, ground water accounts for approximately 2% of the water diverted, or about 900 acre-feet per year for domestic consumption. Less than 25% of the population in the Rio Chama region of the basin is served by community water systems, and the rest of the population is served by private wells. Ground water is derived primarily from alluvial and Tertiary deposits. Many community systems and private wells in the region do not produce sufficient water to meet peak demands, and in addition, many of these systems have water quality problems. Most of the available water supplies in the Rio Chama region of the Española basin are surface water, and most of this water is used for agriculture. Surface water diverted for irrigated agriculture is estimated to be less than 60,000 acre-feet per year. Looking into the future, the region's population growth will put more demand on drinking water consumption, and aquifers may not produce enough to meet the demands. Use of surface water resources may need to be examined further. Existing constraints regarding water rights, interconnection between ground water and surface water, and allocation between regions will need to be addressed.



JEMEZ Y SANGRE WATER PLAN OVERVIEW

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The Jemez y Sangre Water Planning Council convened in 1998 to begin the process of regional water planning. Comprised of 24 member organizations, the Council obtained approximately $600,000 in funding to answer five questions: How much water do we have? How much are we using? How much will we need in the future? What are the alternatives for meeting the future water demands? And what are the public welfare values of the region? The Council has developed a plan that answers these questions.

The Jemez y Sangre region extends from the Embudo Gage north of Española to Cochiti Reservoir and from the Jemez Mountains on the west to the Sangre de Cristo Mountains on the east. The region was divided into 10 sub-basins based on hydrologic boundaries. For each sub-basin the Council developed (1) groundwater and surface water budgets to show both the inflow and the outflow for each component of flow and (2) population projections into 2060 to allow for estimates of projected water use if current trends continue. Based on these analyses, a 31,500-acre-foot gap between supply and demand was projected by the year 2060.

The Council developed a series of alternatives (analyzed in White Papers available at www.dbstephens.com/publications) that could be considered to address this gap between supply and demand. Many of the alternatives focus on protecting or restoring existing supplies to meet the current level of demand in the future, while other alternatives addressed filling the projected gap. Based on the analyses of these alternatives, the Plan provides recommendations and outlines the options available to decision makers. In particular, it shows how much demand could be reduced through growth management or conservation and how much the water supply could be increased through the use of San Juan-Chama Project water and return flow credits. In addition, it dispels myths about what actually creates "wet water" and documents how far each alternative can go towards reducing the future water supply gap. Rather than dictating exactly how each municipality or water utility should solve its problems, the plan provides decision-makers in each community in the region with a clear summary of the options available.

USING SCENARIO ANALYSIS TO ASSIST IN RESOURCE PLANNING UNDER CONDITIONS OF UNCERTAINTY

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Need: Single Point Forecasts generally prove to be inaccurate. Most people have their own assumptions as to how the future will play out. This leads to the creation and strengthening of factions rather than contributing to the formation of consensus. Gaining agreement on assumptions or sets of assumptions (scenarios) with each set of assumptions leading to a different course of action can help in forming consensus.

Challenge: Predicting the future is difficult but the uncertainty tends to decrease as time passes. This suggests creating a planning framework where consensus can be built based on multiple scenarios with the assignment of probabilities to each scenario being refined as time goes by.

Example of Scenario Matrix: This is just an example. Each planning exercise requires the construction of the planning elements tailored to the intended use.

Demand Outcomes / Supply Outcomes	Growth Constrained or Reduced	Growth Continues Along Expected Path	Growth Accelerates
Additional Water Resources Become Available	S1	S2	S3
Water Resources Track Plan	S2	S3	S4
Water Resources Track Plan but Precipitation Shortfalls Create Deficits	S3	S4	S5
Unexpected Loss of Major Water Resource	S4	S5	S6 Is this Possible?

Planning Elements:
- Milestones for Predicting Outcomes
- Mutually Exclusive Outcomes for Each Major Parameter*
- Scenarios (pairs of outcomes which are similar in impact)
- Response Options for Each Scenario

* Supply and Demand in the above example. Any two parameters can be used.