Evaluation of the Geothermal Potential in the Rio Grande Rift: San Luis Basin, Colorado and New Mexico[1]

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ABSTRACT

The San Luis Basin has been evaluated for its geothermal potential by examining the following attributes: physiography, geology, tectonics and structure, water resources, infrastructure, population and target markets, other geothermal factors, and economic considerations and available incentives. This was accomplished by using a combination of literature reviews and data analyses in conjunction with the interpretation of information obtained from digitized map layers created in ArcGIS®. The basin has several known hot springs and wells. Some of these are currently being utilized for direct-use applications including aquaculture, spas and pools, and space heating. The basin is characterized by high heat flow and high geothermal gradients. An interpretive geothermal gradient map of Colorado by Berkman and Watterson (2010) shows an average gradient within the basin of approximately 50 degrees Celsius per kilometer (°C km^{-1}) and several higher gradient areas (70–90°C km^{-1}). The most promising areas for electrical power generation (locations with high geothermal gradients) are just south of Poncha Pass at the northern end of the basin and an area northeast of the San Luis Hills. These locations are in the Baca Graben. Temperatures sufficient for power generation (1-1.2 kilometers (km) for the 90 degree Celsius (°C) isotherm and 2-2.5 km for the 180°C isotherm) are in Santa Fe Group sediments. The heterogeneous nature of these sediments may be challenging in terms of finding a large permeable reservoir for power production. In the event that suitable hydrothermal reservoirs are not found, Enhanced Geothermal Systems (EGS), in which permeability is created artificially, may be an alternative in areas with the high geothermal gradients.

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INTRODUCTION

The San Luis Basin is a Tertiary extensional basin located in the northern part of the Rio Grande Rift in north-central New Mexico and south-central Colorado (Fig. 1). There are several areas within the basin that have hot springs and wells that produce hot water that is exploited for direct-use applications such as aquaculture, spas and pools, and space heating. In addition, like other basins along the Rio Grande Rift, the San Luis Basin is characterized at depth by high heat flow and high geothermal gradients. The shallow thermal regime in the San Luis Basin is locally modified by aquifer recharge and groundwater flow.

PHYSIOGRAPHY

The San Luis Basin consists of the San Luis Valley in south-central Colorado and the Taos Plateau in north-central New Mexico. As an east-tilted graben, the San Luis Basin is bordered to the east by the Sangre de Cristo Range uplift and a system of north trending high angle extensional faults, and on the west by the north-trending San Juan Mountains in Colorado and the Brazos uplift (or Tusas Mountains) in New Mexico (Burroughs, 1981; Broadhead, 2008). The northern limit is Poncha Pass and the southern limit the Embudo constriction in New Mexico (on the Rio Grande northwest of Taos, Fig. 1) (Burroughs, 1981).

The lowest elevation of the basin floor is approximately 1,768 meters (m) at the southern end of the basin. The highest point on its margin is 4,377 m at the summit of Mt. Blanco in the Sangre de Cristo Range (Burroughs, 1981). Upson (1939), as cited by Burroughs (1981), divided the basin into the following physiographic provinces: the Alamosa Basin, the San Luis Hills, the Taos Plateau, the Costilla Plains, and the Culebra Re-entrant (Fig. 1). The San Luis Hills, which trend north-easterly across the basin, are a physiographic barrier between the San Luis Valley and the Taos Plateau. This feature is also a structural barrier between the northern (Alamosa Basin) and southern (Taos Plateau) parts of the basin (Burroughs and McFadden, 1976).

The San Luis Valley has a somewhat cool and semi-arid climate with average January lows of -17°C and January highs of 2°C and July lows of 8°C and July highs of 28°C. Average precipitation is on the order of 18 centimeters (cm) per year (Burroughs and McFadden, 1976). Land use is primarily agricultural; however a large percentage of land in the valley is owned by the United States and managed by the Bureau of Land Management (BLM).

GEOLOGY

Rocks of the San Luis Basin are Tertiary in age and overlie Precambrian crystalline rock. Cretaceous and Paleozoic rocks were either eroded during the Laramide uplift or were not deposited. The basin fill primarily consists of non-marine sedimentary rocks, volcanic rocks, and volcaniclastic sedimentary rocks with total thicknesses of up to 6,400 m (Kluth and Schaftenaar, 1994). Because few oil or gas exploration wells have been drilled in the New Mexico area of the San Luis Basin, information on the subsurface is limited south of the state line compared to the portion of the basin that lies within Colorado.

Formations present in the San Luis Basin include: the Blanco Basin Formation (Eocene, contiguous with Vallejo Formation of Upson, 1939), the Conejos Formation (Oligocene), the Santa Fe Group (Miocene to Pliocene), and the Alamosa Formation (Pleistocene) (Fig. 2). The Blanco Basin Formation is composed of non-volcanic alluvial sandstone and reddish brown shales, which unconformably overlay the Precambrian bedrock. The Conejos Formation consists of 396 m to 2,286 m of volcaniclastic sedimentary rocks, andesitic lava flows, and minor ash flow tuffs (Broadhead, 2008; Brister and Gries, 1994). The Santa Fe Group consists of buff to pinkish-orange clays with interbedded silty sands that intertongue with alluvial-fan sediments of the Los Pinos Formation, and ranges in thickness from 91 m to 610 m (Broadhead, 2008; Burroughs, 1981). The Alamosa Formation is up to 610 m in thickness and consists of gray, black and green beds of clay that are overlain by poorly cemented, fine- to coarse-grained sandstone (Brister and Gries, 1994).

TECTONICS AND STRUCTURE

The Alamosa Basin is divided into two sections by the Alamosa Horst, the western Monte Vista Graben and the eastern Baca Graben (Burroughs, 1981), as shown in

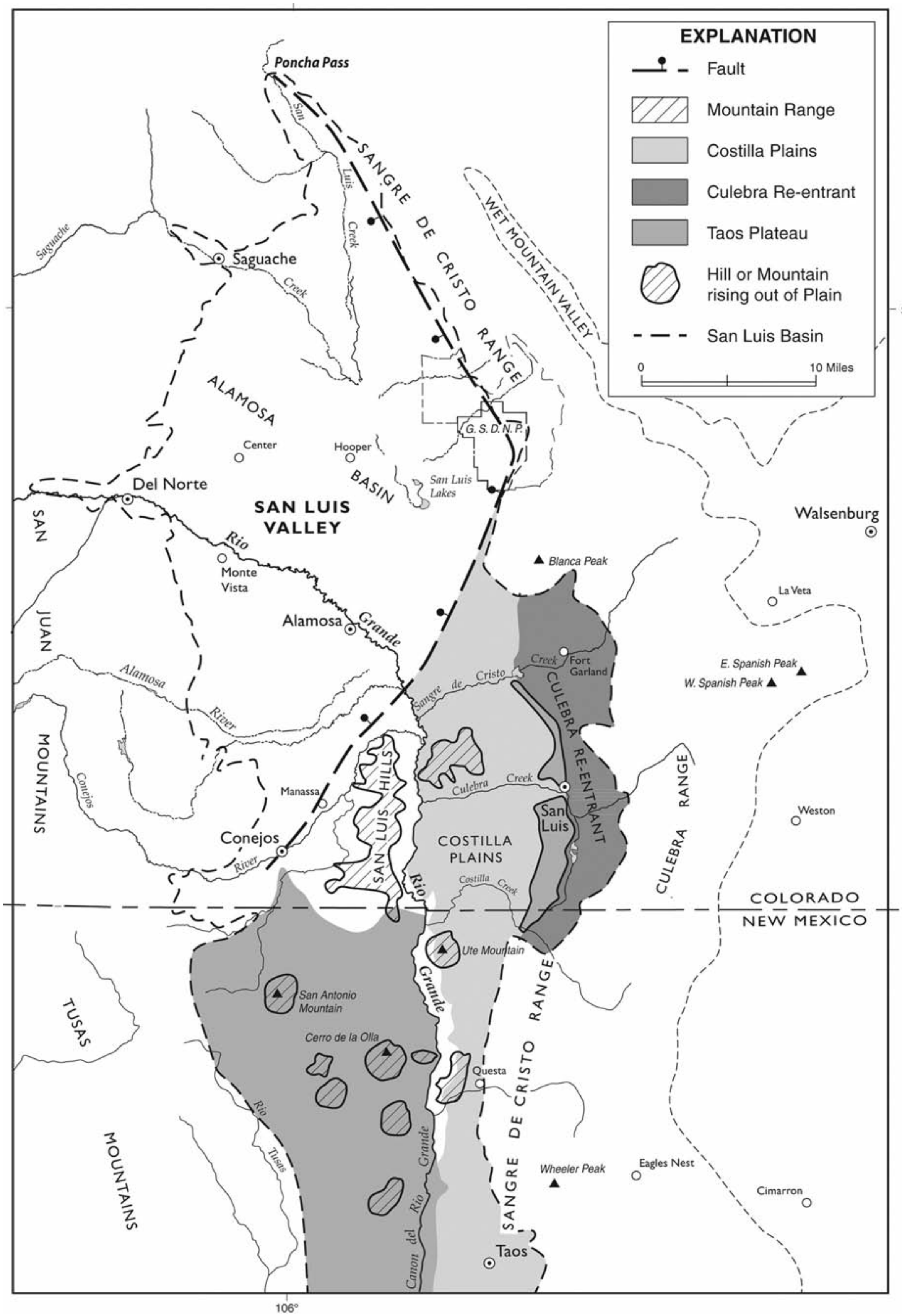

Figure 1.
Location map and physiographic provinces of San Luis Basin (redrawn, based on Burroughs, 1981).

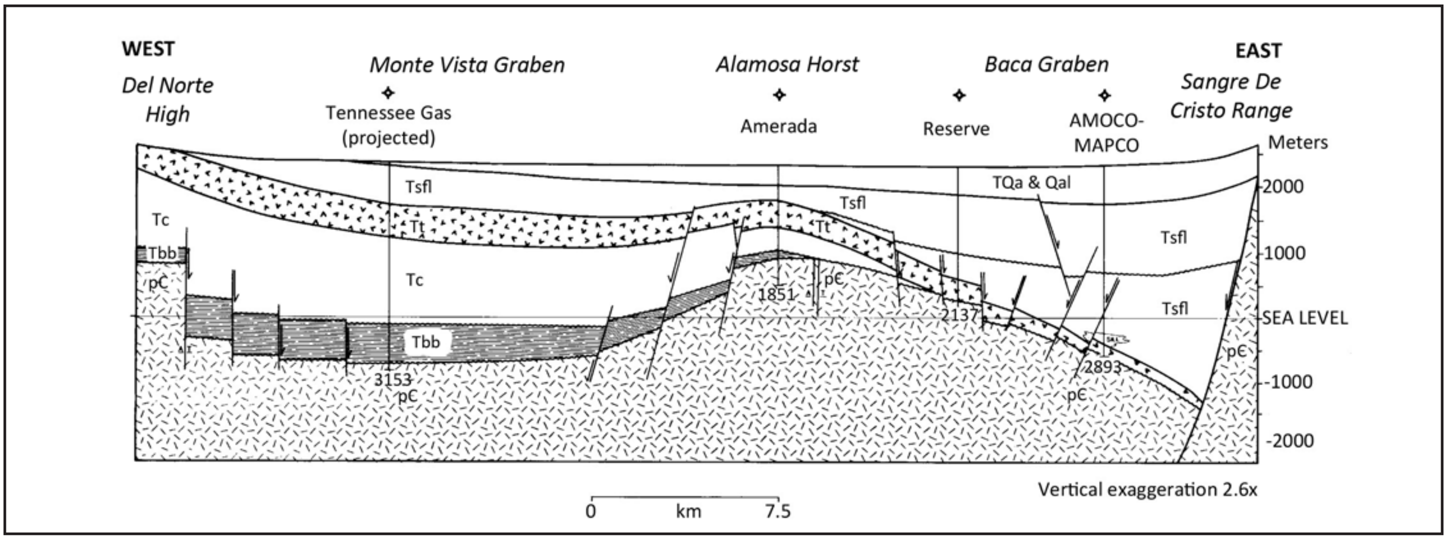

Figure 2. Interpretive west to east cross section of the San Luis Basin approximately 20 km north of Alamosa. Locations of wells used in construction of cross section are shown. Numbers at bottom of lines representing wells are depths of wells in meters. Keys for geological units: TQa and Qal, Alamosa Formation (Plio-Pleistocene) and Quaternary alluvium; Tsfl, lower Santa Fe Group (Mio-Pliocene); Tt, ash flow tuffs of San Juan volcanic field (Oligocene); Tc, Conejos Formation and equivalents (Oligocene); Tbb, Blanco Basin Formation (Eocene); pC-, granite-gneiss basement (Precambrian). Modified from Brister and Gries (1994).

Figure 2. Controlling the subsidence in the basin are north-south trending normal faults as well as tilted, flanking uplifts at the basin margins (Peterson and Roy, 2005). The basin fill is 5,000 m to 6,400 m in depth in some areas with shallow structural benches on the edges of the basin. The normal faults may control ground water circulation and provide permeability for convection of geothermal waters.

The San Luis Hills separate the northern and southern portions of the basin. The La Sauses Fault divides the San Luis Hills into eastern and western segments and the Rio Grande follows this fault (Burroughs and McFadden, 1976). The San Luis Hills are composed of volcanic rocks of the Conejos Formation and are a small erosional remnant of the extensive volcanic field that previously covered much of southern Colorado and northern New Mexico (Burroughs and McFadden, 1976).

Burroughs (1981) presented evidence, based on gravity and magnetic data, and well log correlations, for east-west paleovalleys that transect the Alamosa Horst. He states that “if the appropriate reservoir rocks are present in the volcaniclastics, these areas could have excellent geothermal potential”.

GEOTHERMAL

There are areas of high heat flow, in excess of 80 milliwatts per square meter (mW m^{-2}), within the San Luis Basin (Fig. 3; Berkman and Carroll, 2007). According to Morgan et al. (2010), these regionally high heat flow values may be caused by thinning of the lithosphere, recent volcanism, upwelling of groundwater, or possibly caused by high concentrations of the heat-producing radioactive elements in the upper crust (Uranium 232 and 235, $^{232,\ 235}U$; Thorium 232, ^{232}Th, and Potassium 40, ^{40}K). Barrett and Pearl (1978) and Coe (1980) reported that there were six different known geothermal areas located in the Colorado portion (north of 37°N) of the San Luis Valley including 4 hot springs and 2 wells producing hot water. Barrett and Pearl (1976, 1978) provided pertinent information on these areas, and this information is summarized in Table 1.

Using the above heat flow estimate and assuming a thermal conductivity of 2.6 watts per meter per Kelvin (W m^{-1} K^{-1}), a geothermal gradient of approximately 31°C km^{-1} has been calculated, which compares well with the value obtained from the slope of the bottom hole temperature (BHT) versus depth data as presented in Burroughs (1981) of 32°C km^{-1}. However, an interpretive geothermal gradient map of Colorado by Berkman and Watterson (2010) shows an average gradient of approximately 50°C km^{-1} and several higher gradient areas including where the San Luis Valley narrows before entering Poncha Pass in the north (80 – 90°C km^{-1}) and 70°C km^{-1} near the groundwater sump described by Bexfield and Anderholm (2010; see discussion below and Fig. 4). Morgan et al. (2010) analyzed BHT data from oil wells in the Colorado portion of the San Luis Basin and calculated an average geothermal gradient for the basin of 36°C km^{-1} from a linear trend fit

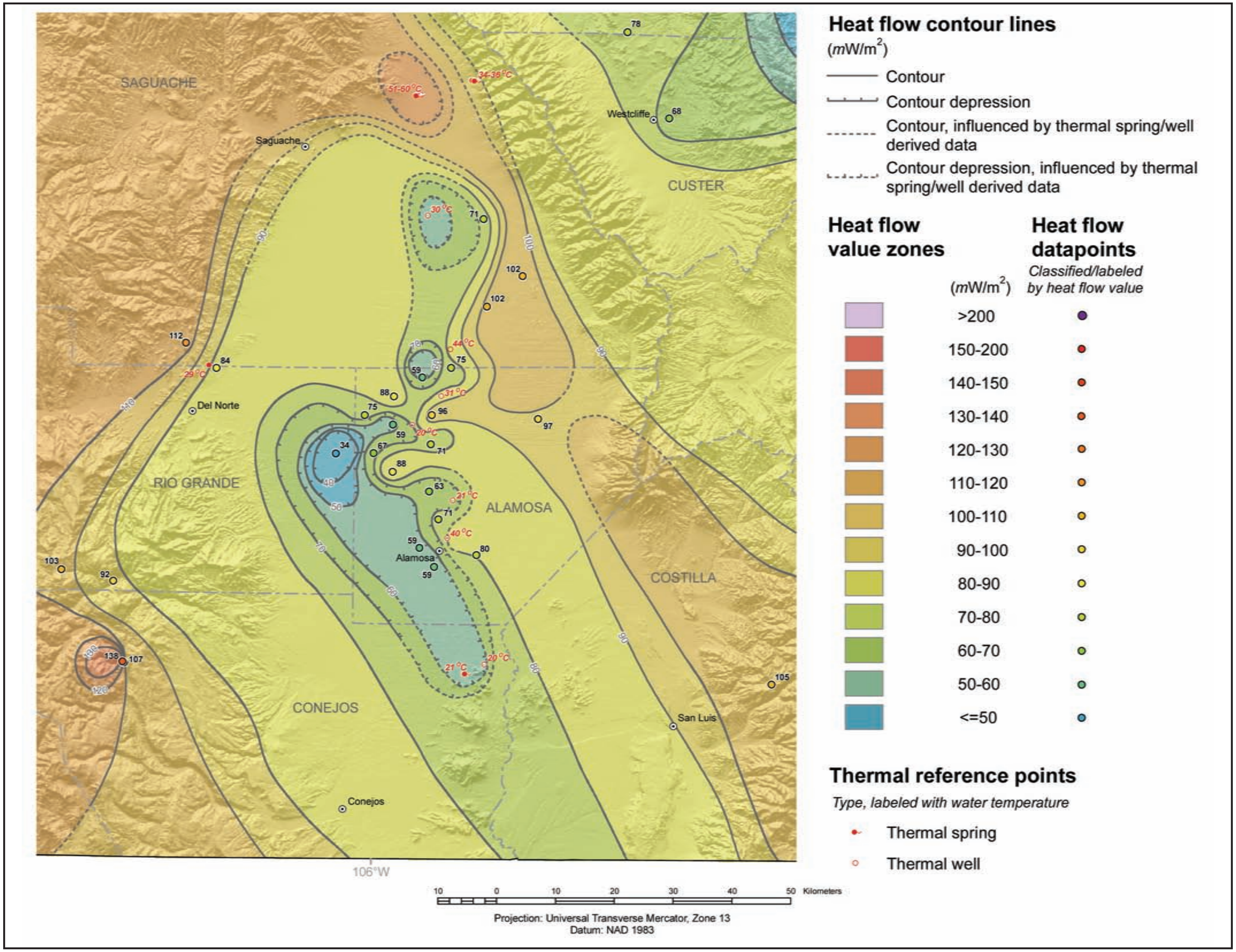

Figure 3. Heat flow map of the San Luis Basin in Colorado. Low heat flow in the north-central portion of the basin northwest of Alamosa is a shallow phenomenon caused by groundwater recharge. Bottom-hole-temperature data from oil wells indicate that heat flow is higher at a depth of 1 km or more. Modified from Berkman and Carroll (2007).

Table 1.
Principal thermal springs and wells in the San Luis Basin. Thermal features in Colorado (north of 37°N) from Barrett and Pearl (1976, 1978). Thermal features in New Mexico from Summers (1965), Morgan and Witcher (this issue), and Witcher (personal communication, 2011). TDS is total dissolved solids in milligrams per liter (mg/l): * indicates that TDS was calculated from specific conductance in micro-siemens using a conversion factor of 0.67. Discharge is given in gallons per minute (gpm).

Name	Latitude	Longitude	TDS (mg/l)	Temperature) (˚C)	Discharge (gpm)	Type
(Joyful Journey (formerly Mineral) Hot Springs	38.1689	105.9181	650	60	70-167	Springs and Seeps
Valley View Hot Springs	38.1922	105.8136	234-252	32-37	60-120	Springs and Seeps
Shaws Warm Springs	37.7503	106.3169	398-424	30	34-50	Springs and Seeps
Sand Dunes Swimming Pool Hot Water Well	37.7783	105.8556	334	44	N/A	4400 ft deep well
Splashland Hot Water Well (currently not in use)	37.4886	105.8575	311	40	N/A	2000 ft deep well
Dexter and McIntyre Warm Springs	37.2947	105.7847	195	20	5 5	Springs and Seeps
Ponce De Leon HS	36.3233	105.6083	525*	34	100	Springs and Seeps
Mamby HS	36.5222	105.7222	495*	38	~30	Springs and Seeps
Hondo (Blackrock) HS	36.5283	105.715	510*	41	0.5	Springs and Seeps

to the data corrected for the effects of drilling. They also report a gradient of 49.9°C km^{-1} from a 1,942 m deep geothermal test well drilled on the south side of Alamosa, demonstrating that geothermal gradients of at least 50°C km^{-1} may be found at some locations in the basin. Projecting the conservative 32°C km^{-1} gradient value from Burroughs (1981) with depth, and using an average surface temperature of 4.2°C (derived from the Western Regional Climate Center), the depth to reach a temperature of 90°C was calculated by the authors to be 2.7 km. Using a gradient of 50°C km^{-1}, the depth to reach a temperature of 90°C is reduced to around 1.7 km, and a temperature of 180°C would be reached at a depth of approximately 3.5 km. For the highest mapped gradient at Poncha Pass (90°C km^{-1}), 90°C would be reached at about 1.0 km and 180°C at approximately 2 km.

WATER RESOURCES

Burroughs (1981) separated the groundwater system in the San Luis Basin into an unconfined aquifer that extends to a clay series in the Alamosa Formation and a confined aquifer from the clay series down to the Precambrian basement. Potential water bearing strata within the unconfined layer include sand and gravel layers within the Santa Fe Group. Burroughs (1981) and Huntley (1976) note that while the hydrogeologic characteristics of the volcanic

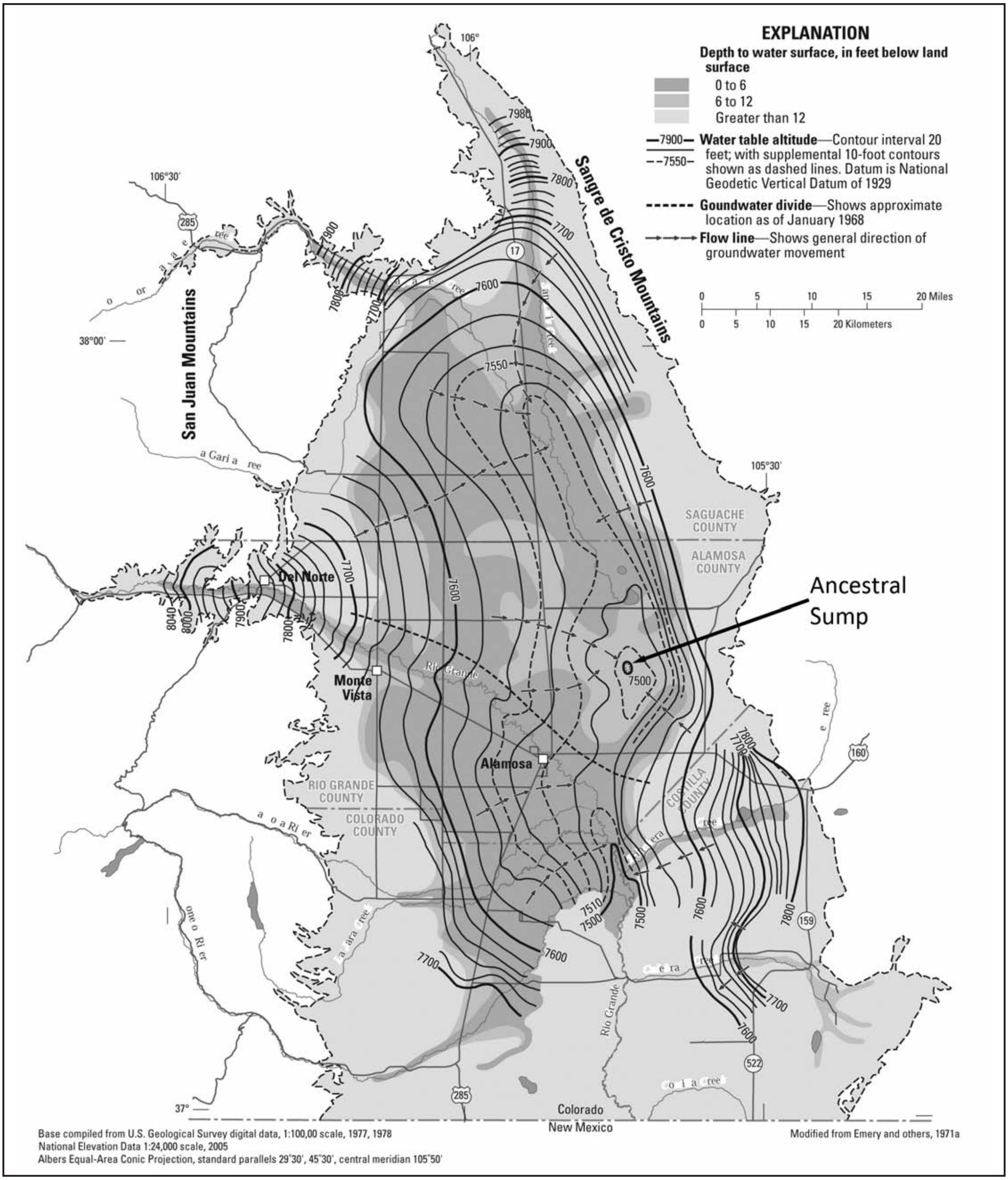

Figure 4. Groundwater flow and water table depth in the San Luis Valley. Modified from Bexfield and Anderholm (2010).

Table 2.
Fine-scale hydrogeologic units in the San Luis Basin from Huntley (1976).

Hydrogeologic Unit		Description	Type of Permeability	Hydraulic Conductivity cm/sec
Recent	Stream Deposits	Ranges in texture from silt-size through cobble and boulder-size. Permeability varies downstream and with age of alluvial unit it crosses.	Intergranular	10^{-6} - $6.0(10^{-2})$ 10^{-6} - $6.0(10^{-2})$
	Eolian Sands	Small, steeply sloped, most recent fan. Poorly sorted with continuous grain-size gradation of silt through cobble.	Intergranular	$5.0(10^{-3})$ - $2.0(10^{-2})$ $5.0(10^{-3})$ - $2.0(10^{-2})$
Quaternary Alluvial Fans	4	Small, steeply sloped, most recent fan. Poorly sorted with continuous grain-size gradation of silt through cobble.	Intergranular	$1.0(10^{-4})$ - $5.0(10^{-3})$
	3	Relatively well-sorted deposits with grain size varying from fine-sand to cobble-size. Largest of the alluvial fans.	Intergranular	$1.2(10^{-2})$- $4.0(10^{-2})$ $1.2(10^{-2})$- $4.0(10^{-2})$
	2	Medium to coarse-grained, poorly to moderately well-sorted. The slope is intermediate between units 1 and 3 and is moderately dissected.	Intergranular	$3.0(10^{-2})$ - $6.0(10^{-2})$
	1	Oldest alluvial fan unit in sequence; very steep and highly dissected. Caliche layer near top of unit is very coarse-grained.	Intergranular	$5.5(10^{-2})$
Plio-Pleistocene Clay Sequence		Interbedded lacustrine clays and alluvial sands. Uppermost clay separates the unconfined surface aquifer from lower confined aquifers throughout much of San Luis Valley.	Intergranular	$1.0(10^{-8})$ - $5.0(10^{-3})$
Tertiary Alluvial Sediments		Paleocene-Pliocene silts, sands, clays, and conglomerates. Moderately well cemented with abundant fine-grained material filling pores.	Intergranular	$1.0(10^{-8})$ - $5.0(10^{-5})$
Youngest Volcanics		Andesite and basalt flows.	Fracture, constant with depth	$9.0(10^{-4})$ - $1.0(10^{-1})$
Uppermost Ash-flow Sequence		Quartz latite to rhyolite ash-flow tuffs. Degrees of welding vary from unwelded to highly welded. Permeability is greatest in highly welded portions. Permeability is strongly anisotropic.	Fracture, constant` with depth	$3.0(10^{-2})$ - $6.0(10^{-2})$

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Table 2.
(Continued)

Hydrogeologic Unit	Description	Type of Permeability	Hydraulic Conductivity cm/sec
Middle Ash-flow Sequence	Includes Carpenter Ridge Tuff (Rhyolite), Fish Canyon Tuff (Quartz latite), and thin andesite flow. Permeability is strongly anisotropic and is greatest in highly welded tuffs.	Fracture, constant with depth. .	1.0(10^{-3}) - 1.0(10^{-1})
Upper Air-fall/ Water-laid Tuff	Fine-grained, unwelded tuffs.	Intergranular	1.(10^{-8}) - 1.(10^{-5})
Sapinero Mesa Tuff	Rhyolite ash-flow tuff.	Fracture, constant with depth	3.0(10^{-2}) - 4.0(10^{-2})
Lower Air-fall/ Water-laid Tuff	Fine-grained, unwelded tuffs.	Intergranular	1.0(10^{-8}) - 1.0(10^{-5})
Conejos Formation	Rhyolite to basalt (dominantly andesite) flows, flow breccias, air-fall/water laid tuffs, laharic breccias.	Intergranular and fracture, constant at depth.	1.0(10^{-8}) - 3.0(10^{-3})
Tertiary Intrusives	Intermediate to silicic intrusive of early Tertiary age.	Fracture	1.0(10^{-6}) - 1.0(10^{-5})
Basement	Paleozoic sandstones, shales, conglomerates, limestones, all very well indurated, and Precambrian schists, gneisses, and granodiorite intrusives.	Fracture, decreasing with depth	1.0(10^{-6}) - 1.0(10^{-4})

rocks can be highly variable and complex (Table 2), welded ash-flow tuffs and andesites generally have good fracture permeability. Burroughs (1981) also states that the Oligocene volcaniclastics (Conejos Formation) should be the main reservoir rocks in the Monte Vista Graben. This formation does not appear to be present in the Baca Graben. For modeling purposes, the San Luis Basin has subsequently been divided into at least five hydrostratigraphic units (Topper et al., 2003). Only three are important to our discussion. Hydrostratigraphic Unit 1, the unconfined aquifer, Hydrostratigraphic Unit 2, the upper portion of the confined aquifer, and Hydrostratigraphic Unit 3, the uppermost unit of the deep confined aquifer, are the main units that are exploited for water.

Emery et al. (1973) performed aquifer tests and specific-capacity tests and estimated transmissivities for the unconfined aquifer of 2,800 square meters per day (m^2/day) for the western part of the Alamosa Basin north of the Rio Grande to approximately 65 m^2/day near the basin margins. They also estimated transmissivity values from 1,245 m^2/day to 14,940 m^2/day for the confined aquifer. General groundwater movement in the San Luis Valley is from the eastern, western, and northern margins toward the central axis (Fig. 4), with flow in the closed portion of the Alamosa Basin being toward the "ancestral sump" area located to the northeast of the San Luis Hills as described by Bexfield and Anderholm (2010). The northern San Luis Basin was broken down by Huntley (1976) into three hydrogeologic regions: (1) the Sangre de Cristo Range that has low permeability, with high surface water flow rates and low groundwater flow rates, (2) the San Juan Mountain Range which has high permeability with low surface water flow rates and high rates of ground water flow, and (3) the San Luis Valley that has high permeability and high rates of water loss through seepage from streams and evapotranspiration.

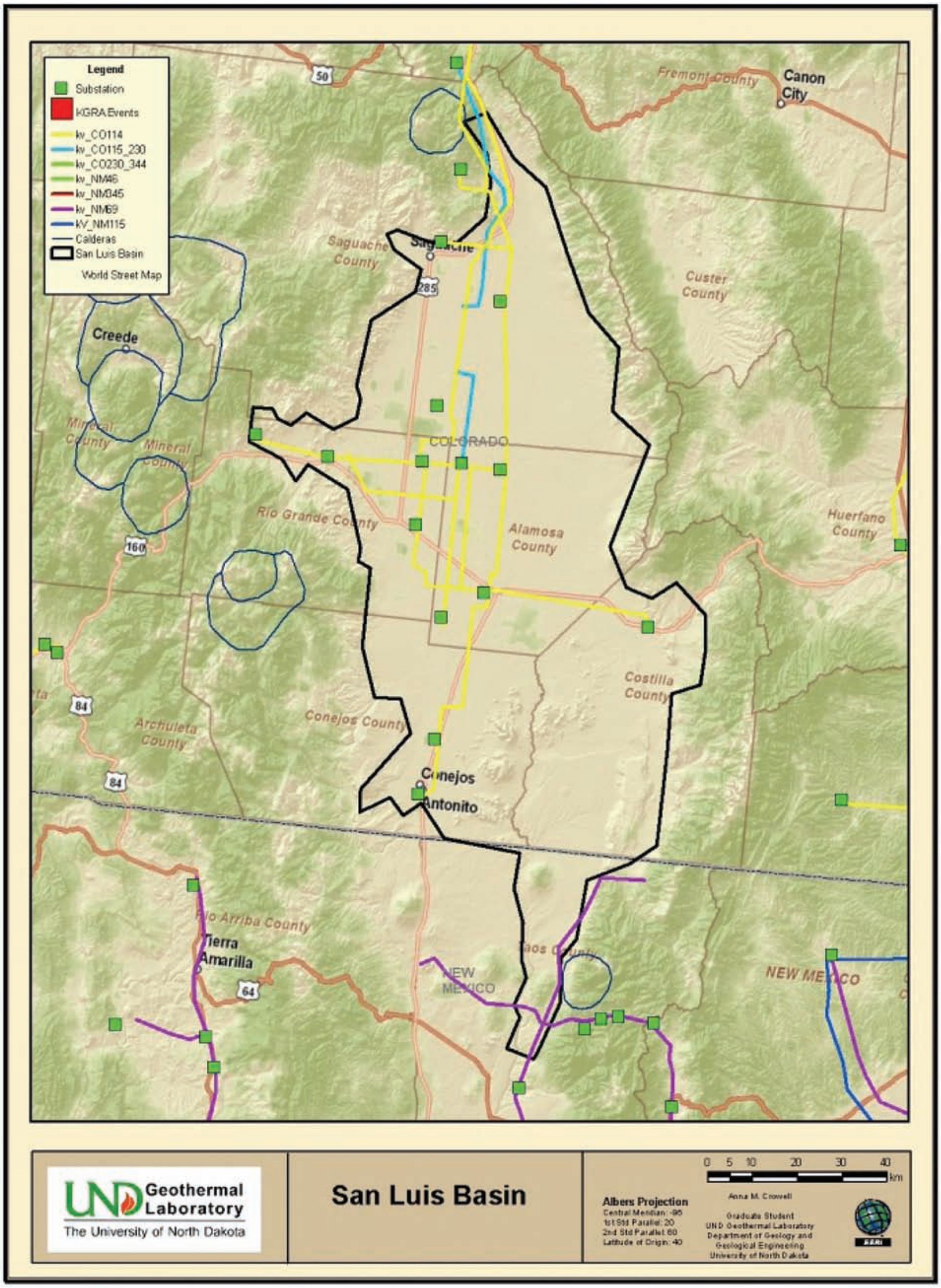

Figure 5. Infrastructure relevant to geothermal power production in the San Luis Basin.

The chemistry of the water in the San Luis Basin is mostly calcium bicarbonate rich, with sodium bicarbonate found in the confined aquifers (Huntley, 1976). Salinity increases considerably as the water migrates from the margins to the center of the valley. The salinity change can be attributed to evapotranspiration (Bexfield and Anderholm, 2010). Reported pH values for the basin range from 7.9 to 8.6.

INFRASTRUCTURE

The San Luis Basin covers part of Taos County in north central New Mexico and parts of Conejos, Costilla, Alamosa, Rio Grande and Saguache counties in south central Colorado. Alamosa is the largest city in the San Luis Basin with a population of 9,000. Two major highways that run through the basin are the north-south U.S. Highway 285 and the east-west U.S. Highway 160. Colorado Highway 17 intersects U.S. Highway 160 at Alamosa and runs north from Alamosa County to Saguache County. In addition, U.S. Highway 285 intersects U.S. Highway 64 near the Embudo constriction in the southern part of the basin. The majority of the basin can be accessed through various state and county roads. Transmission networks in San Luis Basin are primarily concentrated in Alamosa County and Rio Grande County. Most of these lines are less than 115 kilovolts (kV). Originating at northwestern Alamosa County, a 115 - 230 kV transmission line runs through northeastern Saguache County. The southern end of the basin located in Taos County, New Mexico contains several 69 kV transmission networks. Electricity in this area is provided by Kit Carson Electric Cooperative. Electricity around the San Luis Basin in Colorado is provided by San Luis Valley Rural Electric Cooperative and Xcel Energy. Figure 5 shows the basic infrastructure available in San Luis Basin.

ASSESSMENT AND CONCLUSIONS

The simple calculations presented above indicate that the 90°C isotherm is within depth range of 1.0 km to 2.7 km in the San Luis Basin and the 180°C isotherm is in the depth range of approximately 2 to 5.5 km. At these depths, the wells would penetrate Oligocene ash flow tuffs to the Blanco Basin Formation in the Monte Vista Graben, and the Santa Fe Group sediments in the Baca Graben. With the higher geothermal gradient locations, the 180°C temperature would be into the Conejos Formation in the Monte Vista Graben, and the Santa Fe Group sediments in the Baca Graben. For the lower gradients, this temperature would be in Precambrian basement rocks.

The most promising areas for electrical power generation are those with the high geothermal gradients. From the available data these areas are specifically just south of Poncha Pass at the northern end of the San Luis Basin and northeast of the San Luis Hills (the ancestral sump). The latter location is in the Baca Graben with Santa Fe Group sediments. The heterogeneous nature of these sediments may be challenging in terms of finding a large permeable reservoir for power production. On the Monte Vista Graben (west) side, the depths to the 90 and 180°C isotherms would be greater due to lower geothermal gradients, but greater depths may be offset by the Conejos Formation having permeabilities with better geothermal reservoir properties. The paleovalleys on the Alamosa Horst, discussed by Burroughs (1981), may also be filled with permeable sediments and present good targets for geothermal reservoirs.

If sufficient permeability for hydrothermal reservoirs is not found, the shallow depths required to reach temperatures capable of power generation in areas with the high geothermal gradients may make Enhanced Geothermal Systems (EGS) a viable alternative in which permeability is created artificially. Morgan et al. (2010) note that the thick layers of volcanic rocks especially in the Monte Vista Graben may have low permeability and could be candidates for EGS applications for electrical grade geothermal applications.

Direct use applications may be the most practical for the majority of the geothermal resources in San Luis Basin, especially along faulted zones where groundwater is moving towards the surface. A few of the springs and hot water wells are in use, but most are underutilized in terms of their thermal energy content. There is a large untapped energy resource and a good potential for other undiscovered geothermal resource areas without surface expression that might be discovered using geological, geophysical, and geochemical exploration techniques.

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REFERENCES

Barrett, J.K., and R.H. Pearl, 1976, Hydrochemical data of thermal springs and wells in Colorado: Colorado Geological Survey Information Series 6, 124 p.

Barrett, J.K., and R.H. Pearl, 1978, An appraisal of Colorado's geothermal resources: Colorado Geological Survey Bulletin 39, 244 p.

Berkman, F.E., and C.J. Carroll, 2007, Interpretive geothermal heat flow map of Colorado: Colorado Geological Survey, Department of Natural Resources, Denver, Colorado, Map Series 45, Plate 1.

Berkman, F.E., and N.A. Watterson, 2010, Interpretive geothermal gradient map of Colorado: Colorado Geological Survey, Department of Natural Resources, Denver, Colorado, Plate 1 of 3.

Bexfield, L.M. and S.K. Anderholm, 2010, Conceptual understanding and groundwater quality of the basin-fill aquifer in the San Luis Valley, Colorado and New Mexico, *in:* Thiros, S.A., L.M. Bexfield, D.W. Anning and J.M. Huntington, eds., Conceptual understanding and groundwater quality of selected basin-fill aquifers in the Southwestern United States, USGS Professional Paper 1781, Section 10, p. 165-187.

Brister, B.S., and R.R. Gries, 1994, Tertiary stratigraphy and tectonic development of the Alamosa Basin (northern San Luis Basin), Rio Grande Rift, south-central Colorado: Geological Society of America, Special Paper 291, p. 39-58.

Broadhead, R.F., 2008, The natural gas potential of north-central New Mexico: Colfax, Mora and Taos Counties: New Mexico Bureau of Geology and Mineral Resources Open File Report No. 510, 145 p.

Burroughs, R.L., 1981, A summary of the geology of the San Luis Basin, Colorado-New Mexico, with emphasis on the geothermal potential for Monte Vista Graben: Colorado Geological Survey, Special Publication 17, p. 30.

Burroughs, R.L., and D.H. McFadden, 1976, Some hydrogeologic problems in the San Luis Basin, Colorado-New Mexico, *in:* Epis, R.C., and R.J. Weimer, eds., Studies in Colorado Field Geology, Colorado School of Mines, Golden, CO. p. 544-549.

Coe, B., 1980, Geothermal energy potential in the San Luis Valley, Colorado: U.S. DOE report DOE/ID/12018-4, 44 p.

Emery, P.A., R.J. Snipes, J.M. Dymeyer, and J.M. Klein, 1973, Water in the San Luis Valley, south-central Colorado: Colorado Water Conservation Board, Circular no. 18, 26 p.

Huntley, D., 1976, Hydrogeology of Northern San Luis Valley, CO, *in*: Epis, R.C., and R.J. Weimer, eds., Studies in Colorado field geology, Colorado School of Mines, Golden, CO. p. 539-543.

Morgan, P., P. Barkmann, C. Kluth, and M. Sares, 2010, Prospects for Electricity Generation in the San Luis Basin, Colorado, USA, Geothermal Resources Council, *Transactions*, v. 34, p. 615-620.

Peterson C. and M. Roy, 2005, Gravity and flexure models of the San Luis, Albuquerque, and Tularosa basins in the Rio Grande Rift, New Mexico and Southern Colorado: New Mexico Geological Society, 56th Field Conference Guidebook, Geology of the Chama Basin, p. 105-114.

Summers, W.K., 1965, A preliminary report on New Mexico's thermal waters, New Mexico Bureau of Mines and Mineral Resources Circular 80, 41 p.

Topper, R., K. L. Spray, W. H. Bellis, J. L. Hamilton, and P. E. Barkmann, 2003, San Luis Valley and Rio Grande Basin, Chapter 7.1, *in* Ground Water Atlas of Colorado, Colorado Geological Survey Special Publication 53, p. 157-168.

Upson, J.E., 1939, Physiographic subdivisions of the San Luis Valley southern Colorado, Journal of Geology, v. 47, p. 721-589.

Western Regional Climate Center, 2011, Climatological Data Summaries, http://www.wrcc.dri.edu/climsum.html, (last accessed 2011).

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Mark McDonald is a member of the University of North Dakota Geothermal Laboratory, and is currently pursuing a Doctoral Degree in Geology. He earned a Bachelor of Science in Geological Engineering and a Master of Science in Geology, both from the University of North Dakota. Current geothermal research includes evaluating the technical and economic feasibility of producing electricity from binary power plants from geothermal fluids in the Williston Basin, and the analysis, filtering and interpretation of gravity measurements to aid in identifying potential targets for the installation of geothermal production wells at the Rye Patch, Nevada geothermal field.

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Samir Dahal is currently pursuing a Doctoral Degree in Electrical Engineering from the University of North Dakota. He earned his Bachelor of Science degree in Electrical Engineering from Polytechnic Institute of New York University in 2009. As a member of the University of North Dakota Geothermal Laboratory, he has been working on designing an electrical interface between geothermal power plants and the existing electric grid. His research interests include optimizing the placement of distributed generation in the distribution network, optimizing proton exchange membrane (PEM) fuel cell operations, and determining the best interconnection scheme that allows for the safe and efficient operation of the geothermal power plants and local distribution networks.

Anna M. Crowell

Anna M. Crowell is a graduate student at The University of North Dakota, focusing on the use of GIS to enhance the understanding and identification of geothermal resources. She earned her undergraduate degrees in Management and Computer Information Systems from Park University in 2002, and earned her Master of Science degree from the University of North Dakota in 2011. Current research interests include: continental heat flow, bottom-hole temperature corrections, estimating geothermal energy reserves in sedimentary basins, identifying sites for geothermal power plants in oil fields using coproduced fluids, and working on a characterization of the geothermal potential for the Rio Grande Rift.

Angelle van Oploo

Angelle van Oploo is currently part of the University of North Dakota Geothermal Laboratory. She is obtaining her Bachelor of Science degree in geology from the University of North Dakota, with an anticipated graduation date of May 2012. Upon graduation, she plans to continue her education and pursue a Master's degree in geophysics, specializing in the field of seismology. Her overall career goals are to receive a PhD in geophysics and to become a professor teaching at a university.