Hydrogeology of Clayton Valley Brine Deposits, Esmeralda County, Nevada

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Abstract

This paper seeks to define the geology and character of the aquifers in the Clayton Valley brine field, Esmeralda County, Nevada. Six aquifers are recognized in this closed basin playa in west-central Nevada. These are the sources of the lithium reserves and resources of Chemetall Foote Corporation, Silver Peak Operations, Nevada. Lithium-rich brine resides in confined to semi-confined hydrologic units within the playa region.

Several hundred exploration borings as deep as 2,000 feet have been drilled since 1964 seeking brine for production purposes. Approximately 200 production wells over the years have supplied brine to an extensive pond system for the purpose of concentrating the brine by solar evaporation.

Clayton Valley is a graben structure that has enhanced the accumulation of pluvial and interpluvial sediments, the precipitation of evaporites, and accumulation of lithium bearing brine. Extensive faulting has created hydrologic barriers as demonstrated by brine and water samples taken from boreholes on either side of these faults. Basin depth has been determined from geophysical surveys to be several thousand feet.

Seismic and gravity surveys reveal numerous horst and graben features in a gently synclinal, deepening basin to the east-southeast. In the southern and western sections of the playa, downdrop and thickening of the basin-filling sediments is not as pronounced as in the northeast. Each of these areas has its own unique characteristics and is tapped for production.

Introduction

Lithium brine is extracted from aquifers within the closed basin of Clayton Valley, located in the west central region of Nevada, approximately 50 miles east of the Sierra Nevada, within the Basin and Range province (fig. 1). Interest in potassium minerals led Leprechaun Mining and Chemical Inc., to many playas of the western United States. Chemical analysis of Clayton Valley sediments revealed abnormally high lithium, potassium, and sodium chloride concentrations. In 1964, Foote Mineral Company acquired the mining rights and began in earnest the development of the playa system for the express purpose of producing lithium carbonate from brine. Production from the carbonate plant began in 1966. Initially, only a few production wells were constructed in the west central region of the playa. Target production was from a marker aquifer soon to be known as the Main Ash Aquifer. This aquifer, which occurs throughout the playa, has been the largest and most productive horizon.

Production wells currently tap six aquifer systems that yield brine to various evaporation ponds. Upgrading of brine salinity occurs over a 12 to 18 month period. Twenty active evaporation ponds make up 4,150 acres of surface area and hold up to several billion gallons of brine (figs. 2 and 3). Annual brine evaporation is 35 inches compared to freshwater evaporation of 56 inches with an average rainfall of 4 to 5 inches and a temperature range from 2 to 108ºF. Currently, 50 wells are producing brine from all of the aquifers at rates from 30 to 325 gallons per minute (gpm). Depths of production wells vary from 230 feet to 1,160 feet with future plans to complete wells to 1,650 feet.

The playa represents an area of approximately 25 square miles at an elevation of about 4,270 feet above the level of the sea. The surface sediments are characterized by salts, clays, and silts, changing to sands and gravels and boulders towards the periphery of the playa.

Regional Hydrogeologic Setting

Basin and Range topography is represented in this western Nevada valley as a basin that is closed topographically and does not exhibit typical northeast-southwest linear horst and graben valleys seen in much of the rest of the state. The Angel Island and Paymaster Canyon high angle, normal faults act as hydrologic barriers along the southeastern playa edge near Angel Island. The Angel Island fault intersects the Cross Central normal fault (fig. 1).

Stratigraphic impediments occur around much of the rest of the playa, isolating it from significant freshwater recharge and dilution. Groundwater flow barriers have created the ideal environment for the accumulation of the brine reserves being mined today. Basin sediments accumulated in a low energy lacustrine environment where evaporation and precipitation ratios controlled the deposition of either significant amounts of saline minerals or of detrital sediments. Increases in TDS (total dissolved solids) generally correlate to increase in lithium values. Hydrologic recharge in the form of underflow into the basin is occurring from the northwest, where physiographic highs surrounding the basin are at their lowest, and minor dilution troughs are known to exist. Recharge may also be entering through Paymaster Canyon. Recharge to the confined and leaky confined aquifers that comprise this valley may be partially sustained by percolation along range-front faults, growth faults, fault creep zones, and associated paths of deep percolation. Brine temperatures typically do not exceed 80ºF. Basin deepening in the northeastern playa sector is illustrated in numerous borings through marker beds, particularly the Main Ash Aquifer, which strikes along a northeast-southwest trend and dips approximately 30º to the southeast (fig. 4).

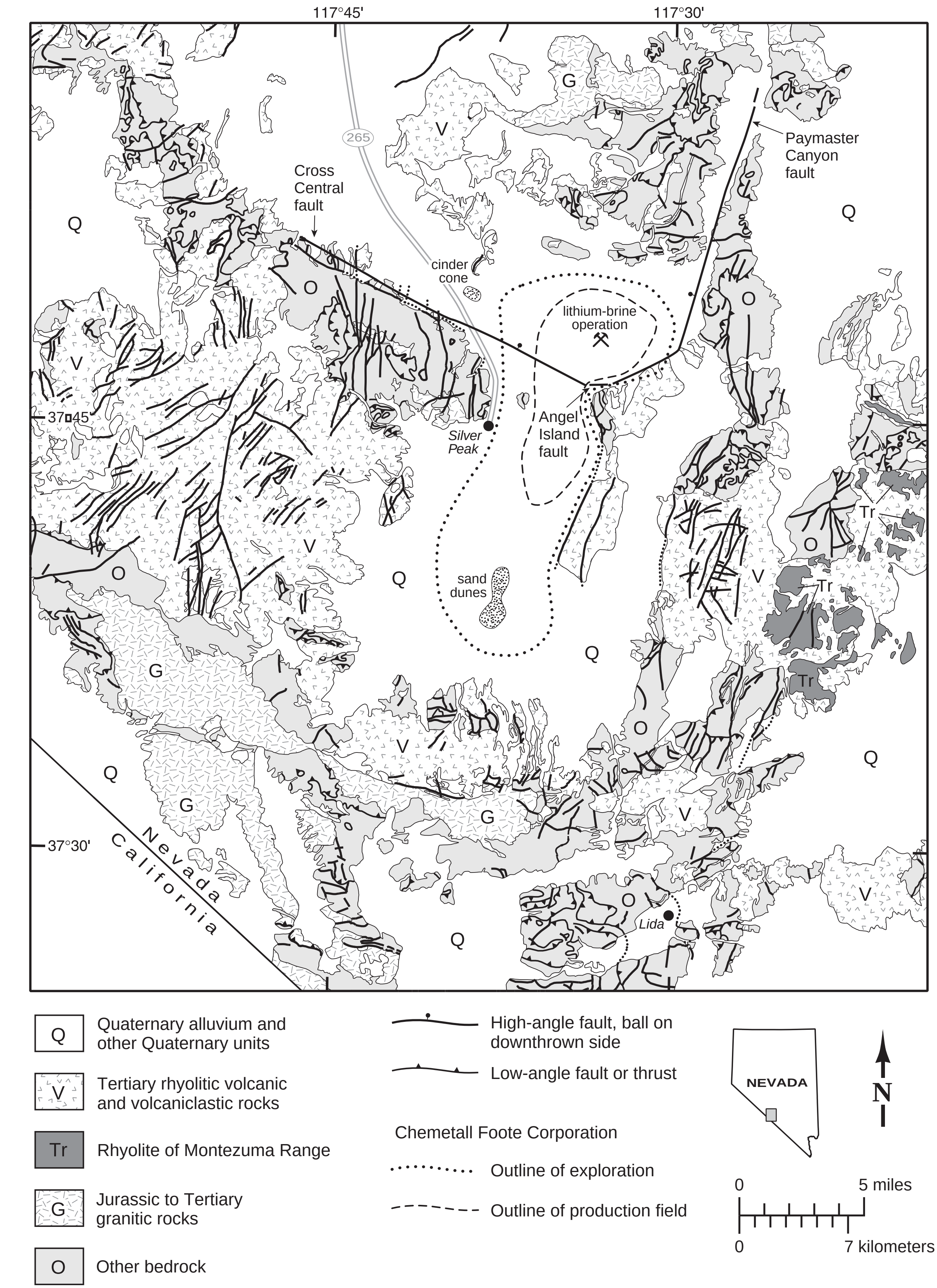

Figure 1. Generalized geology in the Clayton Valley area (modified from Price and others, 2000, and Albers and Stewart, 1972).

Figure 2. Aerial photograph of evaporation ponds at Silver Peak in Clayton Valley. The nearly square pond just north of center is about 1 mile square.

Figure 3. Chemetall Foote pond with salt and carbonate precipitates. Quaternary cinder cone in distance along State Route 265 (photo by J.G. Price, 1995).

Two aquifers, the Main Ash and Lower Aquifer System, are largely composed of air-fall and reworked volcanic ash, which serve as reservoirs for the brine but not as the primary source of lithium. Lithium supply source is probably from lithium-rich rhyolitic tuff on the eastern margin of the basin (fig. 1; Kunasz, 1974; Price and others, 2000) and possibly from deep-seated geothermal water flow that may have conducted lithium-rich water from the magma chamber source for the tuff. Basin filling sediments are largely illite, smectite, and kaolinite clays in order of predominance (Kunasz, 1970), with lenses of silt, sand, and gravel deposited during pluvial and interpluvial events. Ash beds of varying continuity are interlayered with these detrital sediments (fig. 4) as well as chemical sediments such as gypsum, calcium carbonate, and halite. In addition to the two ash aquifers, other aquifers are in beds dominated by tufa, gravel, salt, and silt grading to sand and gravel.

Aquifers

The presence of six aquifers is revealed by data accumulated over the past 39 years from exploration holes, production wells, geochemical analysis, pumping tests, and seismic, gravity, and magnetic surveys (fig. 4):

- Lower Gravel Aquifer (fig. 5)
- Lower Aquifer System (figs. 5 and 6)
- Main Ash Aquifer (figs. 5, 6, and 7)
- Marginal Gravel Aquifer (fig. 5)
- Tufa Aquifer (fig. 5)
- Salt Aquifer System (fig. 5)

Pumping tests and records from continuous production pumping have shown evidence for conductivity between certain aquifer systems. Brine salinity in production wells varies from 40,000 to 170,000 mg/L TDS with corresponding specific gravity varying from 1.025 to 1.21. Lithium values well in excess of 400 ppm have been pumped from the basin (Papke, 1976; Vine, 1980). Kunasz (1970) and Davis and others (1986) report economic grades in the range of 230 to 300 ppm. Recharge to the aquifers is at a lesser rate than depletion by approximately a one-to-two margin. Declines in lithium values are caused by fresh water recharge and can be correlated to specific pathways of dilution by frequent brine analysis over the entire well field. The magnesium/lithium ratio is relatively low, facilitating the economic separation of the magnesium before final processing.

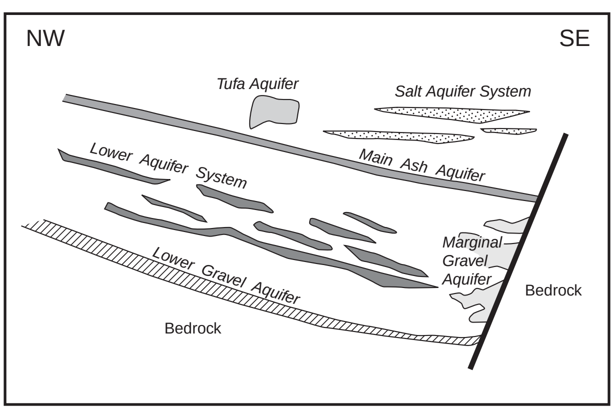

Figure 4. Schematic cross section of aquifers in Clayton Valley along the dip of the basin.

Seismic surveys (figs. 8 and 9) indicate that basin downdrop is on the order of 4,000 feet, creating a structural depression for the accumulation of infilling sediments and brine. Confined to semi-confined aquifers are defined by their artesian characteristics, with levels rising from tens of feet to approximately 200 feet above the top of aquifers. Static brine levels range from 70 to 400 feet below the surface of the playa. The unsaturated zone consists largely of clay, silt, and sand with local halite and gypsum interbeds. Vertical fluid migration within the playa is generally considered to be negligible due to the thickness of the clay sediments of very low hydraulic conductivity. However, geophysical surveys suggest interbasin faults may exist, creating potential pathways for limited vertical migration of fluids. Aquifers are discussed below in order of formation during the evolution of the basin as is currently known.

Geophysical work and exploratory borings have defined the bedrock and lacustrine sediment contact as well as aquifer locations in the Clayton Valley. Drill-hole data have identified the Lower Gravel Aquifer (LGA), which consists of gravel with sand and silt matrix interlayered with local clean gravel. Gravel clasts are of limestone, dolomite, marble, pumice fragments, siltstone, and sandstone. The LGA has high transmissivity estimated from airlift volumes and production rates and has lithium concentrations sufficient to enhance ore reserves significantly if developed further. Currently, one partially penetrating well is producing from the LGA at a rate of 300 gallons per minute. The LGA is shown to thicken to the north-northeast, the deepest part of the basin (fig. 5). Known thickness varies from 25 to over 350 feet. Brine migration down dip may yield higher specific gravity fluids deeper in the basin due to brine density differential. The LGA has not been drilled in the deepest area of the basin.

Above the LGA are the Lower Aquifer System (LAS) ash beds, which are moderately continuous throughout the playa north of the Cross Central fault (figs. 1 and 5). Individual ash beds occur in localized to areally extensive units. Brine from this system is typically high in lithium concentration and contains about 160,000 TDS. The LAS ranges from approximately 350 to 1,100 feet below ground surface, and is below the Main Ash Aquifer marker bed (figs. 4 and 6). Permeability is limited due to narrow lenses of ash of lesser depositional continuity. An inferred origin for some of the thinner lenses of the LAS may be as pluvial events carrying reworked ash, possibly from peripheral highland areas into the lake environment. Alluviation of ash from a single event of ash deposition in the highlands over the extended time suggested by the thick host sequence is unlikely. Therefore, the ash beds probably represent multiple eruptions. Basin subsidence coincided with pluvial deposition over several hundred vertical feet north of the

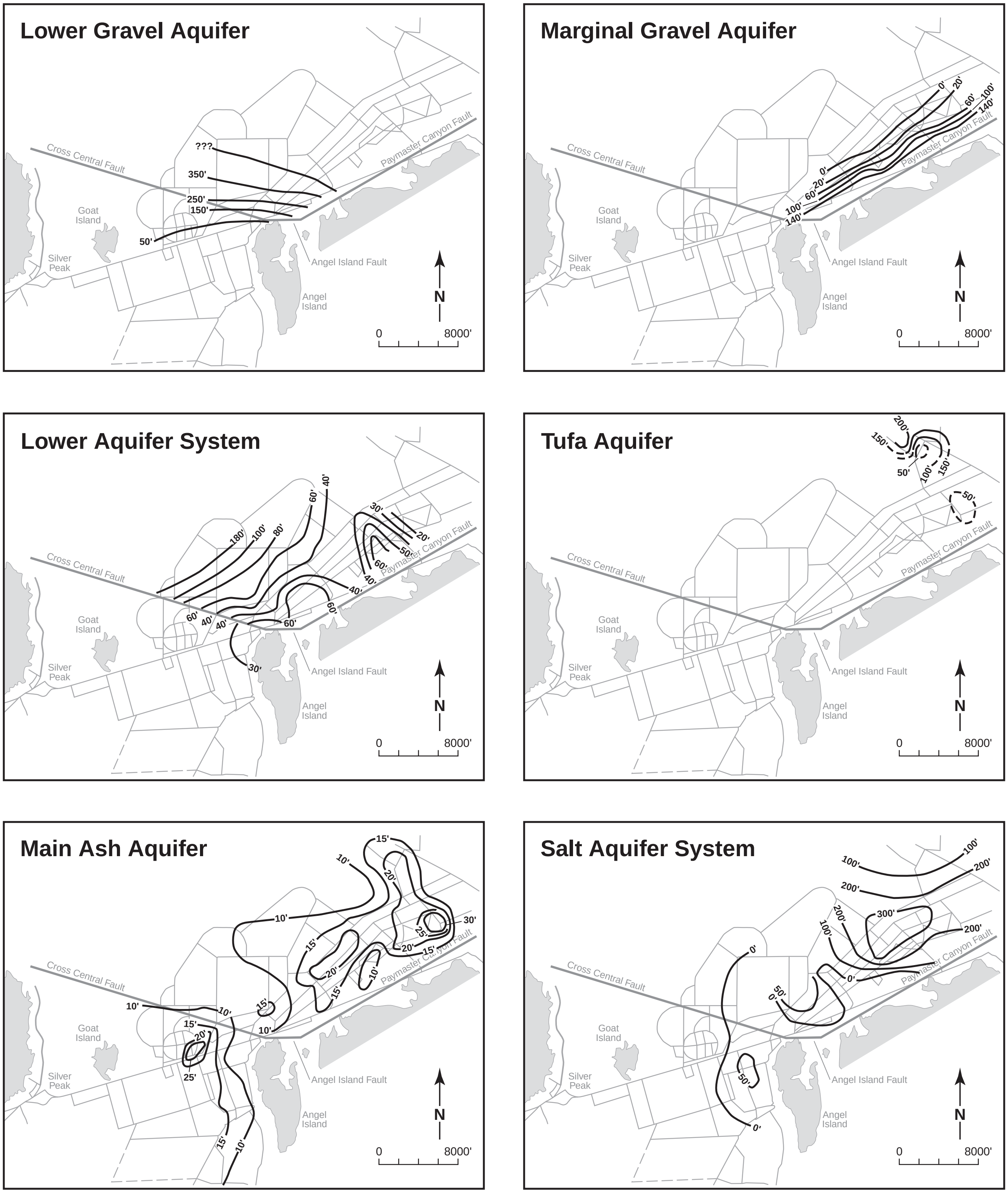

Figure 5. Isopachs of the Lower Gravel Aquifer, Lower Aquifer System, Main Ash Aquifer, Marginal Gravel Aquifer, Tufa Aquifer, and Salt Aquifer System (thickness in feet, superimposed on outlines of brine ponds and pertinent fault systems).

Cross Central fault. With the exception of a small area near Angel Island (fig. 5), the LAS is not present south of this fault, indicating non deposition or subsequent erosion there, and relatively rapid sedimentation north of the fault. Isolithium values in this aquifer system (fig. 10) suggest that the intersection of the Cross Central and Angel Island faults somehow controlled lithium concentration in the aquifer.

Production began in 1966 from the Main Ash Aquifer (MAA), which varies in thickness from 5 to 30 feet (fig. 5). Thicker sequences of ash coincide reasonably well with interbasin depressions also indicated by the overlying Salt Aquifer System (SAS) (fig. 5). Particles in the ash range in size from submicroscopic to welded fragments of several inches or more. Depth to the MAA ranges from 200 feet in the southwest to over 750 feet in the northeastern playa, where downdropping of the hanging wall, or bedrock, has exceeded that of the southwestern playa. Sedimentation in the east likely exceeded that to the west as indicated by the thickening of clay units eastward as detected by gravity and seismic geophysical analysis. Continuity of the MAA throughout the northeastern area of the Clayton Valley playa makes it an excellent marker bed. This aquifer is

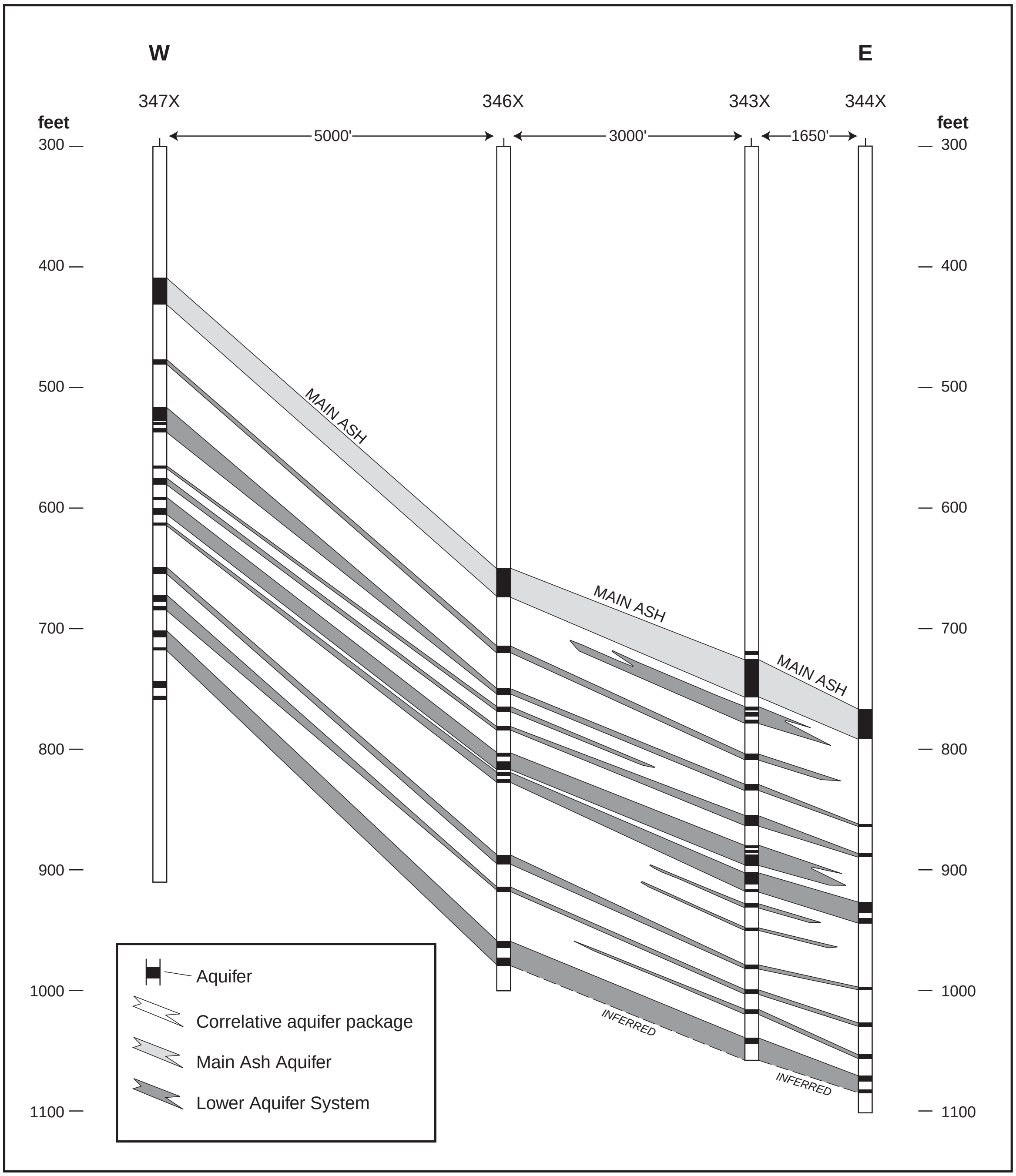

Figure 6. Generalized cross section of the Main Ash and Lower Aquifer System, looking north (depths in feet below the playa surface, modified from a figure drafted by M.W. Hardy, 1993).

characterized by moderate transmissivity and yields. Salinity currently ranges from 80,000 to 95,000 TDS.

The Long Valley caldera eruption and ash coverage from the Bishop Tuff 760,000 years before present is well documented (fig. 11). No other Quaternary eruption of great volume is known to have occurred nearby. Smaller events at Lassen Peak/Brokeoff Mountain 400,000 years before present and Mt. Mazama (Crater Lake) approximately 6,800 years before present are less likely to have deposited as much ash in Clayton Valley; however, the possibility remains. Assuming that the Bishop Tuff is the most plausible source of the MAA, sedimentation in the western playa is estimated at 0.003 inches per year. Thicknesses in the eastern playa suggest a sedimentation rate of as much as 0.012 inches per year.

Marginal Gravel Aquifer (MGA) wells have been exploited over the past 22 years to supplement production with high volume, low salinity brine (40,000 TDS) from the silt, sand and gravel of the linear growth-fault system bordering the playa known as the Angel Island and Paymaster Canyon Fault system (fig. 5). It is along this east-northeast-trending fault system that the majority of basin drop and displacement has occurred. The gravels were presumably eroded from the bedrock in the footwall of the fault and shed down onto the hanging-wall. This growth-fault material and contained brine along the playa side of the fault system is partly constrained by the gravel-playa clay interface. Drill holes to the southeast of this fault zone and up slope contain large volumes of fresh water. Therefore, it is believed that this fault system serves as a major hydrologic barrier that effectively preserves the integrity of the brine field from dilution.

The Tufa Aquifer (TA) is in the northwest sector of the playa. Limited production and exploration holes suggest a ring-like tufa or travertine formation that thickens towards its outside edges (fig. 5). Whether submarine vents seeping fluid into the ancient lake or surficial hot spring terraces composed of $CaCO_3$ formed these features has yet to be determined with certainty. The TA has a moderate to high yield potential. Production from this small, localized aquifer is at moderate rates, with relatively low salinity (40,000 TDS). Historical values have been on the order of 100,000 TDS, suggesting that brine extraction is enhancing fresh water migration into the region from the north-northwest and possibly from Paymaster Canyon to the northeast. Pumping tests and production data have shown hydraulic connection with the Main Ash Aquifer.

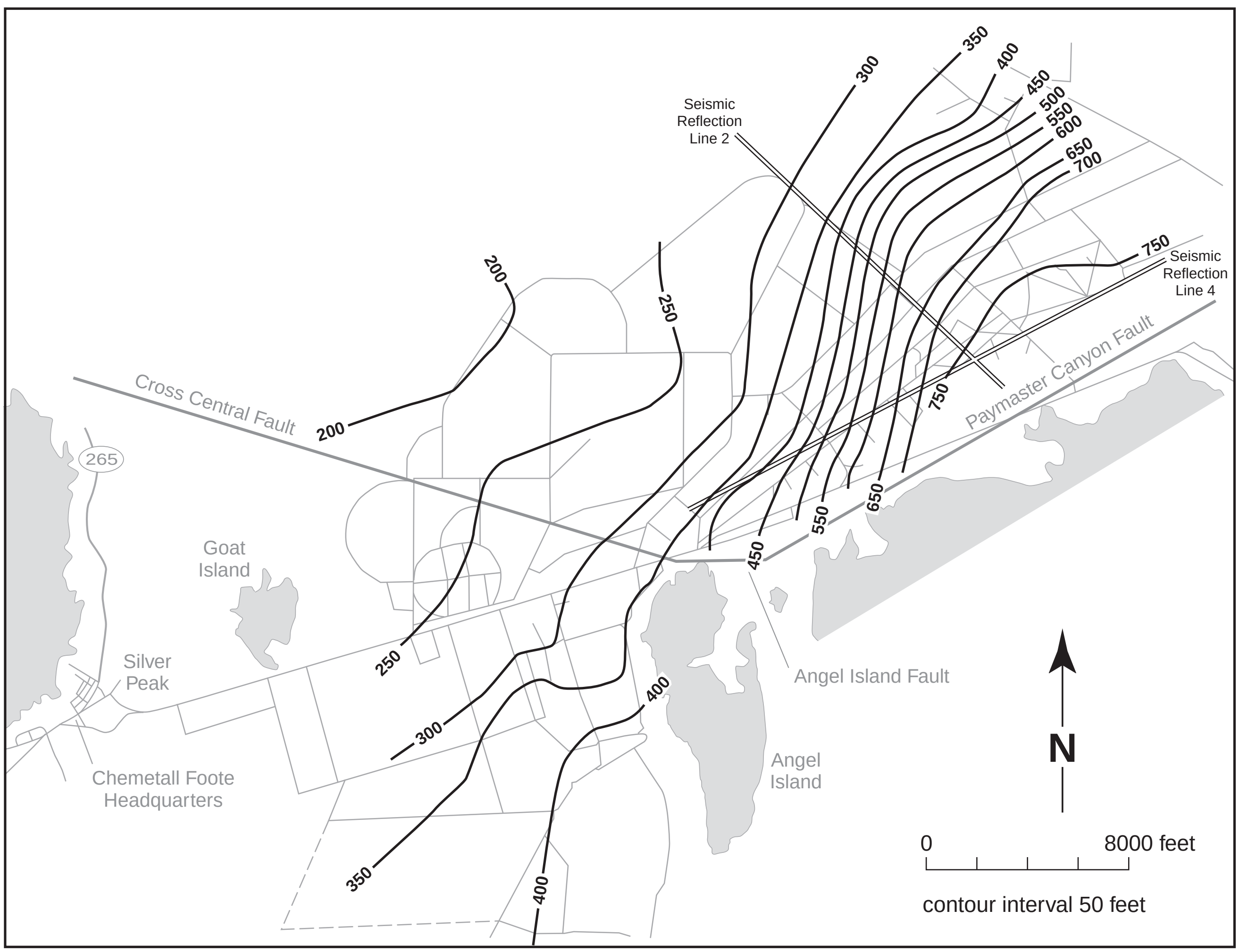

Figure 7. Structural contours of the top of the Main Ash Aquifer (depth in feet below the playa surface).

In the northeast playa, the aerial extent of the Salt Aquifer System (SAS) is somewhat continuous in its occurrence (fig. 5). Vertically, lenses of salt vary from fractions of an inch to approximately 70 feet in thickness with interbeds dominantly of clay, some silt and sand, and minor amounts of gypsum, ash, and organic matter. In addition they contain some caverns. Salt was likely precipitated in lowland standing water by the concentration of minerals through evaporation during contemporaneous subsidence of the basin. Typically less than 600 feet in depth, the SAS provides moderate to high-grade lithium brine at moderate yield rates. Transmissivity varies with depth; deeper salt beds are more compact and less yielding than upper lenses. The moderate pumping levels and the relatively high lithium concentrations make this a viable, economic, and intriguing aquifer.

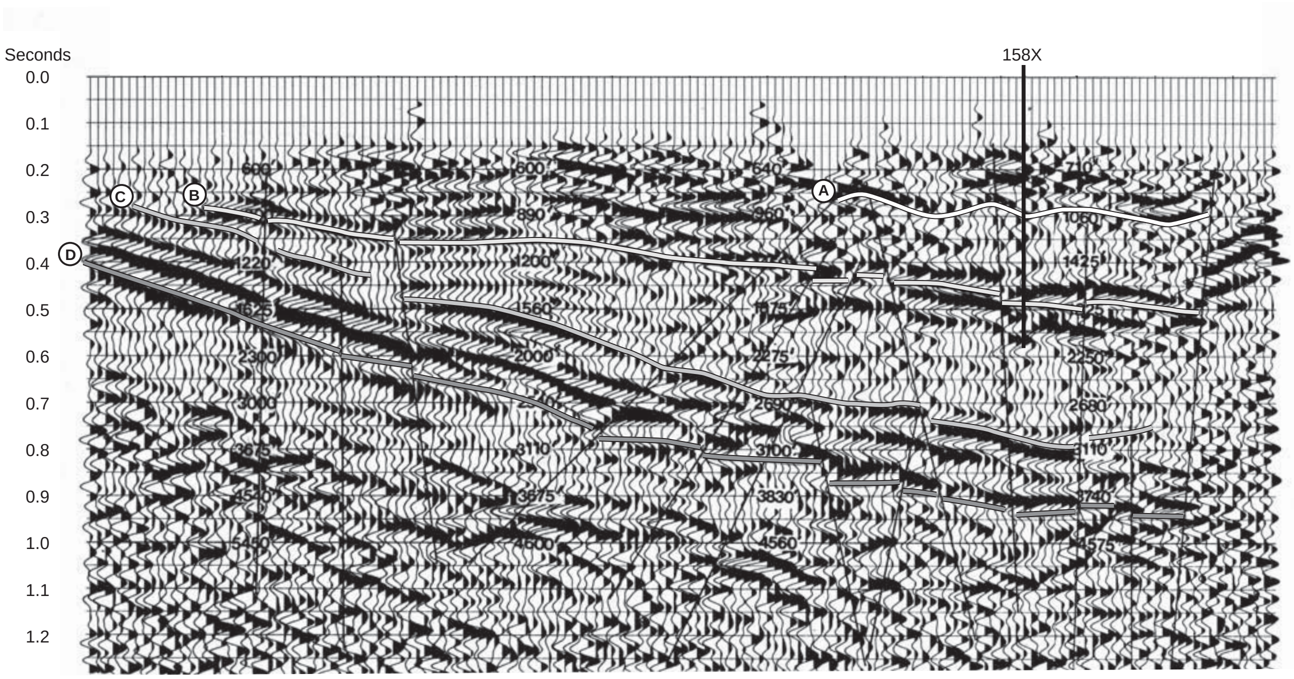

Figure 8. Seismic line 2, looking northeast, potentially identifies aquifers in cross section along basin dip (interpreted depths in feet).

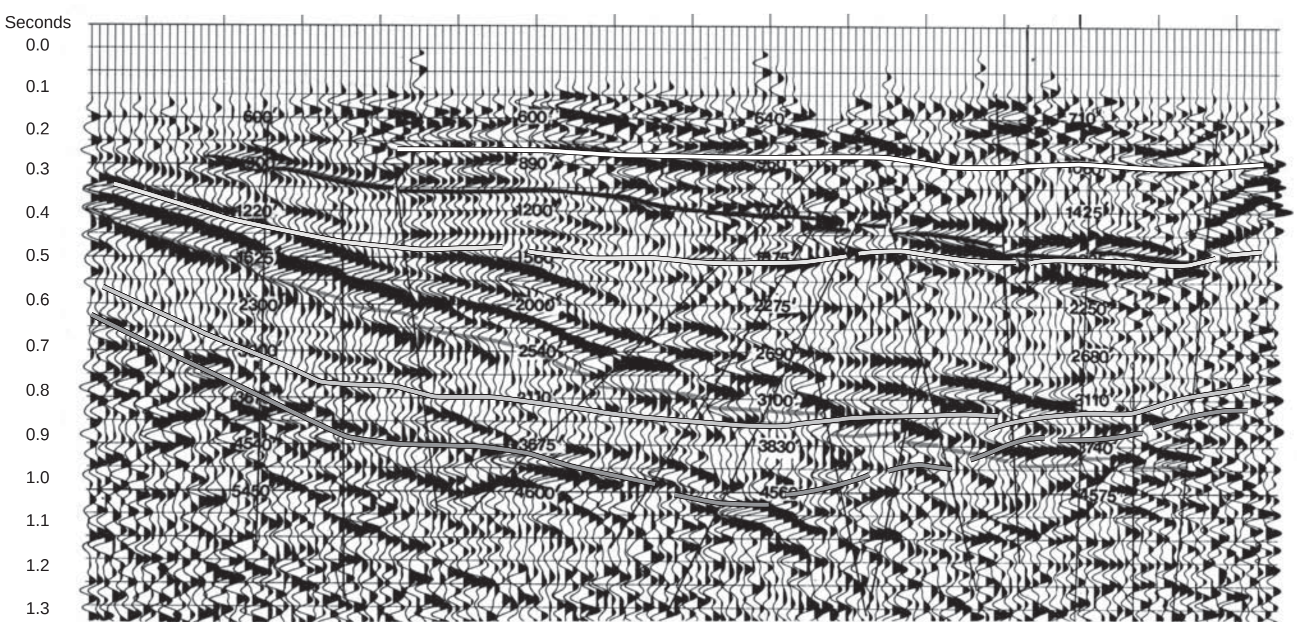

Figure 9. Seismic line 4, looking northwest, potentially identifies aquifers along the general strike of the basin lithology, and suggests a gently asymmetrical character. Interpreted depths in feet.

Summary

Lithium brine at Clayton Valley resides within six economic yet potentially interconnected aquifer systems. The aquifers were created through structural and stratigraphic controls, which were significant in both isolating higher grade brine and in the creation of aquitards within individual and collective aquifer systems. Some aquifers, such as the LAS, are relatively isolated, with production wells showing no interference on neighboring wells drilled into adjoining aquifers. In other systems, such as the TA and MAA, pumping data that indicate interference suggest a connection. In a low-energy lacustrine environment, few sedimentary layers may be sufficiently porous for use as aquifers; however, Clayton Valley has numerous ash layers or lenses that act as ore-bearing aquifers (MAA and LAS) along with chemical sediments (SAS and TA).

Production from all six of the aquifers continues on a regular, full-time basis. Shallow aquifers (SAS) have a high-grade, moderate production rate with a low cost per pound ratio. Deeper aquifers such as the LGA or the peripheral MGA are of lesser grade and cost more to produce, but their high volumes help to sustain production from the pond system. Depletion of the aquifers through production exceeds recharge by a factor of 2. Specific dilution pathways cause a progressive decline in lithium concentration. Proper management of the well field demands close attention to changes due to pumping from such a complex system.

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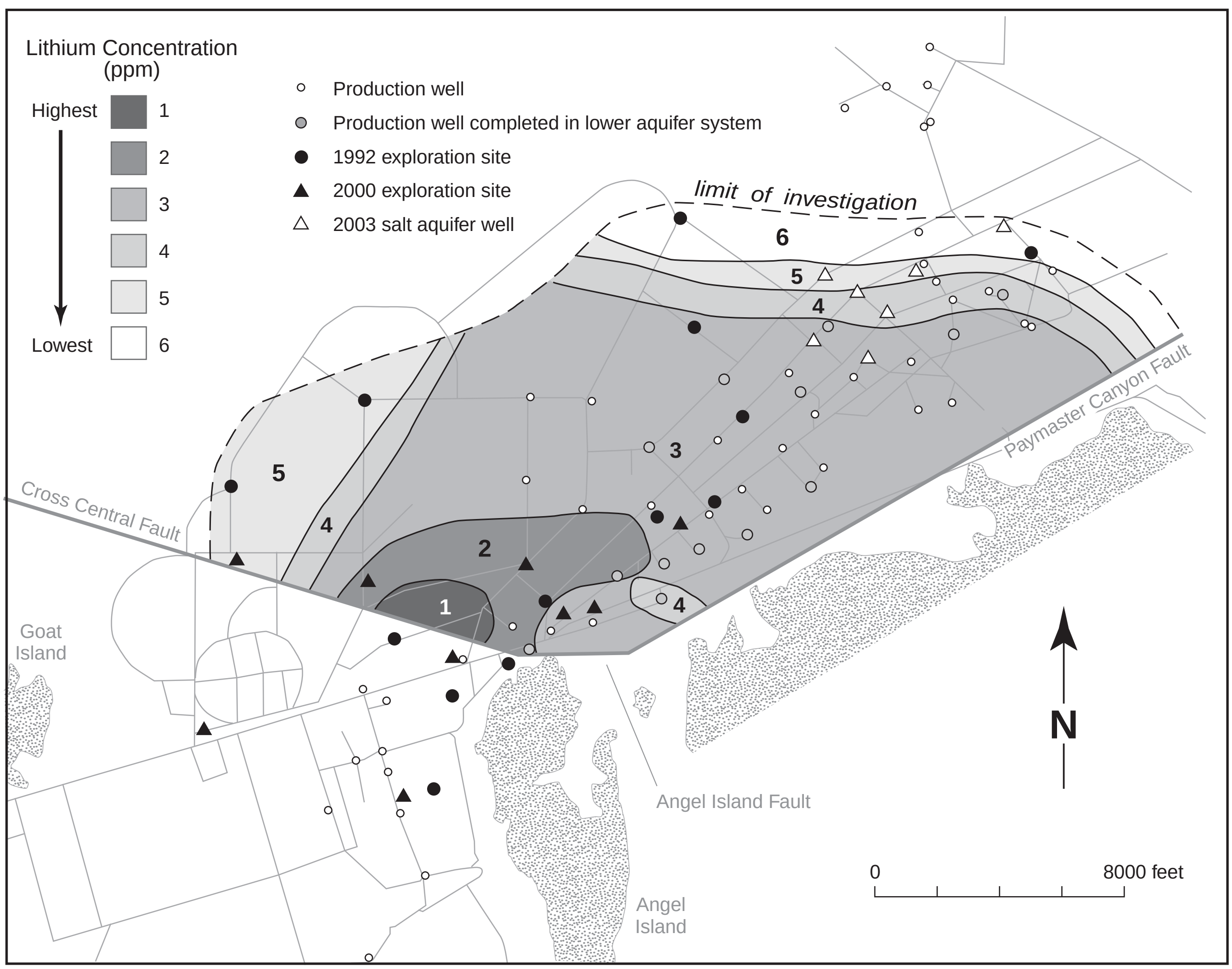

Figure 10. Isolithium map of the Lower Aquifer System (modified from a figure drafted by M.W. Hardy, 1993).

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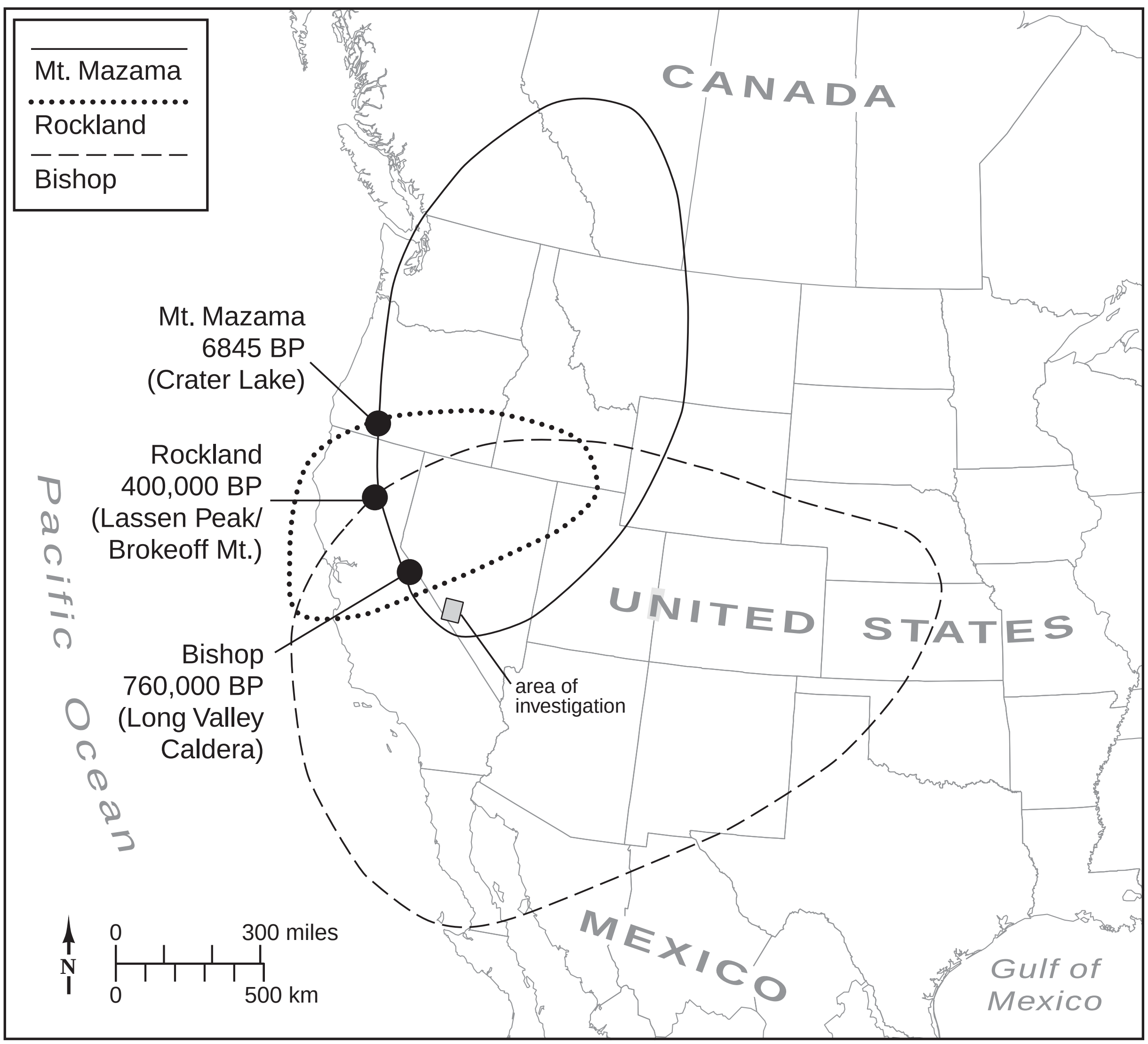

Figure 11. Possible sources of ash aquifer materials comprising the Main Ash Aquifer and Lower Aquifer System.