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THE STATE AGENCY FOR GEOLOGIC INFORMATION

### MISSION

*To inform and advise the public about the geologic character of Arizona in order to increase understanding and encourage prudent development of the State's land, water, mineral, and energy resources.*

### ACTIVITIES

**PUBLIC INFORMATION**
*Inform the public by answering inquiries, preparing and selling maps and reports, maintaining a library, databases, and a website, giving talks, and leading fieldtrips.*

**GEOLOGIC MAPPING**
*Map and describe the origin and character of rock units and their weathering products.*

**HAZARDS AND LIMITATIONS**
*Investigate geologic hazards and limitations such as earthquakes, land subsidence, flooding, and rock solution that may affect the health and welfare of the public or impact land and resource management.*

**ENERGY AND MINERAL RESOURCES**
*Describe the origin, distribution, and character of metallic, nonmetallic, and energy resources and identify areas that have potential for future discoveries.*

**OIL AND GAS CONSERVATION COMMISSION**
*Assist in carrying out the rules, orders, and policies established by the Commission, which regulates the drilling for and production of oil, gas, helium, carbon dioxide, and geothermal resources.*

# DRILL HOLES IN THE LUKE SALT BODY PENETRATE UNDERLYING FAULT

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The logo of the Arizona Geological Survey includes a small geologic map that shows Arizona divided into three regions. The northeast region is the Colorado Plateau, a land of flat-lying to gently inclined, layered sedimentary rocks such as seen in the walls of the Grand Canyon, and of young volcanic rocks like those seen around Flagstaff and between Show Low and Springerville. The southwest region is the Basin and Range province, an area of numerous small mountain ranges separated by flat to gently sloping valley floors that are typically underlain by thick deposits of sand and gravel. Phoenix and Tucson are within the Basin and Range province. Between the two regions is the Transition Zone, a northwest-trending region that has some similarities to the other two but is distinctive in having widespread exposures of very old bedrock.

The Basin and Range province obtained its distinctive topography largely between about 30 and 10 million years ago when the Earth's crust broke apart into numerous fault blocks and extended in a northeast-southwest direction. The faults that slipped during this period of crustal extension dip into the earth at moderate to gentle angles. Where such faults are presently active in southwestern North America, for example along the Wasatch front near Salt Lake City and along the east side of the Sierra Nevada, they are usually found at the foot of each mountain range where faults of this type dip under the adjacent basin. The rocks below the dipping fault ramp are displaced upward to uplift the mountain ranges, while rocks above the fault ramp are displaced downward to make the basins. This type of fault is called a "normal" fault. The Pitaicachi fault in Sonora, south of Douglas, for example, is an active normal fault that produced a magnitude 7.2 earthquake in 1887 (DuBois and Smith, 1980).

Most of Arizona's normal faults have been inactive for so long that they are buried and can only be inferred based on indirect geologic evidence. So it is always interesting to geologists when someone drills a hole that penetrates one of these faults, especially when it appears to be a large fault (Figure 1). It is even more interesting when several drill holes penetrate a buried fault because the dip of the fault can then be determined from the fault depths in the different drill holes. Such a discovery happened recently west of Phoenix.

Between downtown Phoenix and the White Tank Mountains to the west is a broad, flat area that is crossed by the Agua Fria River and includes west Phoenix, Luke Air Force Base, and the communities of Glendale, Peoria, and Litchfield Park. Beneath this region is a deep sedimentary basin called the Luke basin that contains an enormous body of salt (Figure 2). The extent and geometry of this salt body is only approximately known, but it is thought to underlie at least 100 km$^2$ (40 mi$^2$) with an average thickness of perhaps a kilometer (0.6 mi). The geologic age of the salt is probably younger than about 15

**Figure 1.** SunCor #1-2 drill rig located over the central area of the Luke salt body, February 2001.

Of the four wells drilled, the one near the center of the basin penetrated 263 m of fine grained sediments (mostly sand and silt) underlain by 1300 m of salt, and did not reach the bottom of the salt body (Figure 3). Three other holes on the western margin of the salt body penetrated hundreds of meters of salt, clay, silt, and minor anhydrite and then passed abruptly into metamorphic rocks without passing through sand and gravel. (Anhydrite is calcium sulfate [$CaSO_4$], which is similar to gypsum [$CaSO_4 \cdot 2H_2O$] and is also formed by evaporation of lake waters). The underlying metamorphic rocks are severely altered, with no biotite or hornblende (both common black minerals containing iron and magnesium) present for a distance of more than 80 to 100 m below the top of the bedrock, but much chlorite had replaced the dark minerals. In one of the wells, the bedrock was cored over about 3 m, and the cored sample looks identical (Figure 4) to the chlorite-altered, crushed but cemented rock that is seen below large-displacement, gently dipping normal faults known as detachment faults (e.g., Reynolds, 1985).

Because of the abruptness of the boundary between salt and bedrock, and because of the crushed and altered state of the bedrock directly beneath the boundary, the boundary is interpreted as a fault. And because it places unmetamorphosed sediments over metamorphosed bedrock, the fault is interpreted as a normal fault. The depth to the fault in the different wells indicates that, if the fault is planar, it dips 12° toward N64°E, and so is a gently dipping normal fault (Figure 3). The chloritic breccia below the fault is characteristic of normal fault zones that have accommodated at least 10-15 km (6-10 miles) of displacement, and so this fault is probably a type of large-displacement, gently dipping normal fault called a detachment fault. Such a fault had been thought to exist in the area based on the geology of the White Tank Mountains, and had been given the name White Tank detachment fault (Kruger and others, 1998; Ferguson and others, 2004).

million years and older than about 2 million years. The salt was deposited in a closed basin containing a lake that was probably dry most of the time. It is not known what river system entered the lake.

Man-made caverns in the Luke salt body are used for storage of liquefied petroleum gas (LPG, specifically propane and butane). Each cavern was made by pumping fresh water down a drill hole into the salt where the salt was dissolved and the resulting brine was pumped back to the surface. This process gradually created the large underground caverns that are now used to store LPG. Copper Eagle Gas Storage, LLC, recently drilled four holes into the Luke salt body to evaluate the possibility of developing a new underground LPG storage facility. The company was specifically interested in identifying porous and permeable conglomerate or coarse sand beneath the salt so that they could pump the brine derived from salt dissolution into a deeper geologic reservoir and thereby dispose of it.

Millions of years ago, a large, commonly dry lake west of what is now Phoenix received river water intermittently and repeatedly dried to form a salt-pan playa (also known as a "salar"). An active fault along its west side kept the basin deep enough to trap lake water and sediment. Repeated earthquakes gradually uplifted the White Tank Mountains and sent seismic waves rippling across the white surface of the salar. As the fault became inactive, the lake filled with sediments and eventually spilled over and integrated with the regional drainage system that we see today. The Luke salt body is thus a relict of an earlier time when the basin and range landscape of southern and western Arizona was actively forming.

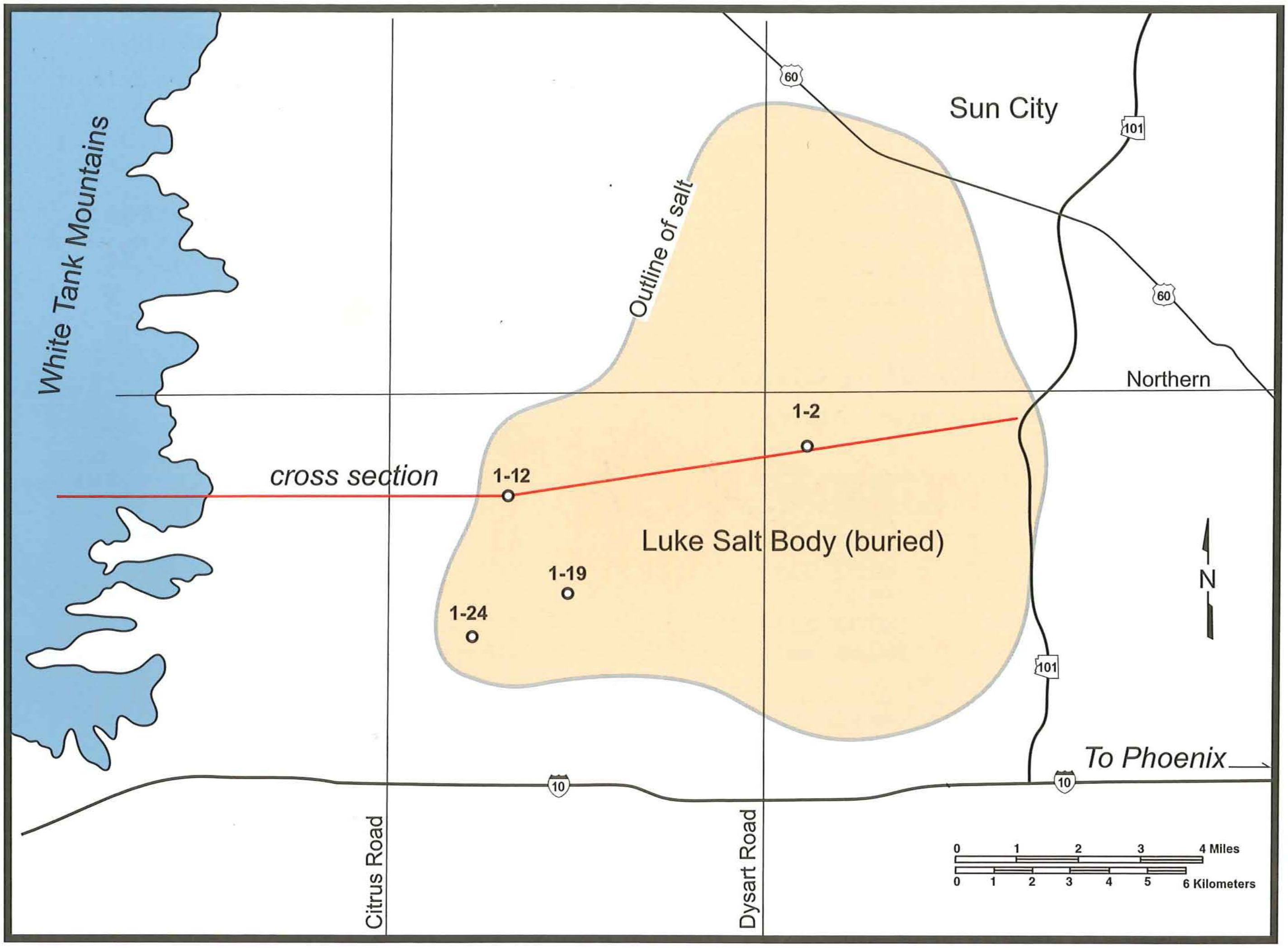


**Figure 2.** Map showing the approximate subsurface outline of the Luke salt body, the location of the drill holes discussed in text, and the location of the cross section shown in Figure 3. The area is between the White Tank Mountains on the west and downtown Phoenix on the east.

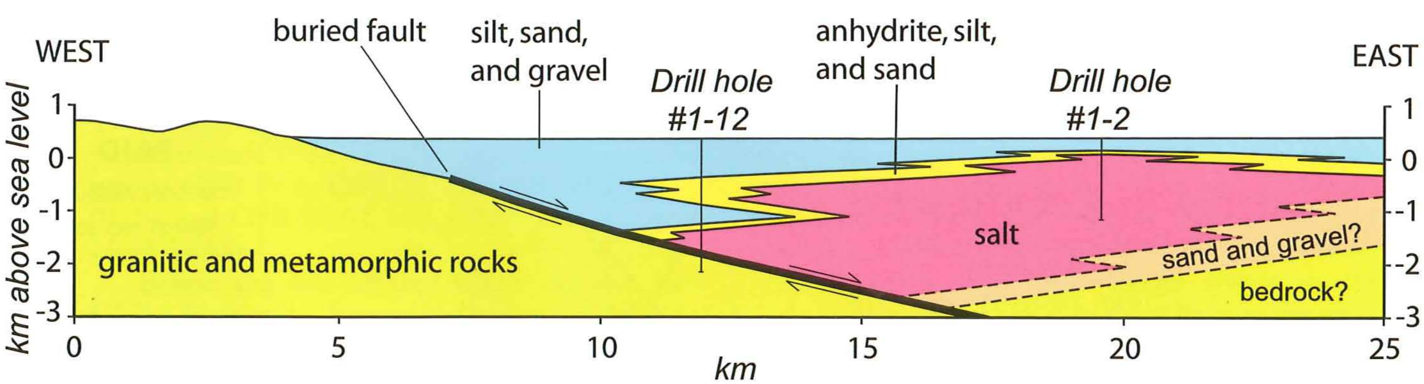


**Figure 3.** Cross section along cross-section line shown in Figure 2. This shows how rocks would be distributed within the subsurface if we could cut open the earth and reveal a vertical surface.

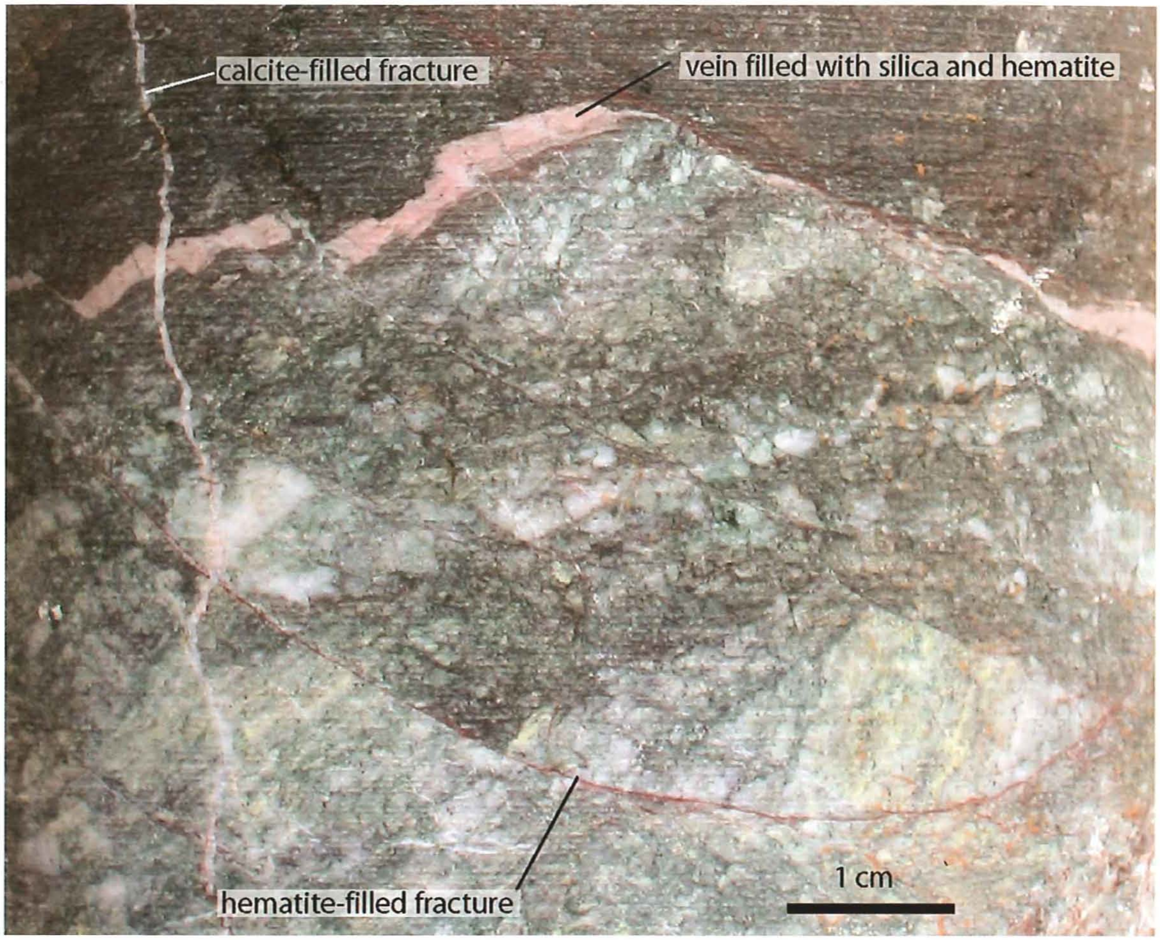


**Figure 4.** Picture of crushed, altered, and cemented bedrock from rock core taken just below the base of the overlying salt and fine-grained sediments of the Luke basin. Crushing and fracturing is interpreted as a result of fault movements on a nearby fault surface. The dark greenish gray color from the mineral chlorite, and the fracture-filling reddish hematite (iron oxide), silica, and calcite are interpreted as a result of hot water moving through the crushed and fractured rocks. The white and grayish white are quartz and feldspar that have been fractured and crushed but have not been altered to other minerals. Core is from 1638 meters depth (5373 feet) in the Suncor #1-24 drill hole (OGCC #909).

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