# Arizona Geology

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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 is a small geologic map that includes 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.

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.

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).

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.

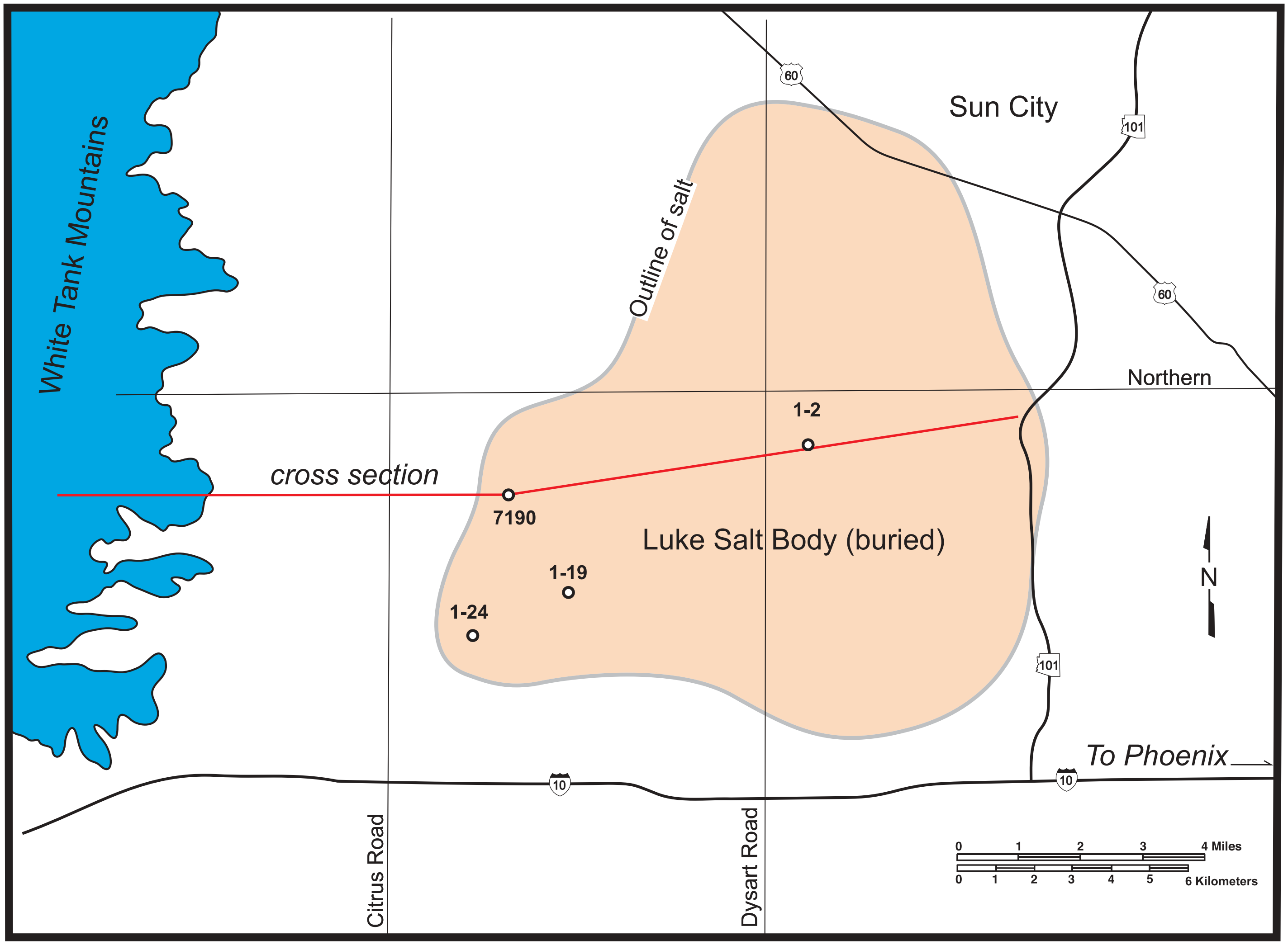


Figure 2. Map showing the approximate subsurface outline of the Luke salt body, the location of the drill holes discussed in text, and the location of the cross section shown in Figure 3. The area is between the White Tank Mountains on the west and downtown Phoenix on the east.

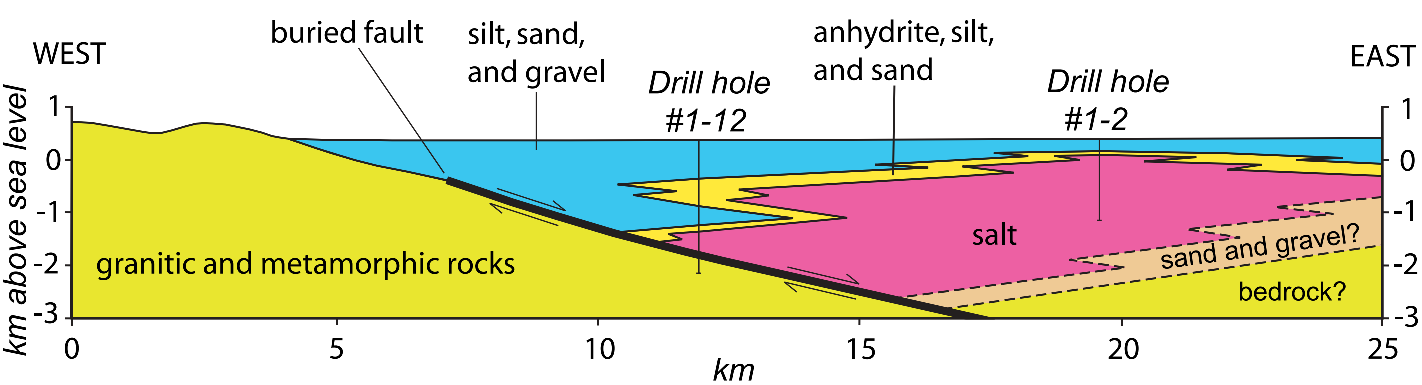


Figure 3. Cross section along cross-section line shown in Figure 2. This shows how rocks would be distributed within the subsurface if we could cut open the earth and reveal a vertical surface.

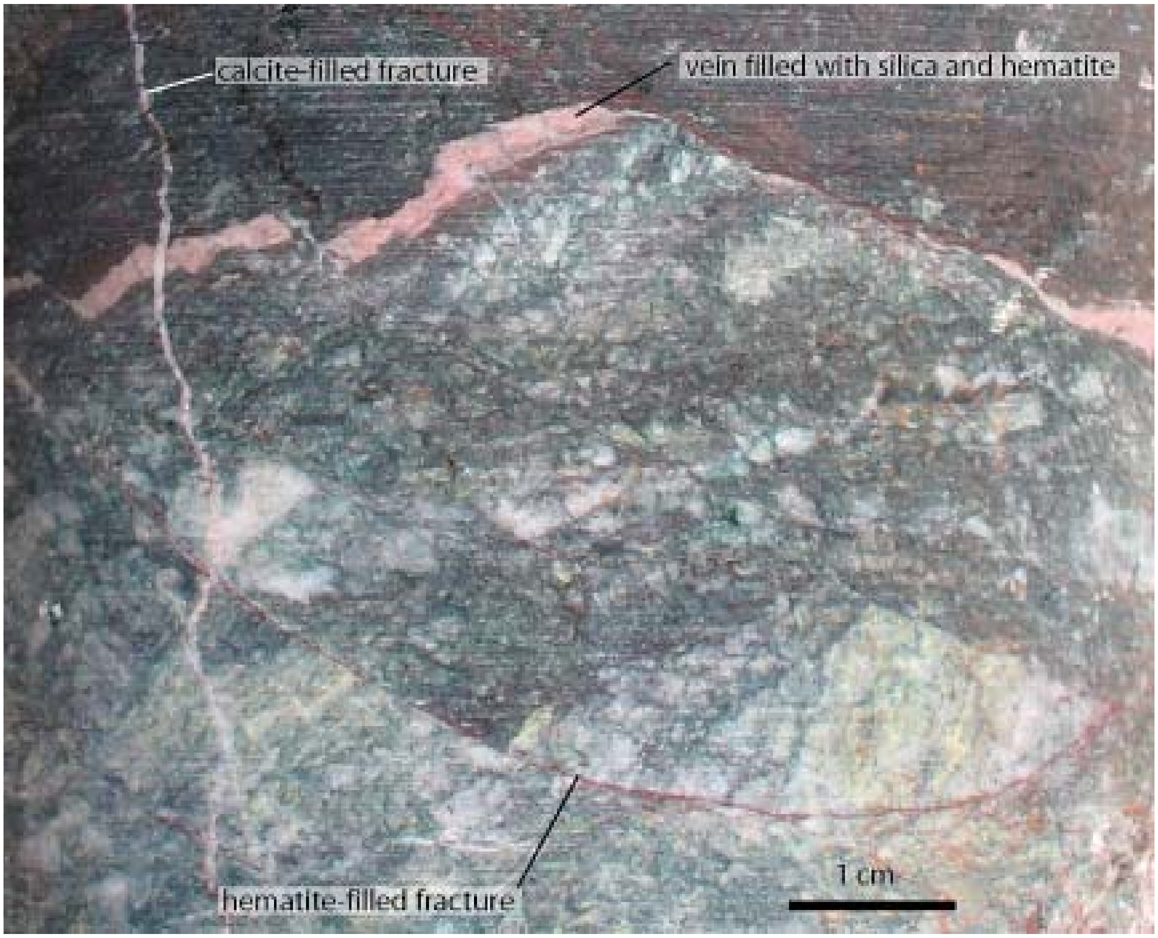


Figure 4. Picture of crushed, altered, and cemented bedrock from rock core taken just below the base of the overlying salt and fine-grained sediments of the Luke basin. Crushing and fracturing is interpreted as a result of fault movements on a nearby fault surface. The dark greenish gray color from the 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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# Update on Earth Fissures

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The summer of 2005 was a busy one for earth fissures in the news. Heavy rain in early August on the north side of the San Tan Mountains produced flooding that affected broad areas of an unincorporated area known as Chandler Heights, south of the town of Queen Creek. Some of the flood water found its way into an old fissure system, parts of which had been covered-over for development. As water flowed through the fissure and under the capping of dirt, the surface collapsed into the underlying void and the old fissure was reborn. That particular fissure was first reported in U.S. Geological Survey (USGS) Circular 466 in 1962, although it formed a few years before that. A fissure opening in the Chandler Heights area was not news to geologists, but was to residents who moved into the area who were unaware of earth fissures, or who were warned of their existence but were unaware of what a fissure actually looked like.

Some recent newspaper articles have given the impression that (1) the Chandler Heights area is the only place in Arizona with earth fissures, (2) the AZGS publication that covers the Chandler Heights area, OFR 94-11, is Arizona's only earth-fissure map, and (3) no earth fissures have been mapped since. First, earth fissures are present in four counties, not just the Chandler Heights area. By far the largest number is in Pinal County. Maricopa and Cochise Counties have perhaps one-tenth the number of fissures that Pinal County has, and Pima County has only half a dozen or so. Second, there are dozens of reports and maps showing earth fissures from AZGS, USGS, U.S. Bureau of Reclamation, and other scientific publications and university theses. In fact, a comprehensive bibliography of references about subsidence and earth fissures in Arizona is 21 pages long! Third, many reports showing earth fissures have been produced since 1994. These include AZGS open-file reports OFR 95-6, OFR 97-19, OFR 99-26, OFR 01-10, and OFR 04-01, and a 2001 ASU thesis by Hugh Larkin.

Before the late 1990s, AZGS did not have Global Positioning System technology and did not produce digital versions of its maps using Geographic Information System software. Mapping was done using topographic maps or aerial photos to determine fissure locations. Many USGS topographic maps are from the 1960s or 1970s and do not show more recent roads and other developments, so fissures were located on maps without the use of clearly identifiable landmarks that are now taken for granted. Aerial photos used for making most of the earth-fissure maps in the 1990s (OFRs 94-11, 95-6, and 97-19) were poster-sized blueline copies with low resolution and poor print quality. Lines on published maps were drawn by hand with ink on mylar, with the geologist locating the fissures on the base map as best as could be done with the materials and technology available at the time. Additional error was introduced during reproduction, where a single mylar was generated by overlaying the mylar with hand-drafted lines over a base map. This old style of map generation typically introduces uncertainty of at least several tens of feet, and simply digitizing old maps will produce a digital map with as much or more error than the original. As a result of this situation, AZGS earth fissure maps were never intended to be used for site-specific engineering purposes.

Whether or not new fissures have opened in an area in the past 10 or 20 years, the old fissures could still be active in that they can continue to open and could still damage structures. This is especially true if some of the cracks were due in part to, or are now controlled by, cycles of near-surface desiccation of clays in the sediment. If the cracks are "active" in the sense that they still occasionally reopen, that means they must be regarded as hazardous and should not be ignored. For both earth fissures originating from groundwater pumping and giant desiccation cracks, the only proper mitigation is to know exactly where they are so development can be planned to avoid placing structures near or on top of them. Both types of fissures can reactivate after years of dormancy. For the Chandler Heights fissures specifically, the one that reopened this past summer did not necessarily reflect new activity in the sense that the fissure was growing or changing, but rather that the fissure has not been filled completely, so there is still void space underground that surface material can wash into. In other words, that fissure system is still "active" because it is still filling, not because the walls of the fissure are moving apart.

To order earth fissure publications and maps call the AZGS Publication Sales Office at (520) 770-3500 or visit us at 416 W. Congress St. Suite 100, Tucson, Arizona.

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