WHY DID THE FISSURE CROSS THE ROAD?

NEW AND OLD EARTH FISSURE ACTIVITY IN COCHISE COUNTY, ARIZONA

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Introduction

In late July 2010, landowners north of the Sulphur Hills, 10 miles southeast of Willcox Playa in central Cochise County, Arizona, were cut off from their farms and homes (Fig. 1) because E. Parker Ranch Road, east of Kansas Settlement Road, was cut by three freshly ruptured earth fissures rendering the road impassable. Repair by Cochise County in order to make the roads passable was completed on July 28, 2010.

The three fissures trend roughly north-south forming curvilear cracks subparallel to one another. Each fissure formed in the flat, relatively unincised mesquite grasslands north of the Sulphur Hills. While no homes were impacted by the new fissures, one abandoned homesite lies approximately 150 feet from the westernmost fissure. At present, the earth fissures crossing Parker Ranch Road have been filled but cracks remain open on either side and possibly at depth. A road sign warning of the possibility of earth fissures has been installed near the west end of Parker Ranch Road.

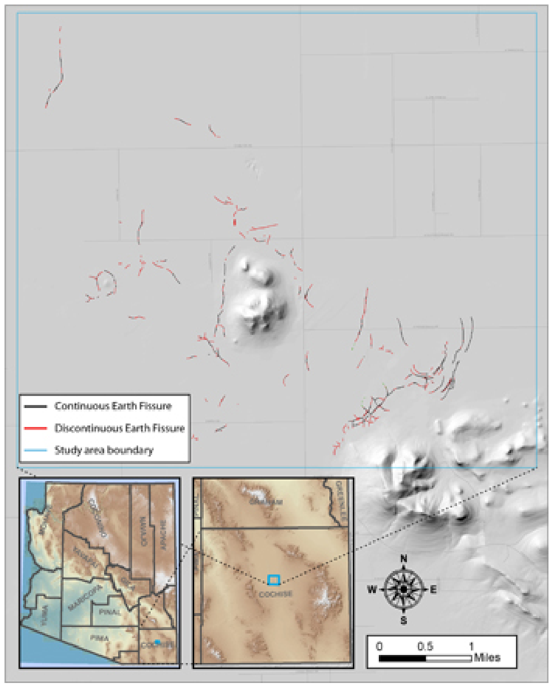

Figure 1. Location map of Three Sisters Buttes Earth Fissure Study area in central Cochise County, Arizona.

Causes of Earth Fissure Formation

Earth fissures are cracks, seams, or separations in the ground surface that form in response to tensional forces related to uneven ground subsidence that accompanies overpumping groundwater (Arizona Land Subsidence Group, 2007). Groundwater levels in the vicinity of the Three Sisters Buttes fissures have dropped from 106 feet up to 260 feet since the early 1950s (Arizona Department of Water Resources GWSI database).

As water levels fall, pore spaces between valley filling sediments formerly filled with groundwater are free to compact. This compaction results in ground subsidence at the surface. Earth fissures commonly manifest near the base of bedrock hills or ranges because the sediments overlying the buried bedrock are thinner and thus compact less than the thick sediments underlying the central valley area (Fig. 2). This model of earth fissure formation is observed in the distribution of fissures of the Three Sisters Buttes study area (Arizona Geological Survey, 2011).

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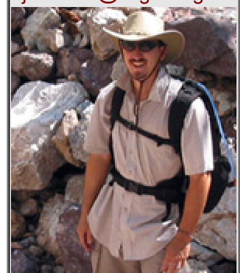

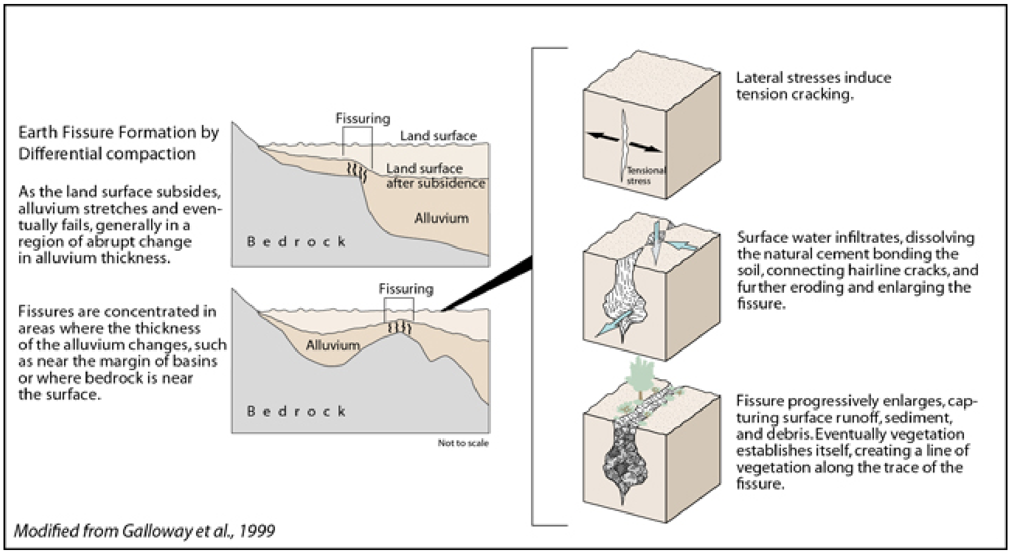

Figure 2. Schematic diagram of earth fissure formation by differential compaction, tensional cracking, and subsurface erosion.

The initial appearance of incipient earth fissures is a hairline surface crack, often crossing or perpendicular to local drainage patterns. Rainwater and overland flow are able to infiltrate the crack and percolate into the subsurface leading to piping erosion that eventually forms an open underground void aligned with the still narrow surface crack. When the void becomes large enough the undermined surface soil may abruptly collapse into the open part of the fissure below.

Fissures in the Three Sisters Buttes Study Area

Earth Fissures Formed in 2010. The new earth fissures north of the Sulphur Hills most likely opened during rapid erosion coinciding with heavy rains in late July 2010. The period of time over which subsurface erosion took place prior to surface failure is unknown but could span years. Narrow surface cracks are difficult to observe due to heavy grass cover and historical disturbance by cattle and agriculture.

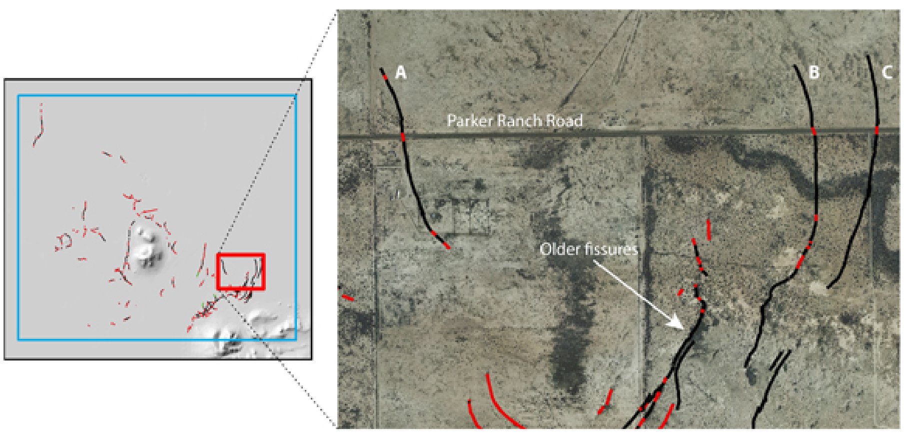

Figure 3. Section of the Three Sisters Buttes earth fissure study area containing the three new fissures cutting Parker Ranch Road. Fissures A, B, and C opened in summer 2010 while fissures to the south were evident in aerial photos from the late 1970s. Continuous fissures are indicated in black and discontinuous fissures are indicated in red.

The cumulative length of the open surface crack portions of the new fissures exceeds 1.3 miles (Fig. 3): it is possible, too, that hairline cracks and voids extend beyond the mapped fissure in the subsurface. Some sections of these fissures are narrow cracks less than six inches across or disconnected lineations of potholes. Other sections have experienced extensive surface collapse resulting in open surface cracks approximately 15 feet across (Fig. 4). The deepest measurable section of the earth fissure complex exceeds nine feet although numerous open cracks and collapse features visible in the base of the open portion of the fissures likely extend to much greater depths. The easternmost newly-opened earth fissure cuts across local drainages, affecting downstream vegetation and drainage patterns. Although the upstream channel is presently wide and unincised, future runoff will pour into the deeper earth fissure enhancing headward erosion along the drainage where there was little incision before. The downstream end of the channel is now abandoned and will no longer receive flow.

Historical Earth Fissures. The newly-opened earth fissure complex is not the first time fissures have been discovered in the area. An earlier generation of earth fissures appears in aerial photos as far back as 1978. Due to capture of precipitation and surface flow, vegetation along older fissures is often twice as tall as that observed in the undisturbed ground away from the fissure. Older fissures can be difficult to access because of the dense tumbleweed and mesquite trees that populate them.

The AZGS recently released the Three Sisters Buttes earth fissure map showing nearly 19 miles of earth fissures concentrated north of the Sulphur Hills and surrounding the Three Sisters Buttes approximately three miles to the northwest. In 2009, the AZGS released the Dragoon Road Earth Fissure study area map detailing nearly six miles of earth fissures southwest of Willcox Playa. Some of these fissures have repeatedly broken the asphalt at the intersection of W Dragoon Road and Cochise Stronghold Road leading to numerous road repairs and the installation of a road sign by Cochise County warning of possible earth fissures. Other fissures in the Dragoon Road study area underlie the coal ash ponds of the Apache Generating Station.

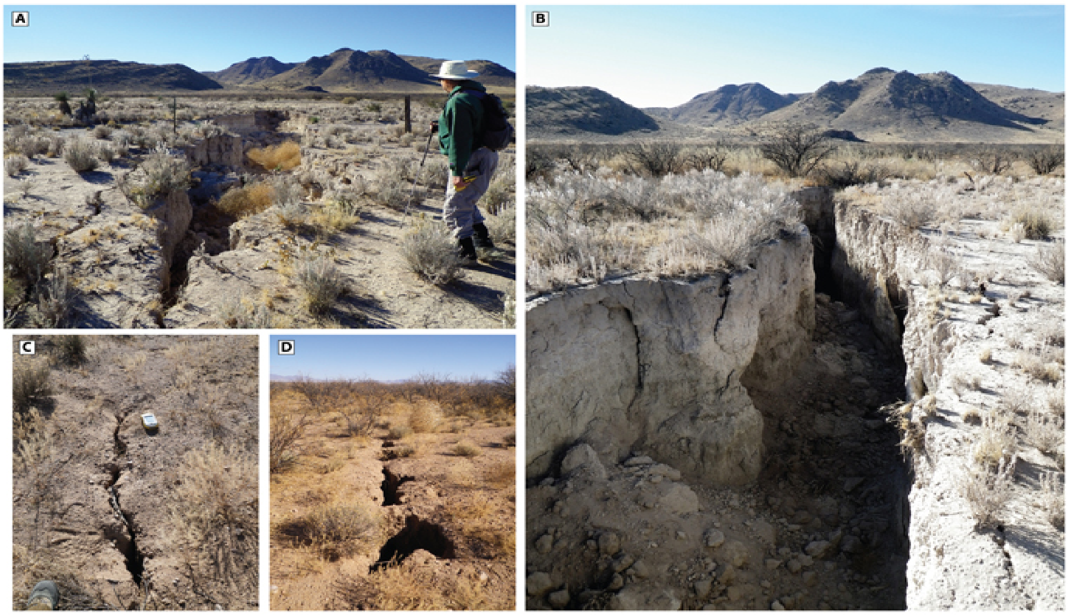

Figure 4. Field photos of newly opened earth fissures. A) A large open section of fissure C from figure 3, note fence stretched across open fissure. B) Deep, steep-sided section of the same fissure. C-D) Narrow surface cracks and aligned potholes representative of portions of earth fissures that have not yet opened completely. A subsurface void likely underlies these features and the overlying soil may one day collapse into it.

Mapping of earth fissures near Bowie and San Simon in Cochise County continues, while work in northern Sulphur Spring Valley north of Willcox begins later this year.

Tools for Monitoring and Predicting Earth Fissures

Once an earth fissure has breached the surface there is little than can be done to mitigate it, other than preventing water from entering and further eroding the sidewalls. Filling fissures with loose unconsolidated fill usually fails as surface flow eventually washes the fill laterally or down into the fissure. Authorities in Pinal County have filled the “Y-Crack” fissure near Chandler Heights several times, just to see the fissure reopen as monsoon rains and sheet flow erode and remobilize the fill.

Roads cut by fissures may require repeated repairs and continuous monitoring especially following intense rains. Because earth fissures form in response to overdrafting groundwater, the only guaranteed means of preventing their occurrence is to cease groundwater pumping in excess of recharge. But even if groundwater overdrafts were to cease today the compaction of valley filling sediments would likely continue for some time, perhaps years, as the compaction process lags behind decades of falling groundwater levels.

Realistically, southern Arizona is not likely to cease overpumping of groundwater any time soon. In Cochise County, numerous pecan and pistachio orchards exist with new plantings occurring near the Dragoon Road and Bowie-San Simon earth fissure study areas. With continued groundwater withdrawal we can expect continued land subsidence and formation of new earth fissures. If overdrafts of groundwater continue, how can we plan around the eventuality of new earth fissures? To prepare for fissures, we need to know where they are likely to form. It is reasonable to expect earth fissures around valley margins that have undergone significant water level decline (100 feet or more) since the early 1900s. However, it is also possible for fissures to form further from the mountain front, similar to those cropping out north of the Sulphur Hills. Because earth fissures form where differential compaction is most severe, it is beneficial to know where and at what rate subsidence is taking place.

Interferometric Synthetic Aperture Radar (InSAR) is a highly accurate method of detecting centimeter-scale changes in ground elevation (i.e., subsidence). Repeat InSAR data can be used to create an interferogram which depicts net subsidence (or uplift) over a window of time. The hydrology and geophysics/surveying unit at the Arizona Department of

Water Resources (ADWR) collects InSAR data throughout Arizona and processes it to monitor ground subsidence. ADWR hydrologists have noted a highly pronounced visible correlation between the surface expression of earth fissures and areas of greatest differential subsidence as shown on InSAR interferograms (pers. comm. Brian Conway December 2010).

InSAR interferograms are proving a useful predictive tool for pinpointing new fissure formation. As Figure 5 shows, the new fissures in the Three Sisters Buttes study area correspond closely with high differential subsidence areas portrayed on InSAR interferograms. We have had some success, too, using InSAR images to guide us to unmapped earth fissures. The ability to accurately quantify subsidence trends and outline fissure-prone areas is a valuable tool for civil authorities, developers, landowners, and the general public.

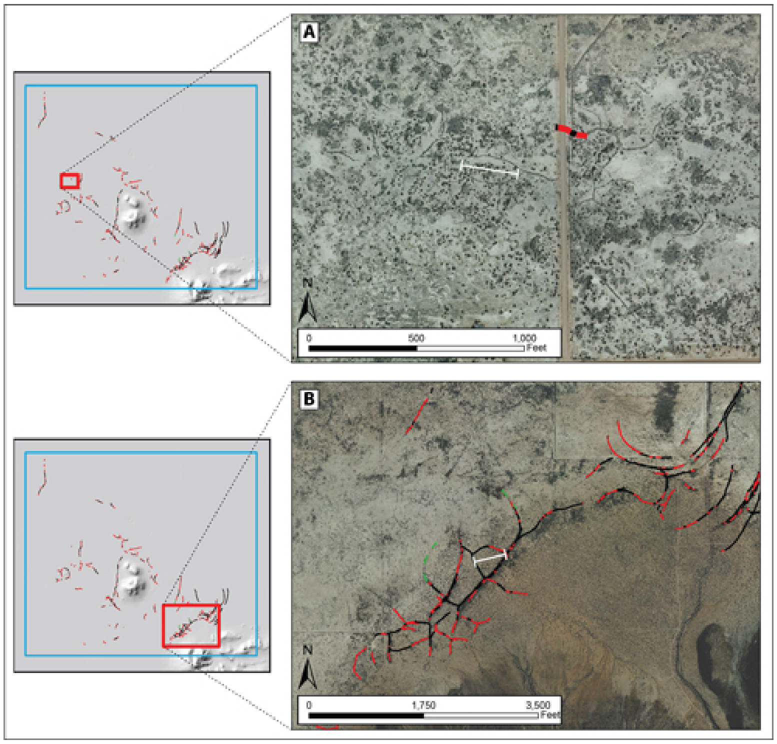

Figure 5. A) Giant desiccation crack field in the Three Sisters Buttes study area. These GDCs have disrupted the surface of Fern Ct (N-S dirt road), which required repair. The distance across the white line in the GDC polygon is 250 feet. B) Polygonal crack network near known earth fissures. These polygonal cracks were previously identified as combination earth fissure-giant desiccation cracks. In the Three Sisters map they are shown as earth fissures. The polygon here measures 425 feet across. Continuous fissures are indicated in black and discontinuous fissures are indicated in red.

Giant Desiccation Cracks

Not all large surface cracks in Cochise County are earth fissures. Giant desiccation cracks (GDCs) are abundant around the present and former margins of Willcox Playa, on the distal toes of alluvial fans, and along the valley axis of fine grained alluvial basins. GDCs form in fine grained, clay-rich soils in response to prolonged drought or repeated wetting and drying (Neal et al., 1968, Harris, 2004). GDCs form polygonal networks reminiscent of mudcracks except GDC polygons can be hundreds of feet across (figure 6). Much like earth fissures, surface cracks forming GDC networks may start out as hairline cracks but evolve into large collapse features due to subsurface piping and erosion. Unlike earth fissures, GDCs are strictly surface features extending mere feet into the subsurface. Older GDC networks may become nearly or partially filled due to wall collapse. Vegetation may preferentially grow in or along GDCs because of loose soil fill and a greater affinity for capturing and storing water. Over time vegetation may help completely fill the surface crack through the capture of windblown sediment resulting in a vegetated mound along the former GDC trace.

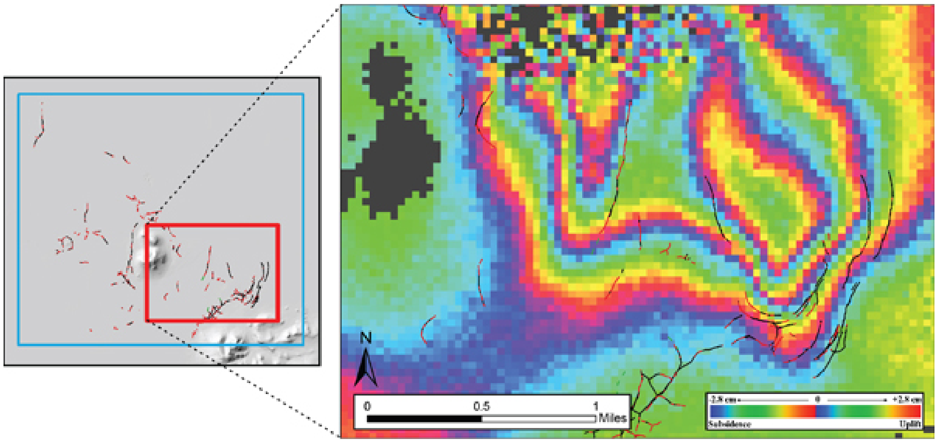

Figure 6. InSAR interferogram spanning May 2008 through May 2010. Each repetition of the color ramp represents 2.8 centimeters (just over an inch) of subsidence. In the past two year, more than 3 inches of ground subsidence occurred. Note close agreement between areas of pronounced differential compaction and earth fissure formation. And note, too, areas of strong differential compaction that lack earth fissures. Are these areas where we can expect fissures to occur in the future? Continuous fissures are indicated in black and discontinuous fissures are indicated in red.

While earth fissures form as a result of the overpumping of groundwater, GDCs can form naturally in response to soil characteristics and climate patterns. In some cases, earth fissures have formed across preexisting GDC networks, as observed in aerial photos as far back as 1935 (Harris, 2004). Where GDCs and earth fissures form in close proximity, it can be difficult to discriminate between them. It is possible the introduction of a deep earth fissure in the vicinity of preexisting GDCs may enhance or renew the formation of GDCs through increased desiccation of near surface soils, base level lowering and subsequent downcutting, or a combination of both. In the Three Sisters Buttes earth fissure study area, some features previously identified as combination earth fissure-giant desiccation cracks were mapped as earth fissures based on similar appearance, morphology, and crack geometry to nearby fissures. Other more shallow polygonal features in the study area were interpreted as GDCs and were not depicted on the map.

Conclusions

Unfortunately, it appears inevitable that additional earth fissures will appear in southern Arizona in response to historical and ongoing groundwater mining. New fissures are opening up in areas with older, supposedly dormant, generations of earth fissures. Although earth fissures are widespread throughout a number of deep alluvial basins in Arizona, there are numerous areas where subsidence occurs unaccompanied by earth fissure formation. Are the latter areas unique in that their subsurface bedrock or consolidated basin sediment topography discourages substantial differential compaction, or is fissure formation awaiting an extreme runoff event? In any case, we must remain alert to the potential for earth fissure formation in basins with significant groundwater lowering. Where earth fissures now exist, we need to monitor changes in fissure length and, using InSAR data, local subsidence patterns to better understand the relationship between differential subsidence and fissure formation and development over time.

Both GDCs and earth fissures can be hazardous to livestock, buildings, and roads. Both can disrupt the natural drainage patterns in the area. Based on our current groundwater usage, earth fissures are a human-induced hazard that we will be dealing with for some time.

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