

# Arizona Geology

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## Recent Debris Flows and Floods in Southern Arizona

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### Widespread damage

Southeastern Arizona experienced an extremely wet interval near the end of July 2006 that generated floods and numerous debris flows (sediment-rich slurries) in some of the mountain ranges of this region. Flooding damaged homes and other property, roads, and infrastructure along Aravaipa Creek and several watercourses in the Tucson area. The most impressive geologic phenomenon, however, consisted of intense debris flow activity in the Santa Catalina Mountains near Tucson, in the northern Chiricahua Mountains near Ft. Bowie and in the Huachuca Mountains near the border with Mexico. Hundreds of debris flows occurred on steep mountain slopes and larger debris flows coursed down several canyons (Figure 1). Access to Sabino Canyon in the Santa Catalina Mountains and Coronado National Memorial in the southern Huachuca Mountains was temporarily closed due to debris flows and flood damage, and Mt. Lemmon Highway was damaged in several places. Debris flows have previously been recognized as a significant hazard in mountain areas in Arizona (Wohl and Pearthree, 1991; Melis et al., 1997; Pearthree, 2004). Nonetheless, the number and size of debris flows that occurred at the end of July was surprising, and they remind us that rare meteorological / hydrological / geological events present significant hazards and are very important in shaping the landscape in Arizona.

### Meteorology and precipitation

More than one-half of the annual precipitation in southern Arizona typically falls during the summer monsoon season. The last week in July 2006 was an exceptionally wet interval in the eastern half of Arizona, however. A cutoff low-pressure system dropped down from Idaho and remained over the White Mountains area for several days – very unusual weather for the middle of the summer monsoon. Disturbances rotating around the low interacted with a moist monsoonal flow, which resulted in several days of nocturnal and early morning rainfall that moistened the mountain watersheds. The wet period culminated in the early morning hours of July 31, when several small disturbances combined with a low-level moisture surge from the southwest to pro-



**Figure 1.** Aerial and ground photos of debris flow deposits burying the end of the tram road in Sabino Canyon. The tram road turnaround is beneath the boulder pile in the ground view; note Lee Allison and Todd Shipman of the AZGS for scale. Large white arrow points to the location of buried rest room facilities. Aerial photo provided by R.H. Webb.

duce up to eight inches of rain in less than six hours in some mountain areas in southeastern Arizona. These rainfall amounts are extreme, on the order of 400 to 1,200-year events (Mike Schaffner, National Weather Service, written communication). Because this intense rainfall occurred after several days of unusually wet weather, this was in essence a perfect storm for generating floods and debris flows.

## 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

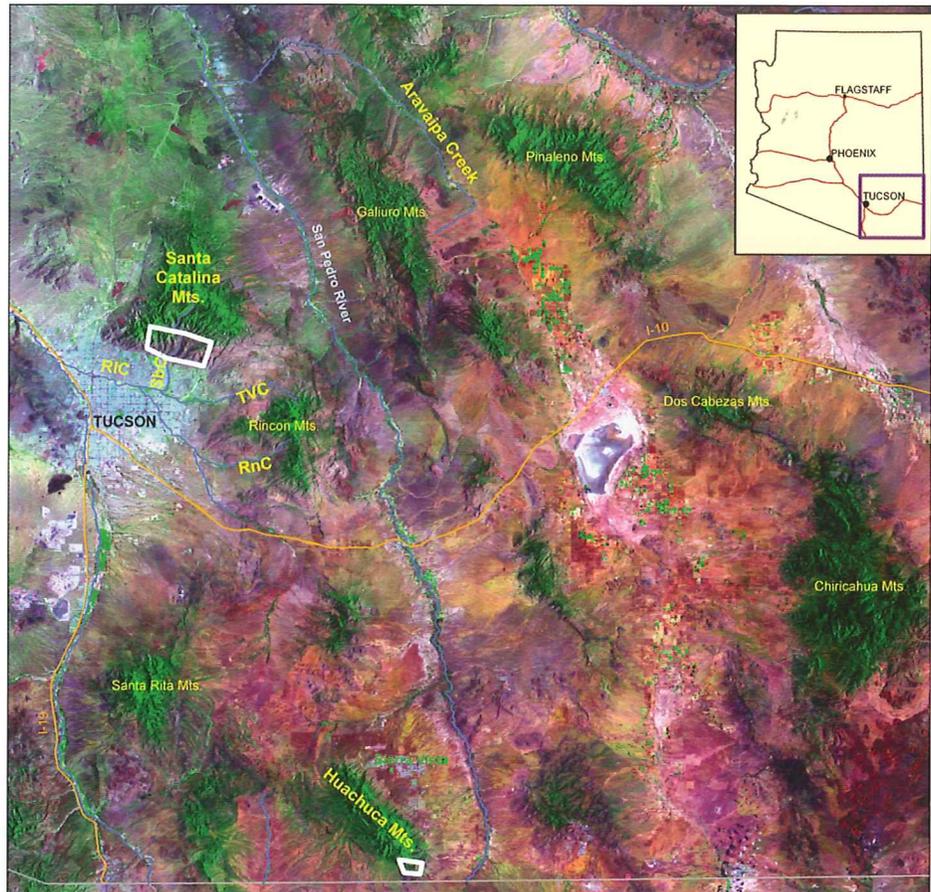
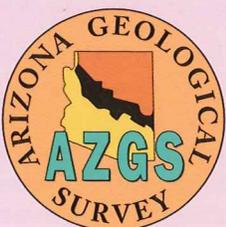
Investigate geologic hazards and limitations such as earthquakes, land subsidence, flooding, and rock solution that may affect the health and welfare of the public or impact land and resource management.

### ENERGY AND MINERAL RESOURCES

Describe the origin, distribution, and character of metallic, non-metallic, 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.



**Figure 2.** Location map of southeastern Arizona. Streams with record floods include Aravaipa Creek, Rillito Creek (RIC), Sabino Creek (SbC), Tanque Verde Creek (TVC), and Rincon Creek (RnC). Boxes outline areas of intense debris flow activity in the Santa Catalina and Huachuca Mountains:

## Regional Flooding

Stream gauges operated by the U.S. Geological Survey and local flood control districts provide records of flooding ranging from a few years to many decades long. For a number of gauged streams in southeastern Arizona, the floods of July 31 were the largest of the historical record. Based on preliminary peak discharge estimates from the USGS and the Pima County Regional Flood Control District, record floods occurred on Sabino, Rincon, and Rillito creeks in the Tucson area (Figure 2). Soil cement bank protection along the more urban reaches of these streams minimized bank erosion, but designed channels were full to overflowing (Figure 3). Sabino Creek experienced increasingly larger floods on July 29, 30 and 31. Each of these floods was larger than any that were recorded at the gage between 1932 and 1992, and the July 31 flood is the largest of the entire gage record. Other drainages in southeastern Arizona also experienced very large floods, including Aravaipa Creek, where the flood peak was larger than the previous record flood of October 1983. These floods occurred because of the unusually large amounts of rain that fell on July 31, but runoff was increased because of the wet weather of the preceding days.

## Debris flows

The most spectacular debris flows occurred in the southern Santa Catalina Mountains just north of Tucson, an area that includes the Sabino Canyon Recreation Area managed by the U.S. Forest Service. At least 250 separate debris flows initiated on steep mountain slopes in a swath extending from Ventana Canyon on the west to the Mt. Lemmon Highway on the east (Figure 4) (Chris Magirl and Peter Griffiths, U.S. Geological Survey, oral communication). Most of the debris flows began as discrete



**Figure 3.** Photo of Rillito Creek looking downstream from the Dodge Boulevard bridge in Tucson during the morning of July 31, 2006. Photo by Todd Shipman.

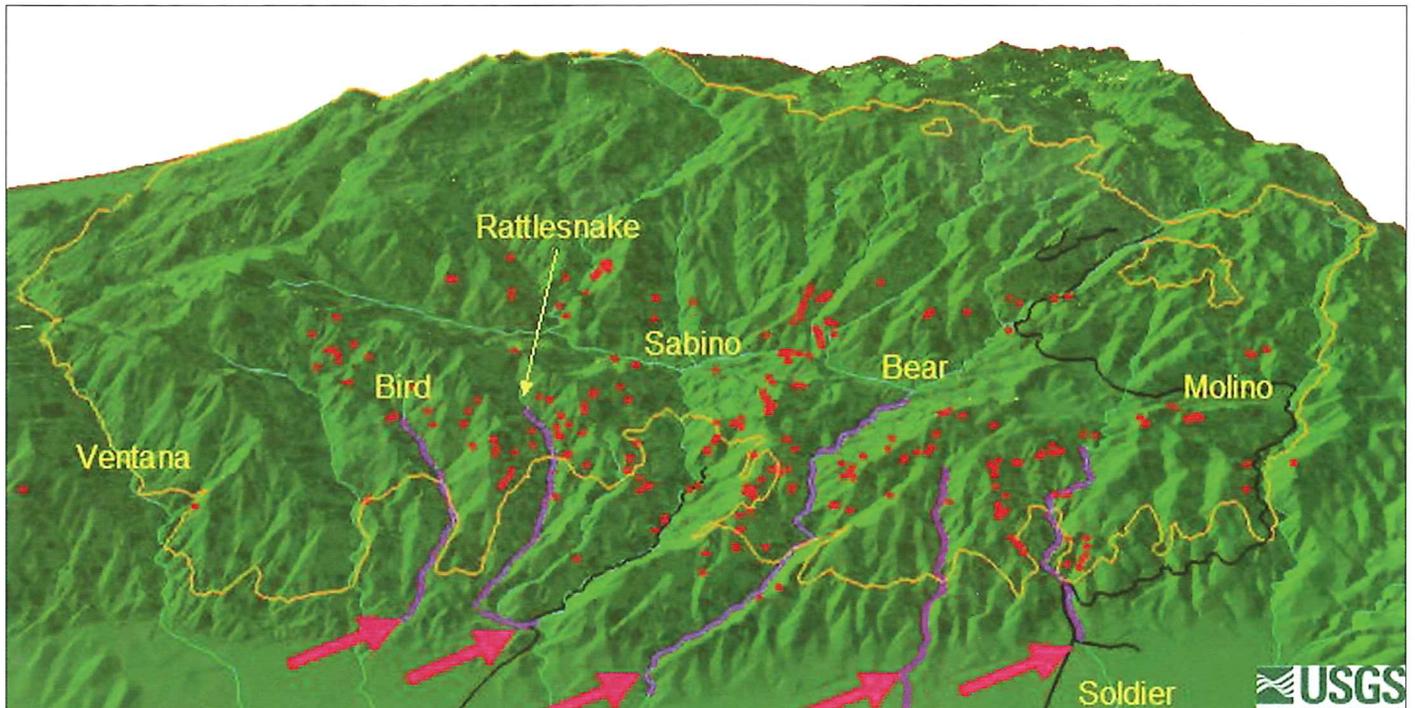
failures of thin hillslope or gully deposits over bedrock, but in a few areas broad swaths of hillslope failed (Figure 5). Many fresh scars on mountainsides left by the debris flows (nearly vertical light-colored stripes) are quite evident from the central and eastern Tucson metropolitan area. Individual flows entrained more sediment as they proceeded downhill, and in some cases merged and developed into large debris flows that continued several miles down the canyons. Debris flows deposited large piles of medium to large boulders where debris flows spread out or stopped; much of the finer-grained sediment in the slurries was washed downstream.

In Sabino Canyon, the tram road that provides access to much of the canyon was damaged in many places. A large debris flow came down Rattlesnake Creek, completely clogged the bridge across this creek and eroded the approach to the bridge (Figure 6). Sediment deposition

immediately downstream raised the bed of Sabino Creek by about 20 feet (Robert Webb, U.S. Geological Survey, oral communication). Farther into Sabino Canyon, boulder deposits blocked the road in at least six places (Figure 7). Between tram stops 7 and 8, an ~500 ft long stretch of road was damaged and covered with sediment, and numerous large boulders were deposited in Sabino Creek (Figure 8). The end of the tram road was completely buried by boulders and restroom facilities were destroyed (Figure 1). Fortunately, no people were killed or injured because the debris flows and flooding occurred in the early morning hours. The U.S. Forest Service has partially reopened the tram road but is still considering whether it is advisable to attempt to repair the remainder of the road.

Debris flows actually reached the mountain front in several canyons adjacent to Sabino Canyon. At Soldier Canyon it appears that a debris flow passed through large culverts beneath Mt. Lemmon Highway and flowed about 0.5 miles farther downslope (Figure 9). A substantial amount of coarse sediment was deposited near the canyon mouth downstream of the highway, stopping just short of several houses. Flooding and sediment run-out from the debris flow did impact these houses, and water flooding spread into areas that had not been impacted by large floods in 1983 and 1993.

Coronado National Memorial and adjacent areas in the southern Huachuca Mountains were also hard-hit. More than 60 debris flows occurred in this area (Figure 10), burying National Park Service facilities and destroying the main gravel road that traverses the park along the U.S. - Mexico border (Figure 11) (Youberg et al, 2006). After four months of repairing the park, Coronado National Memorial is once again open to the public.



**Figure 4.** Map showing locations of debris flow initiation in the Santa Catalina Mountains. Large debris flows that occurred in several canyons are shown with purple lines and pink arrows (modified from Magirl et al, 2006).

## Fire and debris flows

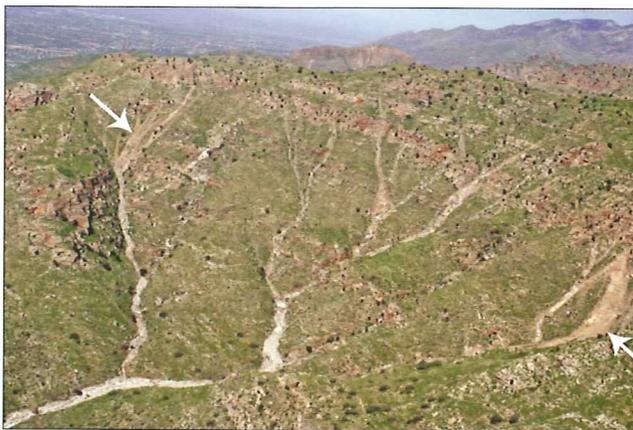
Some debris flow activity in the western U.S. has clearly been linked to wildfires. Recent research has demonstrated that the amount of precipitation needed to initiate debris flows decreases dramatically in the immediate wake of fires because fires remove vegetation that slows runoff (Cannon et al., 2002). The forests and woodlands of the middle and upper Santa Catalina Mountains burned in large fires in 2002 and 2003, so it is tempting to link the debris flows that occurred this year to increased runoff from burned areas. The vast majority of the debris flows occurred in unburned or lightly burned areas, however, so apparently the extremity of the precipitation events was by far the most important factor in generating debris flows.

## Extreme events shape the landscape

The many debris flows that occurred on July 31 illustrate the importance of extreme, rare events in shaping the landscape of Arizona. Geologists recognize that mountains are eroded primarily by flowing water, and that the basins of Arizona are filled with sediment eroded from the surrounding mountains and carried by streams into the basins over millions of years. Humans tend to perceive the landscape as unchanging, however, because so little change typically occurs during our lifetimes. This recent debris flow activity helps bridge this gap in perception. Only minor changes occur in the landscape 99.9% of the time, but a tremendous amount of change can occur in the span of a few hours.

Sabino Canyon has been a popular recreation spot for Tucson residents for more than a century. During that time, a few large floods altered riparian areas along the creek, some rocks fell down from the surrounding cliffs, and at least two small debris flows occurred shortly after the 2003 Aspen fire, but nothing on the order of the July

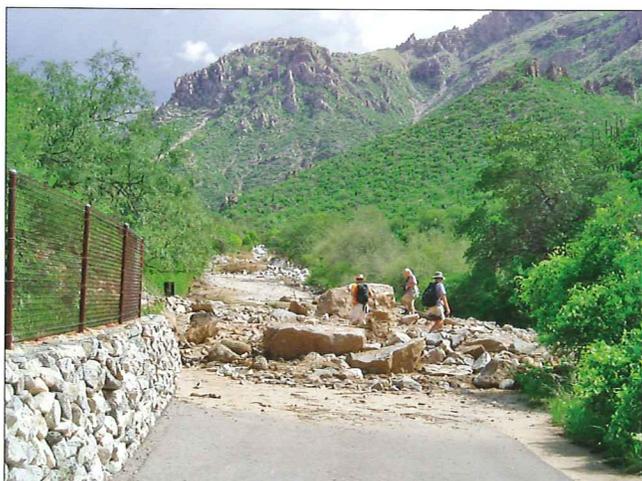
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**Figure 5.** Hillslope failures of various sizes developed into debris flows in Soldier Canyon. Most failures initiated in small channels on hillslopes, but arrows point to large areas of hillslope colluvium failure. Photo provided by R.H. Webb.



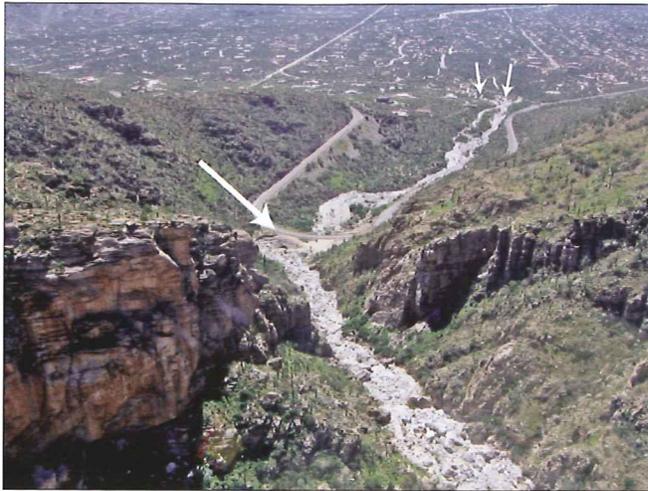
**Figure 6.** A large debris flow that came down Rattlesnake Canyon into Sabino Creek completely blocked the Rattlesnake Creek Bridge with coarse sediment and eroded the northern approach of the tram road. The people are standing on the bridge; Sabino Creek is behind them.



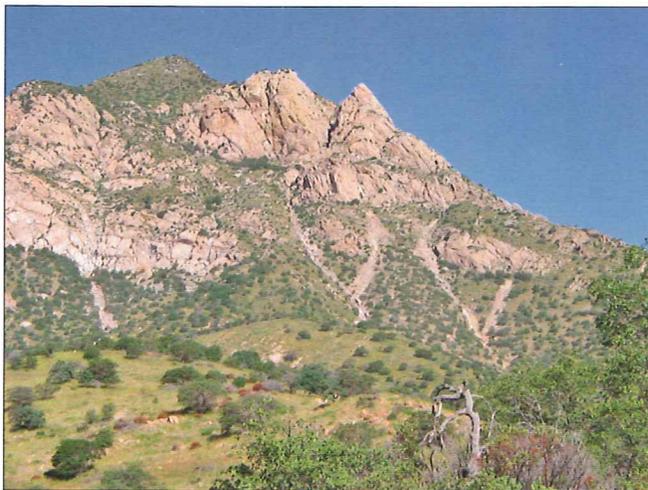
**Figure 7.** Pile of boulders left on the Sabino Canyon tram road by a medium-sized debris flow. Notice that the debris flow avoided the rock and wire fence built to catch rockfall debris.



**Figure 8.** Boulders and other debris dumped into Sabino Creek by a large debris flow near tram stop 8. The tram road is mostly buried by debris flow deposits in the foreground.



**Figure 9.** A debris flow in Soldier Canyon passed through large culverts beneath Mt. Lemmon Highway (large arrow) and deposited cobbles and boulders just upstream from several homes (smaller arrows in middle distance). Photo provided by Chris Magirl.



**Figure 10.** Debris flow scars on the flanks of Montezuma Peak, Coronado National Memorial.



**Figure 11.** Downstream view of flood damage on Montezuma Creek near the Coronado National Memorial Visitors Center.

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31 events had occurred. Nonetheless, geologic evidence of past debris flows exists in the form of very poorly sorted deposits including large boulders at the junctions of smaller tributaries and Sabino Creek, and levees of boulders along the margins of tributary channels. Given the evidence of past debris flows and the erosion and deposition that occurred in the recent events, it is likely that debris flows are the most important mechanism for transferring sediment from hillslopes to larger streams. The largest boulders likely will not be moved by floods, but the finer sediment has been and probably will continue to be carried downstream, and thus may result in aggradation along larger regional drainages like Rillito Creek.

### **New assessment of debris flow hazards needed?**

The occurrence of many debris flows, some of which were quite large, has focused more attention on the potential for debris flow hazards in southern Arizona. The hazard posed by debris flows in steep mountain drainages in the wake of wildfires has been recognized recently, and AZGS geologists have been actively involved in assessing post-fire debris flow hazards. Previous studies had documented fairly young-looking, but undated, debris flow deposits at the mouths of canyons along the Santa Catalina Mountains, but the possibility of large debris flows exiting the mountain canyons in the modern environment was considered quite unlikely (Klawon et al., 1999). In the wake of the debris flows of the past summer, there is new impetus to understand the factors that lead to debris flow occurrence, assess areas that may be subject to debris flow activity, and to consider the impact of debris flows on watersheds and downstream reaches. The AZGS is cooperating with a consortium of agencies led by the USGS, with the National Weather Service and University of Arizona researchers, to investigate debris flows and related hazards along the Santa Catalina mountain front.

### **Acknowledgments**

Chris Magirl, Bob Webb, and Peter Griffiths of the U.S. Geological gathered much of the data on the Santa Catalina debris flows that is summarized in this article. Mike Schaffner and Eric Pytlak of the National Weather Service provided the meteorological analyses. U.S. Forest Service staff and National Park Service staff and volunteers have facilitated investigations of the debris flows in Sabino Canyon and Coronado National Memorial.

### **References**

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