Measuring bedrock topography using gravity to understand subsidence along a portion of the CAP canal in northeast Scottsdale.

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ABSTRACT

Subsidence due to groundwater withdrawal and resulting sediment compaction is an important environmental problem in the Basin and Range province of the southwestern United States. Remote sensing InSAR (Interferometric Synthetic Aperture Radar) data show a large subsidence bowl, approximately 4km by 2km, centered near Via Linda and Frank Lloyd Wright Boulevard in Northeast Scottsdale, Arizona (Pool 24 subsidence feature). The CAP (Central Arizona Project) canal has subsided approximately 0.5 meters (1.5 feet) there since construction in the late 1980s. This subsidence is a threat to the canal's maximum flow capacity, and has forced the CAP to raise the canal liner at a cost of more than $500,000. The Pool 24 feature and four additional ellipsoidal (in map view) subsidence bowls to the northwest trend N50W to N60W. Their attitudes and shapes suggest a large structurally controlled zone of subsidence along the southwestern McDowell Mountain-front.

We have performed a high sensitivity relative gravity survey, including elevation control using differential GPS, to measure microgal variations in the earth's gravitational field on the Pool 24 subsidence feature. These variations are caused by density contrasts between bedrock and alluvium. 540 gravity stations in an approximately 16 square kilometer area around the canal were established. These measurements are used to model the bedrock topography beneath the canal area. The residual gravity anomaly shows depth to bedrock increasing to the southwest, away from the mountain front. Features in the residual surface may correspond to boundaries of the subsidence bowl, and may indicate bedrock control on its attitude and shape.

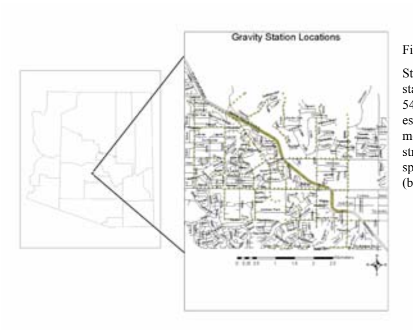

Figure 1:

Study area with gravity station locations plotted. 540 gravity stations were established, with 100-meter spacings along the streets and 50-meter spacings along the canal (both sides).

Figure 2:

Due to subsidence and the resulting loss of freeboard, the canal liner (arrows) was raised at a cost of about $500,000 between Cactus Rd. and Shea Blvd. View from Cactus Rd. Bridge, looking downstream (southeast).

HYPOTHESIS

The orientations and shapes of the subsidence bowls in the Paradise Valley Basin observed with InSAR indicate structurally controlled subsidence. The formation of an earth fissure near the Cactus Road bridge indicates a relatively steep drop-off in the bedrock/alluvium interface in that area. Gravity is used to model depth-to-bedrock to determine how the Pool 24 subsidence feature is controlled by the bedrock/alluvium interface.

METHODS

- Gravity measurements are made with a Scintrex CG-3M relative gravity meter (gravimeter) using standard gravity data collection procedures. The gravimeter has a standard resolution of 1 µgal with a standard deviation of <5 µgals.
- Differential GPS is used to establish station locations.
- A Complete Bouguer Anomaly (CBA) and a residual anomaly are produced.
- The slope and curvature of the residual anomaly are calculated to find variations.
- The residual gravity anomaly is used to model depth-to-bedrock.
- Incorporate the existence of an earth fissure in the study area.

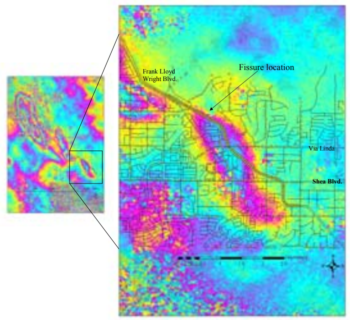

Figure 3:

These InSAR images show surface displacement and are therefore good tools for imaging subsidence. Each color cycle in these InSAR images (from green through the color cycle to green again) represents 2.8 cm of vertical displacement. The images span 1330 days from 1996-2000. Independent surveying done along the CAP canal shows maximum subsidence of 1.5 feet at the Via Linda bridge since canal construction (late 1980s).

The figure at left shows the subsidence features that exist near the McDowell Mountain front in Scottsdale, AZ. These ellipsoid features trend generally the same direction (N35W to N50W). Their similar trends and shapes could indicate a large scale structural (bedrock) control on subsidence in this area.

The Pool 24 feature is shown at right. An earth fissure has formed in the vicinity of the Cactus bridge, and indicates a steep drop-off in the bedrock/alluvium interface (see Figure 7). The InSAR image shows a high subsidence gradient in that area (green to blue in a short distance).

InSAR images produced by Sean M. Buckley at the Center for Space Research, University of Texas at Austin.

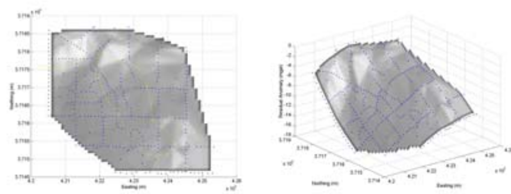

Figure 4:

Surface of the residual gravity anomaly. The residual anomaly is the result of variations in the near-surface geology. The figure on the left shows the location of the Pool 24 subsidence bowl (shown in yellow for reference). The figure on the right shows the residual anomaly surface. To the east, the residual is relatively flat, and it begins to drop off close to the boundary of the InSAR bowl. See Figure 3 for reference locations. (Plots produced in Matlab.)

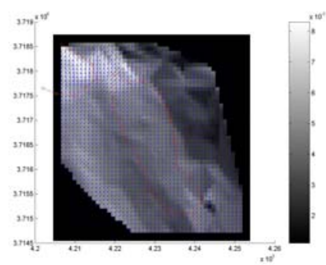

Figure 5:

Slope (values in mgal/m) of the residual anomaly, created by taking the residual's first derivative. The outline of the Pool 24 subsidence bowl is shown for reference. On the northeast side of the bowl, a linear feature trending roughly N30°W shows a break between a gentle slope to the east and a steeper slope to the west. The arrows are vectors representing the slope of the residual at each grid point. (They point toward more negative values.)

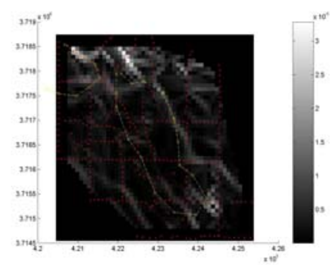

Figure 6:

Curvature (change in slope) of the residual anomaly, created by taking the residual's second derivative. The outline of the Pool 24 subsidence bowl is shown for reference. High curvature values exist for the linear feature described in Figure 5. This may represent a buried fault scarp, where the southwest has dropped down relative to the northeast.

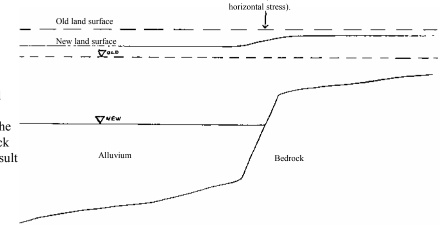

Figure 7:

Schematic drawing of bedrock controlled subsidence, which could produce the observed subsidence feature and the earth fissure. The bedrock structure could be the result of faulting or bedrock paleo-topography.

Figure 8:

Earth fissure in Pool 24 study area. The canal can be seen in the background. Looking west. See Figure 3 for location.

SUBSIDENCE AND EARTH FISSURES

Pore collapse due to the lowered water table is the process driving subsidence. As the water table is lowered, pores once supported by water become dry. The air in these pores can no longer support the mass above them, and they collapse. When this occurs over a thickness of de-watered alluvium, downward displacement occurs at the land surface. Points on the surface where the alluvium cover is thick subside more than where the alluvium is thin. This produces differential subsidence (observed using InSAR).

Differential subsidence produces horizontal stress in the alluvium. When the magnitude of the stress is high enough, horizontal strain and tensile failure occurs, resulting in the formation of an earth fissure. See Figure 7

CONCLUSIONS

Groundwater withdrawal is causing subsidence in the Paradise Valley Basin along the CAP canal. A gravity survey was performed to model depth-to-bedrock. Analysis of the residual anomaly shows a linear feature trending roughly N30°W. This feature is a break between a gentle slope to the east and a steeper slope to the west and an area of high curvature. When compared to the InSAR image, the feature is close to the boundary between subsiding ground and stable ground. This feature may represent a buried fault scarp, where the southwest has dropped down relative to the northeast. This hypothesis fits with the fissure model shown above (Figure 7). The formation of a fissure along a portion of this linear feature indicates a rapid drop-off in the bedrock/alluvium interface. Analysis of the residual anomaly and the formation of an earth fissure indicates bedrock control on the subsidence bowl's attitude and shape.

ACKNOWLEDGEMENTS

Funding for Summer and Fall 2002 research is provided by the Central Arizona Project (CAP). The Central Arizona – Phoenix Long – Term Ecological Research (CAP-LTER) project at Arizona State University provided funding for field work done in Summer 2001 and Summer 2002. We would also like to acknowledge Alex Richards at the Central Arizona Project for all of his help, Mimi Díaz at the Department of Geological Sciences at Arizona State University for her help with field and lab work this summer (funded by CAP-LTER), Marshall Brown of the City of Scottsdale (Water Resources) for providing high resolution topography data and Arnold Roy at the Frank Lloyd Wright Foundation for allowing access to Taliesin property.

Produced for CAP-LTER 2003 5th Annual Poster Symposium

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