RECONNAISSANCE INVESTIGATION OF GROUND CRACKS ALONG THE WESTERN MARGIN OF PAROWAN VALLEY, IRON COUNTY, UTAH

by

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ABSTRACT

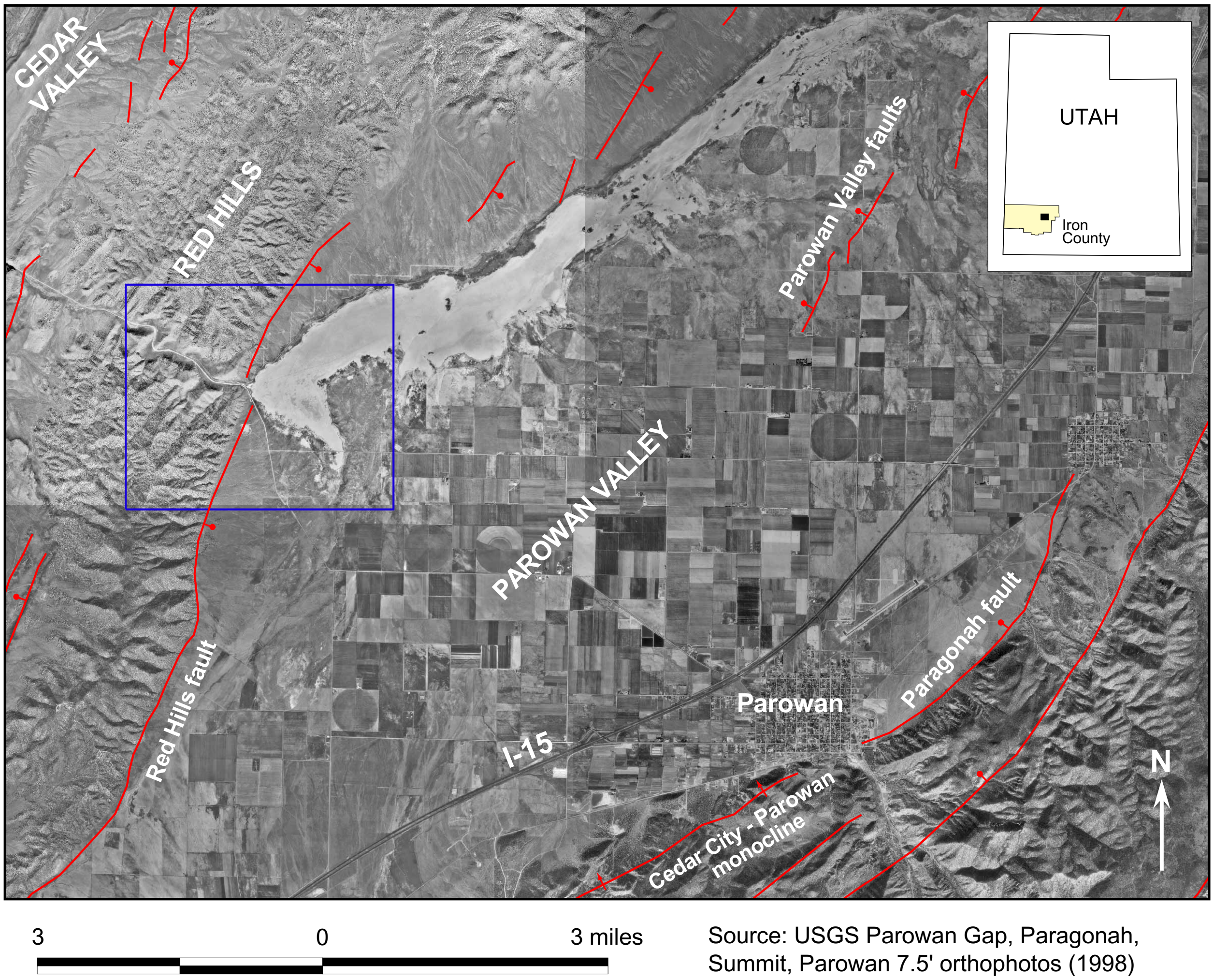
We investigated ground cracks localized at the eastern end of Parowan Gap and the western margin of the Little Salt Lake playa within western Parowan Valley in Iron County, Utah. Our reconnaissance investigation focused on determining the extent of the ground cracks and understanding the geologic and hydrologic conditions responsible for their formation. The ground cracks range from several meters to about 200 m long, and form east-west- to northwest-southeast-oriented, linear to arcuate traces on unconsolidated alluvial-fan and playa sediments, as well as the Parowan Gap road. Depending on the surface (e.g., alluvial fan, playa, road), the cracks are expressed as either closed to interconnected, elongate depressions or continuous hairline cracks. The depressions are tens of centimeters wide by up to a meter deep, indicating erosion by surface-water flow and subsurface piping. The cracks have been active since at least 1995.

We conclude that the ground cracks are localized features related to the desiccation and irreversible consolidation of clay-rich playa deposits due to a lowered ground-water table. A rapid increase in ground-water withdrawal in central Parowan Valley beginning in the early 1990s may have resulted in a lowered water table along the western valley margin, near Parowan Gap. However, a lack of well data for the Parowan Gap area and either insignificant or undetected subsidence in Parowan Valley preclude making a definitive correlation between ground-water withdrawal and the formation of ground cracks. To fully understand the origin of the ground cracks we recommend regional investigations to quantify potential subsidence in central Parowan Valley and clarify the hydrogeological framework of the area.

INTRODUCTION AND PURPOSE

On August 24 and 25, 2004, we investigated a series of generally east-west-trending ground cracks and centimeter-to-meter-scale depressions formed on alluvial-fan, hillslope, and playa-margin deposits within and adjacent to Parowan Gap, at the western margin of Parowan Valley in Iron County, Utah (figure 1). Parowan Valley occupies a northeast-southwest-oriented basin structurally controlled by the west-dipping Paragonah fault to the east and the east-dipping Red Hills fault to the west (Black and others, 2003). The basin geometry is asymmetric, and basin-fill deposits thicken to the east (Hurlow, 2002); the Little Salt Lake playa extends along the western margin, east of Parowan Gap and the Red Hills normal fault (figure 1). The playa surface formed during the Holocene due to uplift along the Red Hills fault and blockage of Parowan Gap with alluvial-fan sediments (Nielson, 1983; Anderson and Christenson, 1989; Maldonado and Williams, 1993). At the time of this investigation, the western part of the Little Salt Lake basin was a desiccated playa surface.

We performed this reconnaissance investigation to determine the extent and nature of the ground cracks. Our documentation of ground cracks is extensive, but by no means exhaustive. The scope of work for the investigation included examination of



Source: USGS Parowan Gap, Paragonah, Summit, Parowan 7.5' orthophotos (1998)

Figure 1. Parowan Valley, east of Cedar Valley. Red lines are Quaternary fault traces (Black and others, 2003); ball and bar on downthrown side, arrow points to downwarped side of monocline. Blue box indicates extent of figure 2.

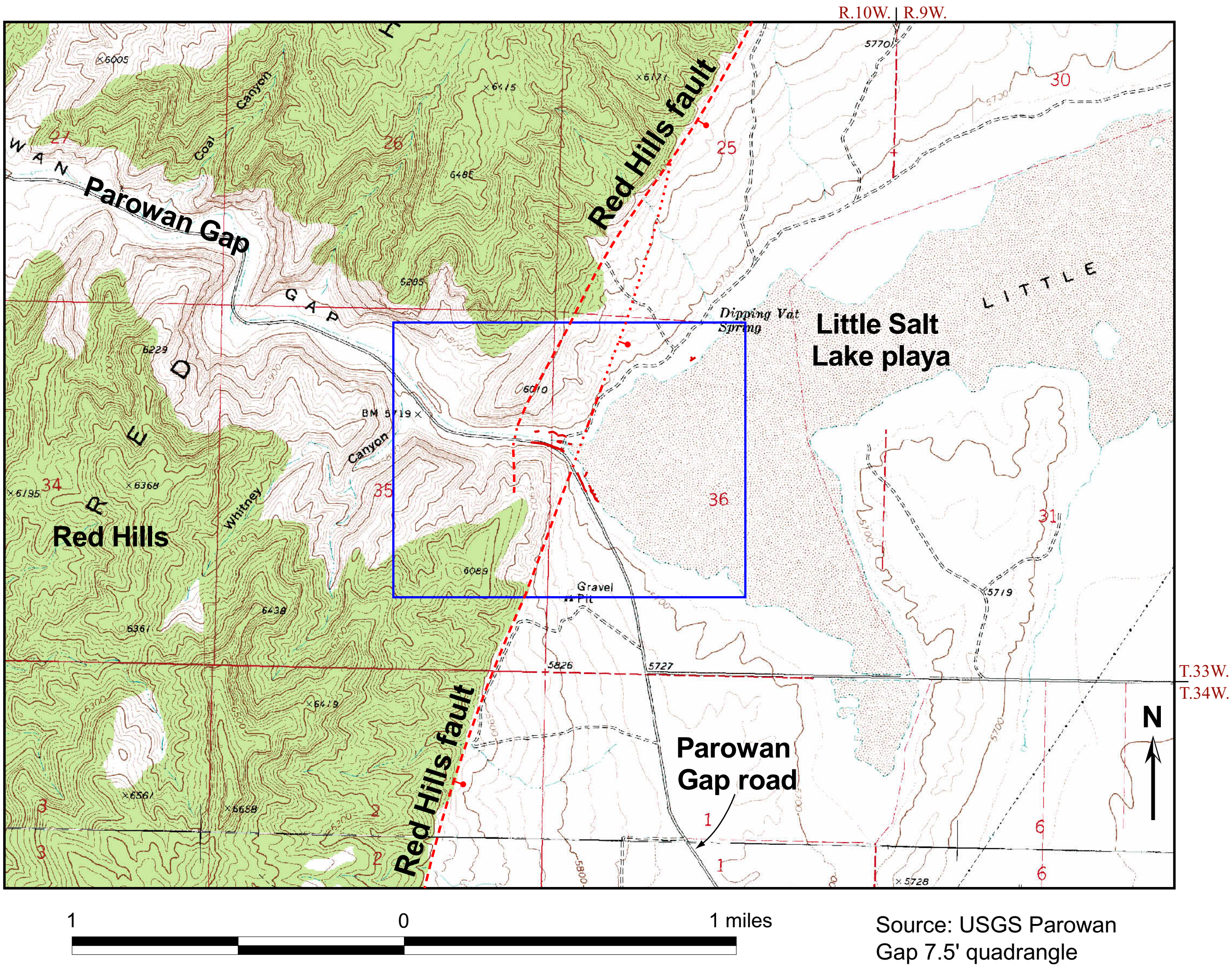


Figure 2. Western Parowan Valley, along the western margin of the Little Salt Lake playa. Solid red lines represent ground cracks. Red dashed and dotted lines indicate inferred location of the Red Hills normal fault; ball and bar on downthrown side (modified from Maldonado and Williams, 1993). Blue box indicates extent of figure 3.

aerial photographs, review of published geologic and hydrogeologic reports and maps (Maldonado and Williams, 1993; Hurlow, 2002), and construction of a geologic cross section across Parowan Valley, based on 51 water-well logs. Fieldwork focused on locating, describing, mapping (with a hand-held GPS unit), and photographing the ground cracks at the western margin of Parowan Valley (figure 2).

CONCLUSIONS

We conclude that the ground cracks along the western margin of the Little Salt Lake playa and within Parowan Gap are localized features related to the desiccation and compaction (i.e., irreversible consolidation) of clay-rich playa deposits, due to a lowered water table. Ground-water withdrawal in central Parowan Valley, combined with the current drought conditions, may be the controlling factors in the dewatering of the westernmost playa sediments. However, the lack of evidence for ground subsidence in central Parowan Valley and inadequate well control for the western valley margin (Parowan Gap area) preclude attributing a postulated ground-water-level decline at Parowan Gap to increased pumping in Parowan Valley.

If the ground cracks are related to ground-water withdrawal, then their localized nature in the area of historically shallowest ground water and most susceptible soils may indicate an early stage of aquifer compaction. Subsidence in central Parowan Valley near pumping wells may be inhibited by coarse-grained and minimally compactable basin-fill sediments, or overlooked due to an inability to detect it at the wellhead. Continued work investigating the potential for broad areas of subsidence within Parowan Valley and clarifying the hydrogeological setting of the basin is required to unequivocally attribute the ground cracks to increased ground-water development.

Due to continued drought conditions and demand for ground-water resources at the time of this investigation, the ground cracks are expected to remain active. Storm runoff may continue to erode the ground cracks, forming more continuous, meter-scale crack systems, which may pose a hazard to humans, livestock, and vehicle traffic on the Parowan Gap road.

BACKGROUND

Physical Setting and Geology

Parowan Gap is a narrow antecedent drainage cut into the Red Hills that drains western Parowan Valley westward toward the Escalante Desert. The ground cracks are located at the eastern end of Parowan Gap and along the western margin of the Little Salt Lake playa surface at approximately 5680-5700 ft (1731-1737 m) elevation (figure 2). In general, the cracks contour the western margin of the Little Salt Lake playa on the hanging wall of the Red Hills fault, and extend into Parowan Gap on the footwall. The

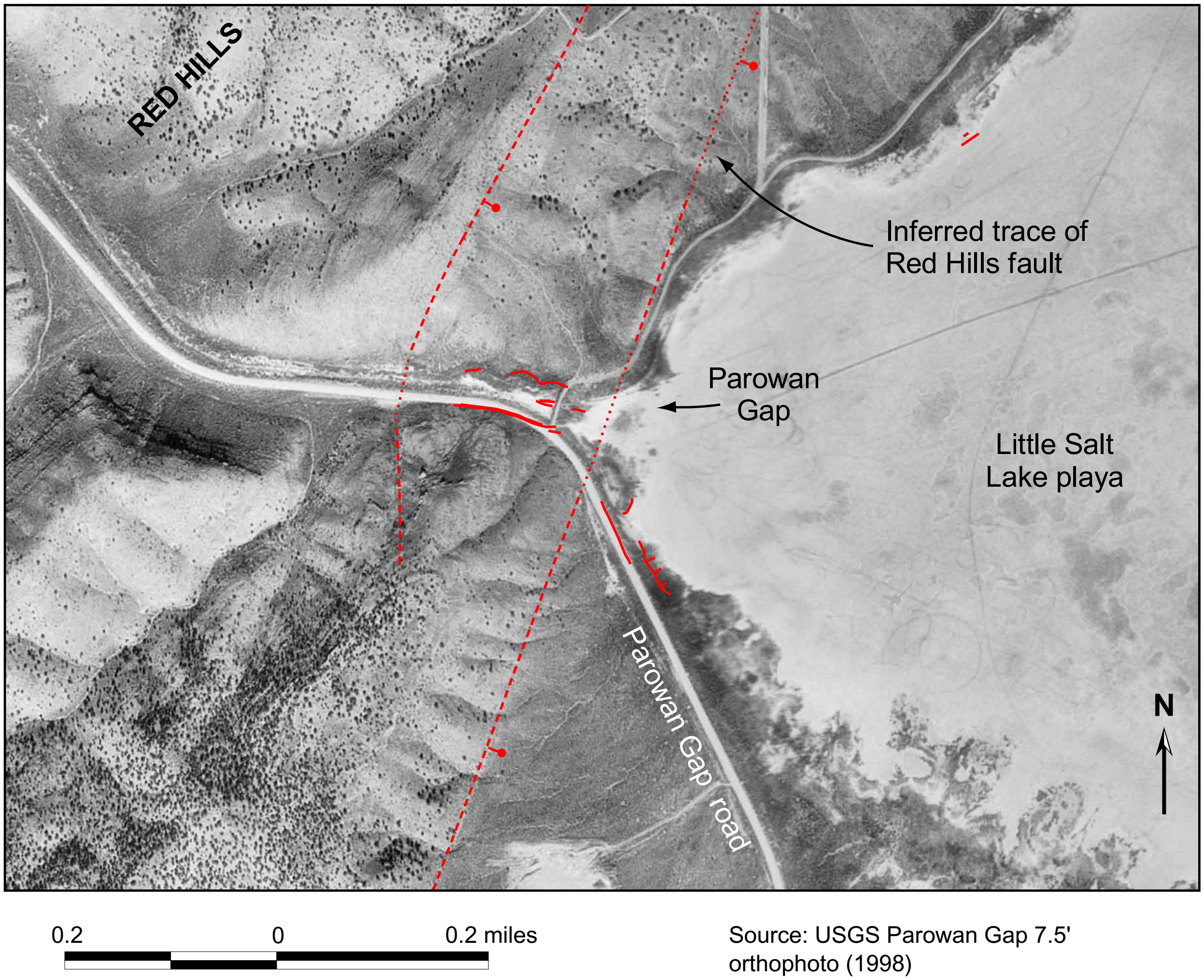


Figure 3. Ground cracks (solid red lines) along the western margin of the Little Salt Lake playa. Dashed and dotted red lines indicate the inferred location of the Red Hills normal fault; ball and bar on downthrown side (modified from Maldonado and Williams, 1993).

Red Hills fault strikes northeast-southwest, dipping east below Parowan Valley, and possibly intersecting the Paragonah fault at depth (Hurlow, 2002).

Along the western margin of the Little Salt Lake playa, we infer that Holocene alluvial-fan and hillslope deposits overlie a thin (several-meter-thick) finger of Holocene playa sediments extending into Parowan Gap (figure 3). The overlying deposits include unconsolidated and uncemented red-brown silty-sandy alluvial-fan sediments and slope-wash colluvium approximately 20-25 cm thick, with abundant subrounded 1-2.5 cm clasts. The red-brown fan alluvium overlies and in places is interbedded with more cemented chalky-gray, pebble-rich fan alluvium. At a depth of 50 cm the gray fan alluvium is more indurated, indicating increased cementation, compaction, and/or carbonate development. No pin-hole structure was observed in the alluvial-fan deposits. The playa deposits, which underlie the fan sediments and make up the bulk of the Little Salt Lake playa, are clay- and silt-rich, and are much more cohesive. Near the playa margin, the upper part (15-18 cm) of the deposits is dry and has moderate pin-hole structure.

Ground Water

Ground water generally occurs in an unconfined basin-fill aquifer in Parowan Valley, although confining beds exist locally. Springs are present in the Parowan Gap area, although all were dry at the time of this investigation. Parowan Gap is the outlet for surface drainage from Parowan Valley, and therefore we presume represents the area of shallowest historical ground-water tables, although no wells presently exist in the area. Monitoring wells in central Parowan Valley indicate that the potentiometric surface, or water table in an unconfined aquifer, slopes gently to the east and south (Howells, 2003). Principal recharge to Parowan Valley is from the east.

Table 1. *Depth to ground water for monitoring wells shown on figures 10 & 11.*

Monitoring well	1975 water level (m)	2002 water level (m)	Drawdown (m)
A	1	10	9
B	8	17	9
C	9	28	19
D	47	57	10

Data are from Howells (2003). All levels are in meters below ground surface.

Ground-water withdrawal in Parowan Valley has increased significantly since the mid-1980s to early 1990s due to persistent drought and an increased number of pumping wells (Howells, 2003). As of 2002, the total volume of ground water withdrawn in Parowan Valley was approximately 39,000 acre-feet (Howells, 2003). This amount is expected to increase as the network of working water wells is expanded. The withdrawal of ground water in Parowan Valley is significant, resulting in a lowered water table across at least central Parowan Valley. Over about four decades, from the early 1960s to the present, water levels in monitoring wells have fallen as much as 31 m, with the level in many wells dropping 9-19 m (table 1) (Howells, 2003). Western Parowan Valley may have experienced a water-table decline as well; however, well-level data are limited to the central parts of the valley.

DESCRIPTION OF GROUND CRACKS

Northern Parowan Gap

Along the northeastern part of Parowan Gap, east-west-oriented arcuate cracks extend across south-sloping alluvial-fan and hillslope-colluvium deposits (figures 4 and 5). Numerous small, disconnected depressions are aligned in an east-west direction, and are locally eroded by surface-water flow and piping, forming several 20-25-m-long eroded cracks and elongate depressions. The cracks have an en-echelon pattern and extend for a total of 124 m. Depressions range from less than 2.5 to 43 cm wide and less than 6 cm to about a meter deep, and most are about 15 cm wide by 30 cm deep, separated by 0.3-1.2 m (figure 5). The depressions commonly continue laterally below the surface along the trend of the crack, indicating active piping. No uneroded "hairline" cracks connecting the depressions were observed.

Southern and Central Parowan Gap

Along the southern part of Parowan Gap, sinuous, hairline cracks cut across the Parowan Gap road in an east-west direction (figure 6). The cracks are continuous, extend for 110-170 m, and locally form a narrow (about 1 m wide), shallow (less than 2 cm deep) symmetric graben. Collapse of the pavement indicates void spaces below the road surface, possibly due to piping of road construction materials (figure 7). According to the Iron County Road Department, damage to the Parowan Gap gravel road was first recorded in 1995, and hairline cracks were repaired shortly after the road was paved in 1998. About 35 m north of the road, ~45-m-long ground cracks and depressions extend in an east-west direction across playa deposits in the middle of Parowan Gap, normal to a north-south-oriented raised dirt road across the playa deposits (figure 3). The cracks are 10-20 cm wide and tens of centimeters deep due to erosion by surface-water flow; the closed depressions are up to a meter wide and tens of centimeters deep, and are possibly related to subsurface piping.

Playa Margin

East of Parowan Gap, northwest- to northeast-oriented ground cracks and centimeter-to-meter-scale depressions parallel the western margin of the Little Salt Lake playa (figure 3). Along the southwestern margin, south of Parowan Gap, meter-scale cracks, 12-18 cm wide and up to 30 cm deep, parallel both the playa margin and a continuous hairline crack on the Parowan Gap road for approximately 150-200 m (figure 8). Also, short, polygonal, centimeter-scale tension cracks locally outline areas of gentle subsidence, and are eroded by surface-water flow and piping (figure 9). The northwestern playa margin is characterized by centimeter- to meter-scale cracks and an area of local subsidence about 12 m long by 6 m wide by 0.5 m deep, with the long axis parallel to the margin. South of the depression, a meter-scale crack has formed due to

Figure 4. Ground cracks along the northern part of Parowan Gap. Part of scale visible in foreground is about 15 cm long (10 cm divisions). View is to the southwest.

Figure 5. Ground cracks eroded by surface-water flow and piping. Scale is 50 cm long (10 cm divisions).

Figure 6. Hairline cracks along Parowan Gap road. Road patches indicate collapse of subsurface erosional pipes below the surface. View is to the east.

Figure 7. Evidence for piping below a dirt road, along strike of cracks on the Parowan Gap road (top of photo). Part of scale visible is about 20 cm long (10 cm divisions). View is to the west.

Figure 8. Ground crack (middle of photo) along southwestern playa margin, adjacent to centimeter-scale desiccation cracks (foreground). Hand-held GPS unit is for scale.

Figure 9. Eroded ground cracks along (A) the southwestern playa margin, adjacent to Parowan Gap (pen is for scale), and (B) the northeastern playa margin (crack is approximately 50 cm wide by 50 cm deep) (view is to the southwest).

surface-water flow and piping into an approximately 2.5-cm-wide uneroded crack in clay-rich sediments 15-20 cm below the ground surface (figure 9).

DISCUSSION

Several processes may be responsible for the formation of ground cracks within Parowan Gap and adjacent to the western margin of the Little Salt Lake playa deposits, including: (1) compaction of silt- and clay-rich deposits in the Little Salt Lake aquifer due to lowering of the ground-water table, (2) desiccation of clay-rich deposits along the margin of the Little Salt Lake playa due to lowering of the ground-water table, (3) hydrocompaction of alluvial-fan and slope-wash sediments due to recent precipitation and surface-water flow, and (4) deformation of playa and alluvial-fan deposits due to active fault movement.

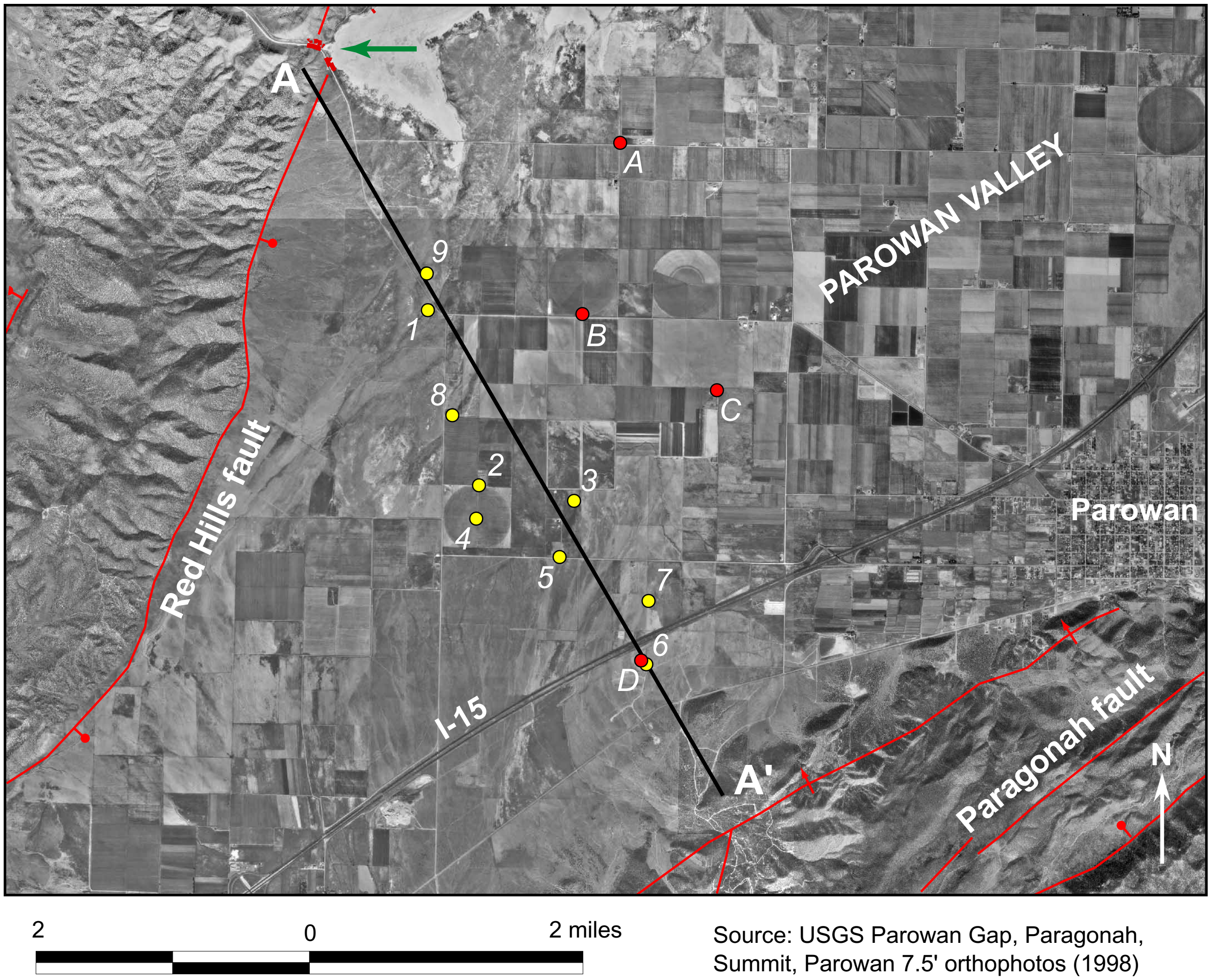
Compaction of the Parowan Valley Aquifer

Compaction of the Parowan Valley aquifer due to severe drought conditions and withdrawal of ground water is a reasonable explanation for the ground cracks. Compaction refers to the irreversible compression or consolidation of less permeable aquifer layers during aquifer drainage (Galloway and others, 2004). Parowan Valley occupies an asymmetric structural basin, with the western flank dipping gently eastward toward the basin center. A cross-sectional interpretation of the basin fill, based on water-well logs, indicates that the majority of aquifer units are laterally continuous and interconnected across the basin (figures 10 and 11; table 2). Thus, ground-water withdrawal in the center of the valley could result in a water-level drop in the western part of the valley, near the Little Salt Lake playa. Aquifer compaction due to a loss of pore space results in general subsidence of the basin (e.g., San Joaquin Valley, California; Galloway and others, 2004), and/or ground cracks (e.g., Picacho Basin, Arizona; Pool and others, 2000), which are commonly long, linear, and deep, and parallel the basin margin (Harris, 2004).

***Table 2**. Water well locations and depth to bedrock*

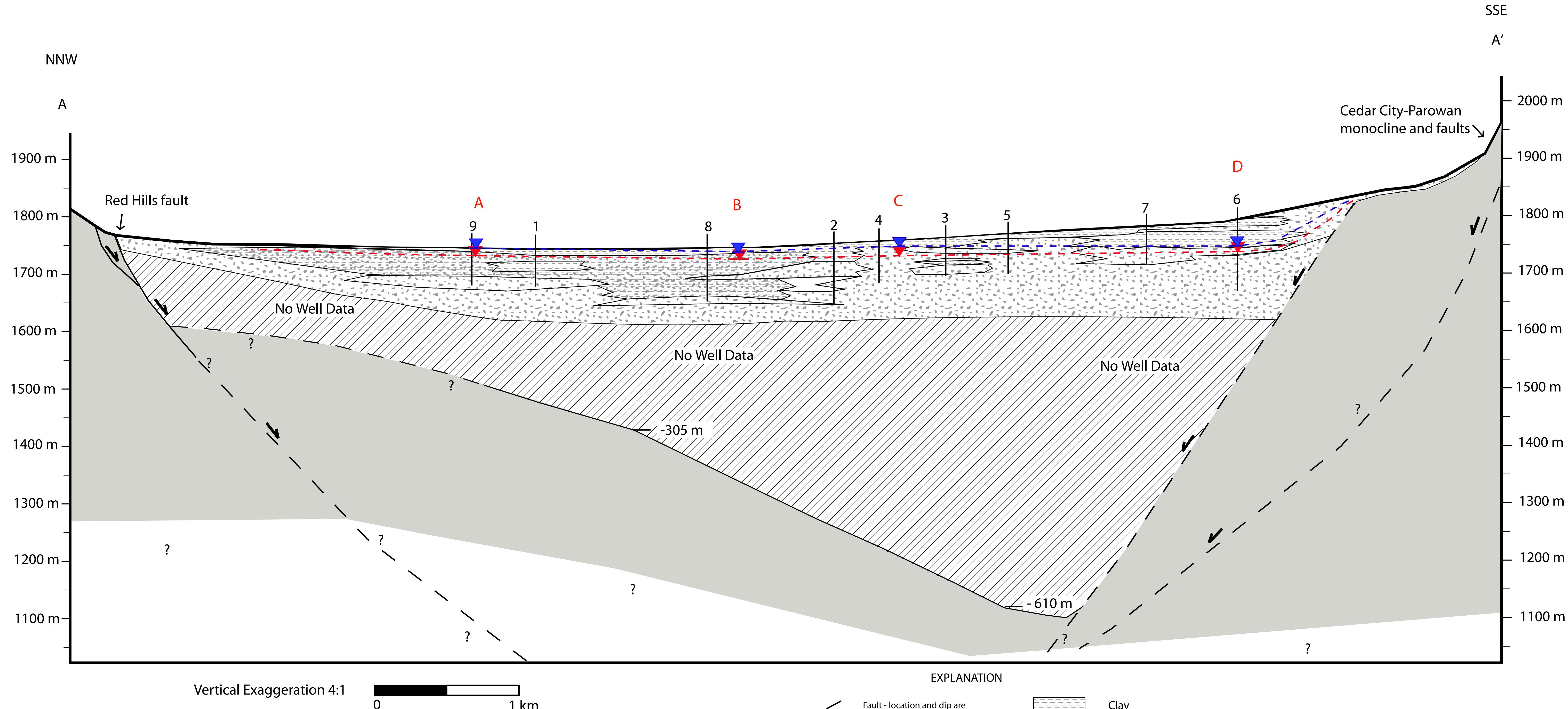
Well reference # [a]	UTM Location (easting, northing)	Depth to bedrock (m) [b]
1	330960, 4192969	>62
2	331366, 4190262	>91
3	332491, 4190051	>62
4	331257, 4189855	>61
5	332414, 4189437	>68
6	333333, 4188167	>120
7	333337, 4188891	>61
8	331047, 4191077	>84
9	330674, 4192750	>61

[a] Corresponds to water-well labels on figures 10 & 11.
[b] Estimated depth to bedrock based on well drillers logs. Logs are available from the Utah Division of Water Rights Web site (<http://www.waterrights.utah.gov>).



Source: USGS Parowan Gap, Paragonah, Summit, Parowan 7.5' orthophotos (1998)

Figure 10. Location of cross section A-A' (figure 11). Yellow dots indicate location of water wells used for cross section (well numbers correspond to figure 11 and table 2); red dots represent location of monitoring wells (from Howells, 2003) used for the potentiometric surface (letters correspond to figure 11 and table 1). Green arrow indicates location of ground cracks investigated in this study. Quaternary fault traces (red lines) from Black and others, (2003); ball and bar on down thrown side, arrow points to downwarped side of monocline.



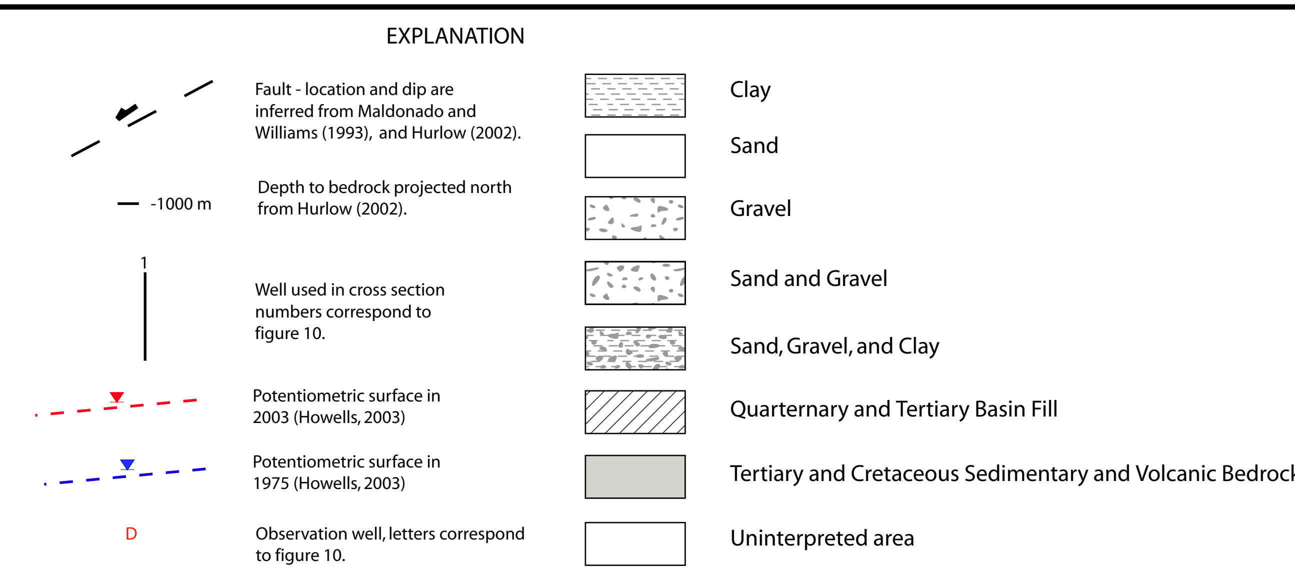


Figure 11. Cross section A-A'. North-northwest to south-southeast cross section through the Parowan Valley. Location of cross section shown on figure 10. Well numbers and letters correspond to figure 10 and tables 1 and 2. Faults north-northwest to south-southeast include the Red Hills fault (Maldonado and Williams, 1993), unamed fault (Hurlow, 2002), and the Cedar City-Parowan monocline and faults (Black and others, 2003).

No evidence of surface cracking or subsidence was apparent near the wellheads of the 51 water wells examined; however, all wells terminate at approximately 60-120 m below the surface in the upper basin fill, and subsidence may not be evident. Along the western playa margin, localized ground cracks and areas of subsidence may be a result of a lowered water table; however, the most continuous and linear cracks are oriented normal to the western margin of Parowan Valley. The ground cracks are very localized features, and western Parowan Valley may be the only location where subsidence is expressed as ground cracks at the surface due to the abundance of fine-grained playa deposits, in contrast to the more coarse-grained alluvium in the parts of the basin near pumping centers.

Desiccation of Playa Deposits

The dewatering of silt- and clay-rich material results in tension across the material and the development of polygonal desiccation cracks, commonly tens of centimeters (i.e., mudcracks) to tens to hundreds of meters (i.e., giant desiccation cracks; Harris, 2004) across. The network of cracks along the southwestern margin of the playa is consistent with a desiccation origin, based on the roughly polygonal-shaped tension cracks. Erosion and piping at the surface and the exposure of an uneroded 2.5-cm-wide crack in a clay unit approximately 15-20 cm below the playa surface indicate that the underlying clay unit may develop meter-scale desiccation cracks, whereas the silty upper part of the playa develops centimeter-scale cracks. This model explains the voids and eroded features, including continuous crack systems on the playa surface, but does not account for local subsidence along the margin and the linear and continuous cracks within Parowan Gap. The centimeter- and meter-scale cracks may or may not be correlated with ground-water development in the Parowan Valley, as desiccation cracks can occur as a result of both natural and human-related reductions in ground-water level.

Hydrocompaction

The playa-margin deposits locally contain slope-wash colluvium and both distal fan and stream alluvium (Maldonado and Williams, 1993), which may be subject to hydrocompaction when wetted. The upper part (15-18 cm) of these deposits exhibits moderate pin-hole structure, which may increase the susceptibility of the deposits to collapse with sufficient surface-water infiltration. The alluvial fans within Parowan Gap do not have noticeable pin-hole structure, due to organic soil horizons and potentially water-lain pebble-gravel deposits. Along the playa margin, arcuate tension cracks, hummocky topography, and highly-vegetated areas of subsidence may indicate local hydrocompaction, though it is not considered the main mechanism for ground-crack generation. Within Parowan Gap, the linear ground cracks do not fit with typical hydrocompaction cracks, and a linear wetting front necessary to generate linear hydrocompaction cracks on the alluvial fans is not easily explained. Flooding of the playa would generate a linear wetting front; however, no evidence for a historical flood above the current playa margin exists. Although a hydrocompaction model does not explain the linear cracks within Parowan Gap, the model may explain local subsidence features found along the southwestern margin of the playa deposits, and cannot be precluded as contributing to ground cracking.

Active Tectonism

We do not consider tectonic movement along faults to be a plausible explanation for the ground cracks. Mapped faults in the Parowan Gap area strike north-northeast and have not been active during the Holocene (Black and others, 2003). In general, the ground cracks are oriented east-west and parallel the playa margin rather than the mapped faults. Concealed east-west-oriented faults collocated with the Parowan Gap cannot be precluded; however, subsidence along such faults would not explain the margin-parallel cracks along the southwestern part of the playa, and lack of vertical differential displacement along the crack systems within Parowan Gap. Subsidence along an active but buried normal fault would be expressed as vertical offset of the ground surface (forming a linear fault scarp). Within Parowan Gap, ground cracks and minor subsidence are inferred to be limited to the buried playa deposits. This supports a ground-water-related origin for the ground cracks.

SUMMARY

Ground cracks are localized at the eastern end of Parowan Gap and the western margin of the Little Salt Lake playa, and have been active since at least 1995. The crack traces are east-west- to northwest-southeast-oriented, and tens to hundreds of meters long. The cracks are arcuate and en echelon within Parowan Gap, and segmented and polygonal along the southwestern playa margin. In general, the ground cracks are limited to clay-rich playa deposits, with varying crack properties a function of different overlying material (silt-rich playa deposits, alluvial-fan sediments, and road construction material). We found no uneroded cracks on the fan sediments within Parowan Gap, and observed no vertical differential displacement across the cracks. Surface-water flow and subsurface piping have eroded the cracks, which originally may have been less than a few centimeters wide, to form significant depressions up to about 1 m deep and 0.5 m wide. We observed localized areas of subsidence along the western margin of the Little Salt Lake playa.

We observed no evidence of subsidence at water wells in the Parowan Valley. The Parowan Valley aquifer consists of interconnected and laterally continuous aquifer units, and ground-water development in the center of the valley may lower the ground-water level along the western flank of the valley. Ground-water development in Parowan Valley is significant, and water levels in most wells have dropped 9-19 m since the early 1960s.

We conclude the following:

- Along the northern and southern margins of Parowan Gap, ground cracks and depressions on alluvial surfaces and pavement, respectively, are inferred to be related to ground cracks in clay-rich playa deposits at depth.
- The Parowan Gap ground cracks may be related to desiccation and compaction (i.e., consolidation) of the clay-rich sediment, possibly a result of ground-water development in Parowan Valley heightened in the 1990s (Howells, 2003) when the cracks were first reported.
- The ground-water-level decline in central Parowan Valley is significant, but cannot be directly correlated with the formation of ground cracks without further investigation and monitoring.

RECOMMENDATIONS

To better understand the origin of the ground cracks we recommend the following:

- Application of satellite interferometry (InSAR) to quantify possible subsidence across the entire Parowan Valley.
- An investigation into the hydrogeology of Parowan Valley to better understand the basin-fill stratigraphy and nature of the ground-water aquifer(s).
- Completion of a thorough search for ground cracks along the southern and northern margins of the Little Salt Lake playa, and the monitoring of existing ground cracks and the top of water wells for continued or new movement.

Geologic investigations such as excavating trenches across the cracks and drilling to determine soil types and ground-water levels in the Parowan Gap area would also assist in understanding the cause of the cracks.

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