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Investigation of Subsidence Along Segment of Missouri Route 65, Springfield, Missouri

by

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16. Abstract

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The interpretation of the ERT data indicates the limestone roof rock above the tunnel is dissected by several prominent clay-bearing near-vertical solution-widened fractures (joints or faults) that are not visually exposed on the ceiling of the tunnel. Roof rock failure in the mine access tunnel occurred at the intersection of projected northwest trending lineament and one of the more prominent solution-widened fractures identified on the ERT data.

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INVESTIGATION OF SUBSIDENCE ALONG SEGMENT OF MISSOURI ROUTE 65, SPRINGFIELD, MISSOURI

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Abstract

Electrical Resistivity Tomography (ERT) data were acquired on the ground surface across an underground limestone mine access tunnel in an effort to characterize the roof rock. This investigation was conducted because simultaneous localized failure occurred on the ceiling of the access tunnel and elsewhere in the mine along a previously unknown northwest trending lineament.

The interpretation of the ERT data indicates the limestone roof rock above the tunnel is dissected by several prominent clay-bearing near-vertical solution-widened fractures (joints or faults) that are not visually exposed on the ceiling of the tunnel. Roof rock failure in the mine access tunnel occurred at the intersection of projected northwest trending lineament and one of the more prominent solution-widened fractures identified on the ERT data.

Introduction

In 2007, simultaneous localized roof rock failure occurred in a mine access tunnel and several rooms elsewhere in a limestone aggregate mine. A plot of incident locations indicated the failures occurred along a previously unknown northwest trending lineament. The approximate location and orientation of the lineament is shown in Figure 1. The lineament, as shown in Figure 1, extends across public roadway and intersects the access tunnel to the west of the DOT right-of-way (ROW).

The rock fall debris in the access tunnel was comprised of limestone. However, in other areas of the mine, significant quantities of clay was intermixed with the fallen rock, suggesting failure occurred along a pre-existing solution-widened fracture (joint or fault). The linear and vertical nature of the more extensive roof failures indicated collapse probably occurred along a previously unknown near-vertical solution-widened fracture (joint or fault).

To prevent further rock fall, anchor bolts were installed immediately in the ceiling of the access tunnel (Figure 2). During the installation of the anchor bolts, workers encountered uniform Burlington-Keokuk limestone; there was no evidence of prominent clay-filled solution-widened fractures (Figures 2 and 3). However, water with entrained sediment flowed through several narrow fractures (estimated widths of less than 0.25 in) in the collapse zone (Figure 4). It was noted that the fractures through which water flowed were oriented east-northeast, rather than northwest (parallel to the projected lineament).

In an effort to determine the cause of the rock fall and to elucidate the geologic nature of the projected lineament, electrical resistivity tomography (ERT) data were acquired along four parallel traverses located on the shoulders of the north and south bound lanes and in the median (Figure 1).

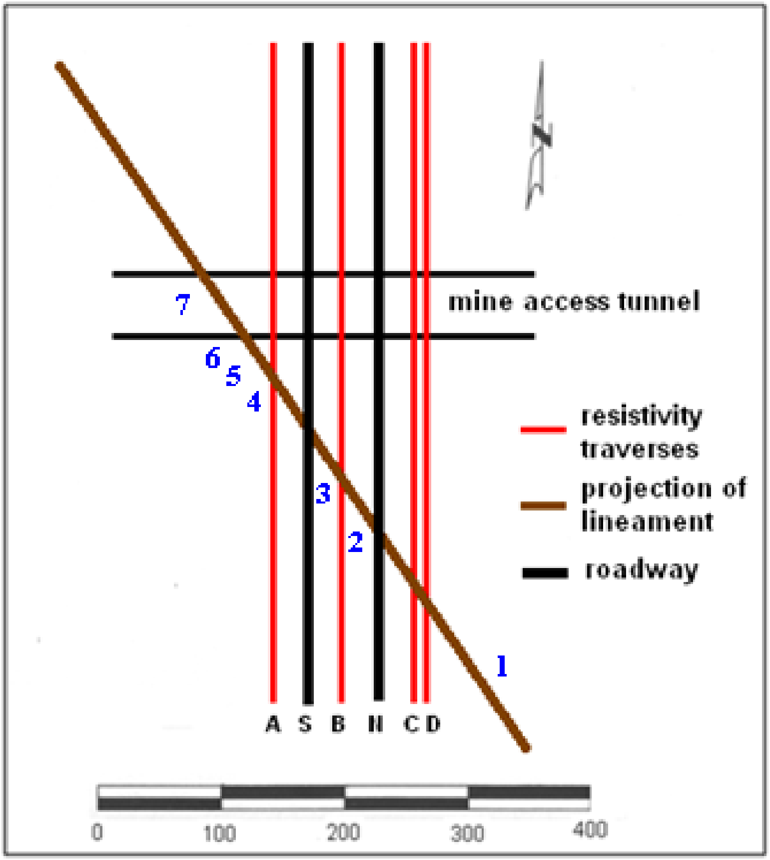

Figure 1: Map of study site showing locations of four north-south surface electrical resistivity tomography profiles (A, B, C and D). The centerlines of the northbound (N) and southbound (S) roadways, the mine access tunnel, the projected lineament and the approximate locations of seven boreholes are shown.

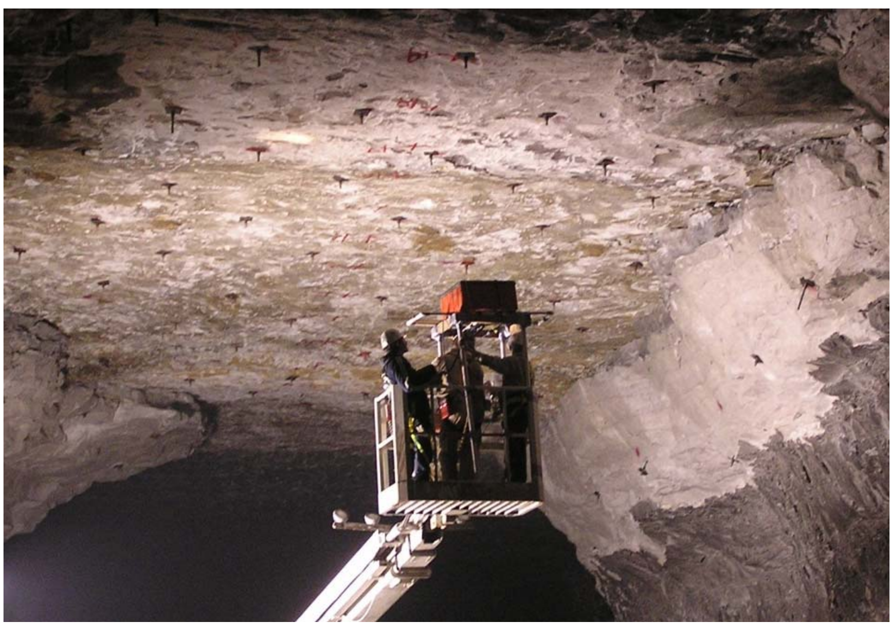

Figure 2: Photograph of ceiling of access tunnel several tens of feet to the west of the zone of failure. Newly installed rock bolts are observed. The crew is acquiring GPR data using a 200 MHz GSSI antenna in an effort to locate clay-filled solution-widened fractures.

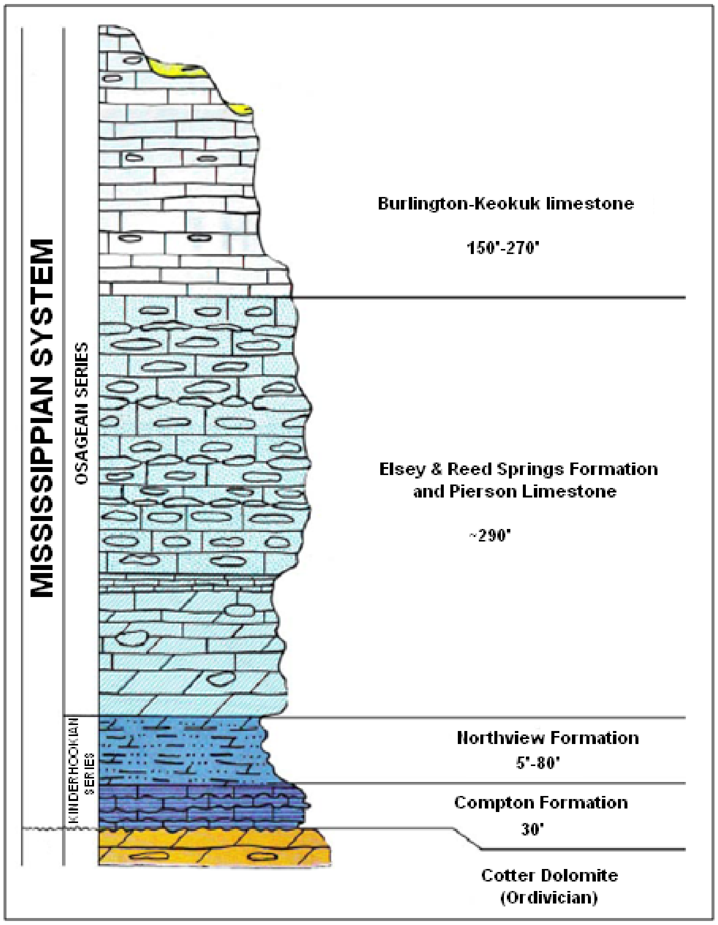

Figure 3: Stratigraphic column for the study site (after Fellows, 1970).

Figure 4: Water, with entrained sediment, flowed from several newly-exposed linear fractures in the collapse zone.

Geology and Mining

The shallow subsurface in the study area is comprised of a thin veneer of residuum (0-20 ft) overlying Mississippian Burlington-Keokuk limestone (Figure 2). The limestone, where it outcrops, is intensively jointed and faulted (Figure 5). Faults and lineaments in the Greene County tend to strike approximately northwest or northeast (Figure 6).

The Burlington limestone is "room and pillar" mined in the study area. The ceiling of the access tunnel (connecting mined areas on either side of the roadway; Figure 1) is at a depth of about 80 ft relative to the ground surface (elevated embankment). The ceiling of the access tunnel is not characterized by prominent solution-widened fractures. However, water, with entrained sediment, flowed freely from several newly-exposed linear fractures (estimated widths of less than 0.25 in) in the collapse zone.

The apparent relative uniformity of the roof rock immediately above the ceiling of the access tunnel is consistent with anchor bolt information and acquired ground penetrating radar (GPR) control. The workers who placed the anchor bolts reported relatively solid rock to depths of 10 ft at all anchor bolt locations. The interpretation of acquired GPR control also suggests the roof rock within 10 ft of the ceiling is not intensely karsted. On the GPR profile of Figure 7, a relatively uniform near-horizontal reflector (parallel to mine ceiling) is imaged at an estimated depth of about 10 ft (dielectric permittivity of 15 for moist limestone). Two less prominent vertical anomalies are observed centered at stations 39 and 46 (collapse zone). These anomalies appear to originate several feet from the mine ceiling and may be images of near-vertical fracture zones that are not prominently exposed on the mine ceiling.

Borehole Data

Seven exploratory boreholes were acquired in the study area in immediate proximity to the surface projection of the failure lineament (Figure 1 and Table 1). Overburden was not sampled in any of the borings, but is described as red, high plasticity residual clay with chert and limestone rock fragments. Its thickness is highly variable, ranging from 8.6 feet in Boring 1 to 24.8 feet in Boring 4.

The deepest borehole (Borehole 1) was drilled to 122.6 feet. Boreholes 2 through 7 were terminated at depths of between 39.3 feet to 90.0 feet. Burlington Limestone only was encountered in boreholes 2-7. This unit is generally described as gray to light gray, alternating from fine- to coarse-grained with occasional stylolites and fossils. At a depth of 94.5 feet in Boring 1 (off embankment), the Reeds Spring Formation was encountered. This unit is generally described as a brown to gray, fine grained limestone with chert nodules.

The Rock Quality Designation (RQD) for the Burlington-Keokuk limestone was generally in the Good to Excellent range, with some isolated core runs having RQDs in the Fair range. The lower RQD values are generally associated with broken zones near the overburden contact, healed vertical fractures, weathered seams, and/or fractures. Near-vertical clay-filled solution-widened fractures were not encountered in any of the boreholes. However, multiple fractures were encountered. Borehole 4 (Figure 1) which is on-line with the projected lineament (Profile A; Station 320) encountered open seams or fractures with and without flow at multiple depths (26.7 ft, 29.2 ft, 30.5 ft, 30.8 ft, 32.4 ft, 41.3 ft, 41.7 ft, 42.0 ft, 48.8 ft, 49.4 ft) and standing water at 47.9'.

Figure 5: Outcropping Burlington-Keokuk limestone is typically dissected by solution-widened joints or faults. The ceiling of the access tunnel in underground limestone (~100 ft below the ground surface) is not characterized by prominent fractures (Figure 2).

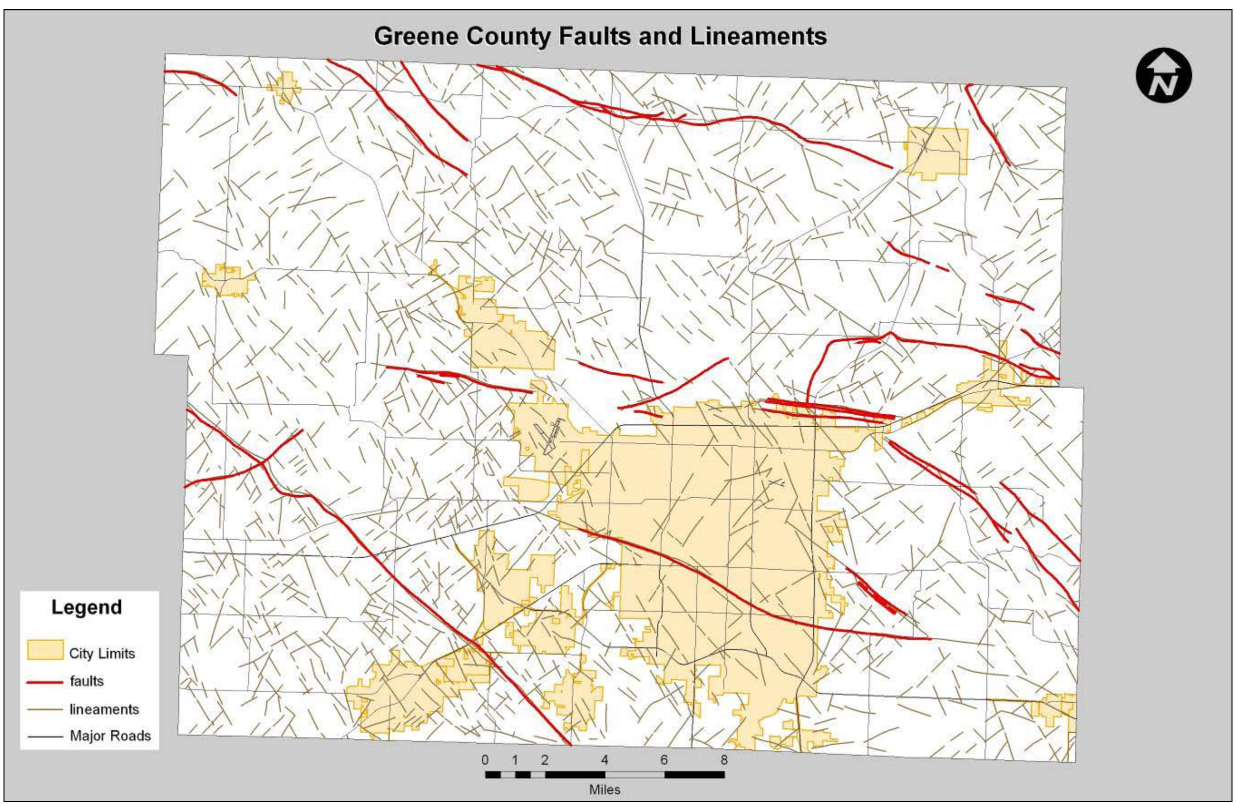

Figure 6: Locations and orientations of mapped faults and lineaments in Greene County (Coots, 2007). Faults and lineaments in the region tend to strike approximately northwest or northeast.

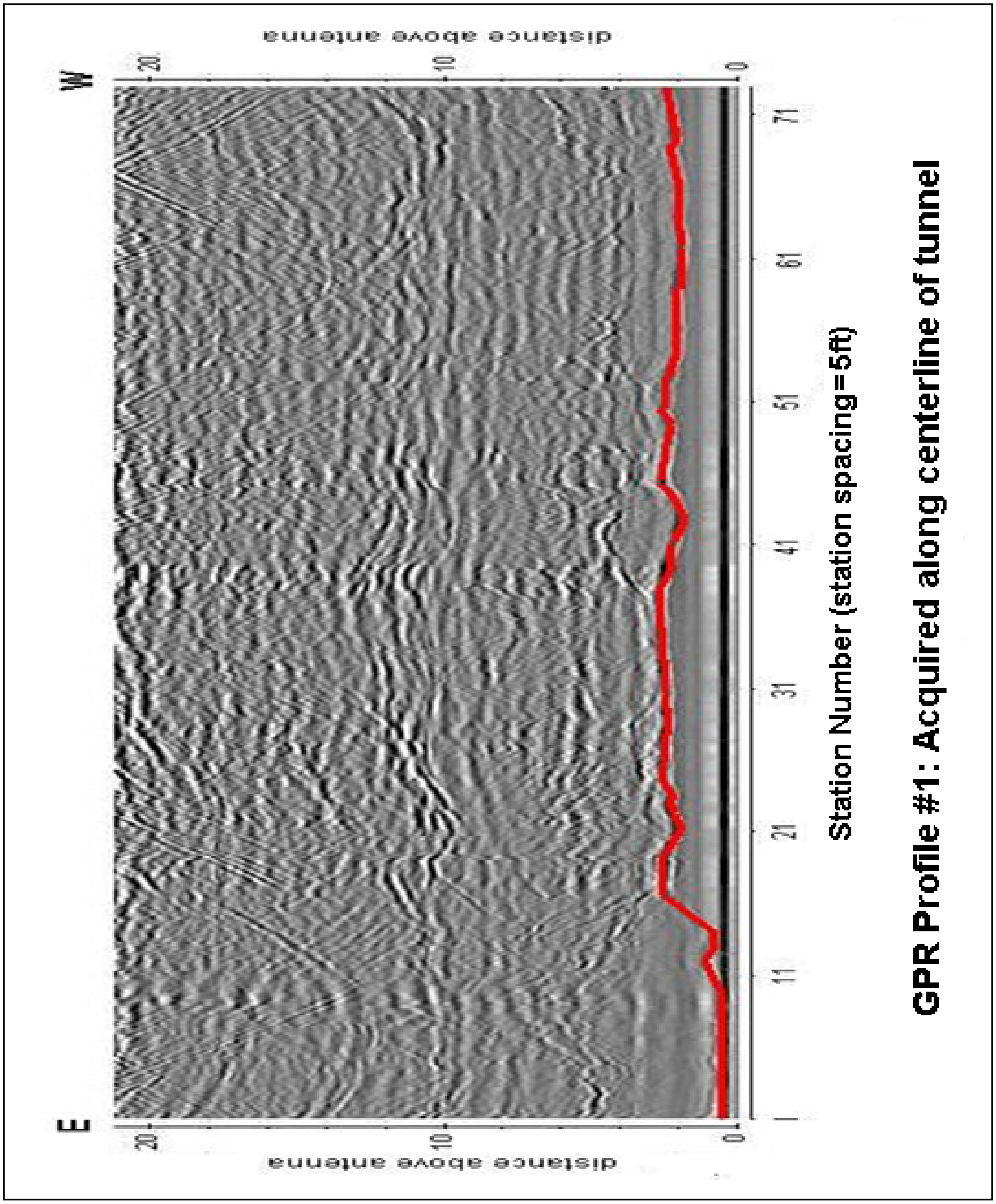

Figure 7: Example GPR profile (length ~370 ft) acquired along centerline of access tunnel ceiling using a GSSI 200 MHz antenna. The vertical axis is in feet; the lower continuous red line represents the surface of the ceiling. The apparent effective depth of investigation (highest prominent continuous reflector) is at least 10 ft.

Acquisition of Electrical Resistivity Tomography Data

Four parallel north-south ERT profiles (A, B, C and D) were acquired on the ground surface above the mine access tunnel in an effort to characterize the roof rock from the top down (Figures 1 and 8). The ERT data were acquired using a GSSI SuperSting R8 resistivity unit equipped with a dipole-dipole array consisting of 72 electrodes spaced at 5-ft intervals. The acquired field data were good quality with the exception of the northernmost segment of Profile C (Stations 0 to 300). This segment of Profile C is immediately adjacent to a metal guard rail. Poorer quality data was obtained along this segment of roadway, probably because some of the induced current flowed through the guard rail, rather than into the subsurface. The acquired resistivity data were processed using RES2DINV.

Interpretation of ERT Data

Uninterpreted versions of the ERT profiles are presented as Figure 8; interpreted versions of the four profiles acquired are displayed as Figure 9. The interpreted top of bedrock has been superposed on the ERT profiles. As indicated in Table 1 the interpreted top of rock correlates reasonably well with boring control (In addition to the boreholes listed in Table 1, the authors had access to 18 shallow borings placed in the roadway right of way that terminated at top of rock. These data were also used to constrain the interpretation of the ERT data). The locations of several interpreted near-vertical solution-widened fractures (joints or faults) have been highlighted on the ERT profiles.

To the south of Station 600, bedrock does not appear to have been extensively dissected by solution-widened fractures. The top of limestone bedrock, as per borehole control, correlates reasonably well with the 50 ohm-m contour interval (except where interpreted fractures are present). Soil to the south of Station 600 is characterized by resistivities less than 50 ohm-m. (The roadway embankment south of station 600 is elevated by only a few feet. The eastern right of way south of station 600 was largely covered by up to 1 ft or more of ponded water.)

As noted, the resistivity of bedrock to the south of Station 600 is less than 50 ohm-m only where interpreted solution-widened fractures are present. Presumably, bedrock in proximity to the fractures is more extensively fractured and weathered, and contains some clay. This interpretation is supported by boring data. As noted previously, Borehole 4 (Figure 1; Table 1) encountered open seams or fractures with and without flow at multiple depths. Similarly, Boring 2 which is immediately adjacent to an interpreted solution-widened fracture (Profile B; Station 398) encountered open seams or fractures with/without flow at multiple depths (24.0 ft, 26.2 ft, 27.0 ft, 28.0 ft, 29.3 ft, 33.5-35.0 ft, 37.4 ft, 38.0 ft, 39.2 ft, 40.1 ft, 44.0 ft, 48.5 ft) and standing water at 60.0 ft.

The authors' experience has been that limestone bedrock in Greene County is more typically characterized by resistivities higher than 200 ohm-m, rather than resistivities higher than 50 ohm-m (Anderson et. al., 2006; Muchaidze, 2009; Myat et. al., 2008A, 2008B; Robison and Anderson, 2008). The low bedrock resistivities observed at the mine access tunnel study site are attributed mostly to the relatively high moisture content (as evidenced by the presence of ponded water on the ground surface in the right of way, boring reports and flow from the mine ceiling).

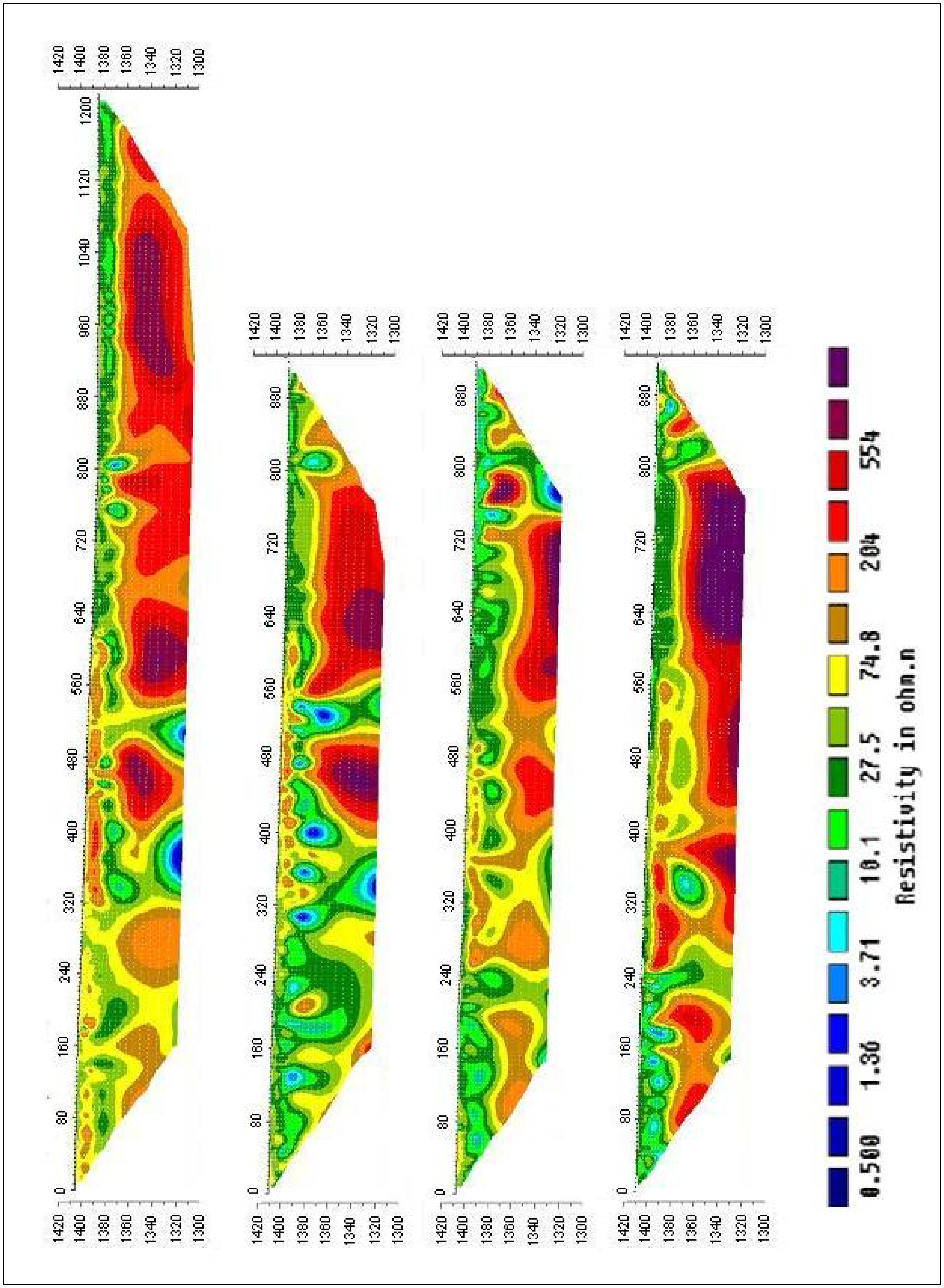

Figure 8: Un-interpreted ERT profiles (A-D; bottom to top; Figure 1). Distances and depths are in feet. Station 270 overlies the center of the mine access tunnel on all profiles. The top of the mine access tunnel is about 10 feet below the base of the zone imaged on the ERT profiles.

Table 1. Borehole and electrical resistivity data comparison.

Borehole	Elevation of Bedrock in Borehole (ft)	Tie Point: ERT Profile (Figures 1, 4 and 5)	Elevation of Bedrock on ERT Profile at tie point (ft)
1	1379	Profile D; Sta. 543	1373
2	1375	Profile B; Sta. 410	1375
3	1376	Profile B; Sta. 398	1374
4	1374	Profile A; Sta. 320	1376
5	1374	Profile A; Sta. 305	1372
6	1375	Profile A; Sta. 290	1370
7	1373	Profile A, Sta. 266	1374

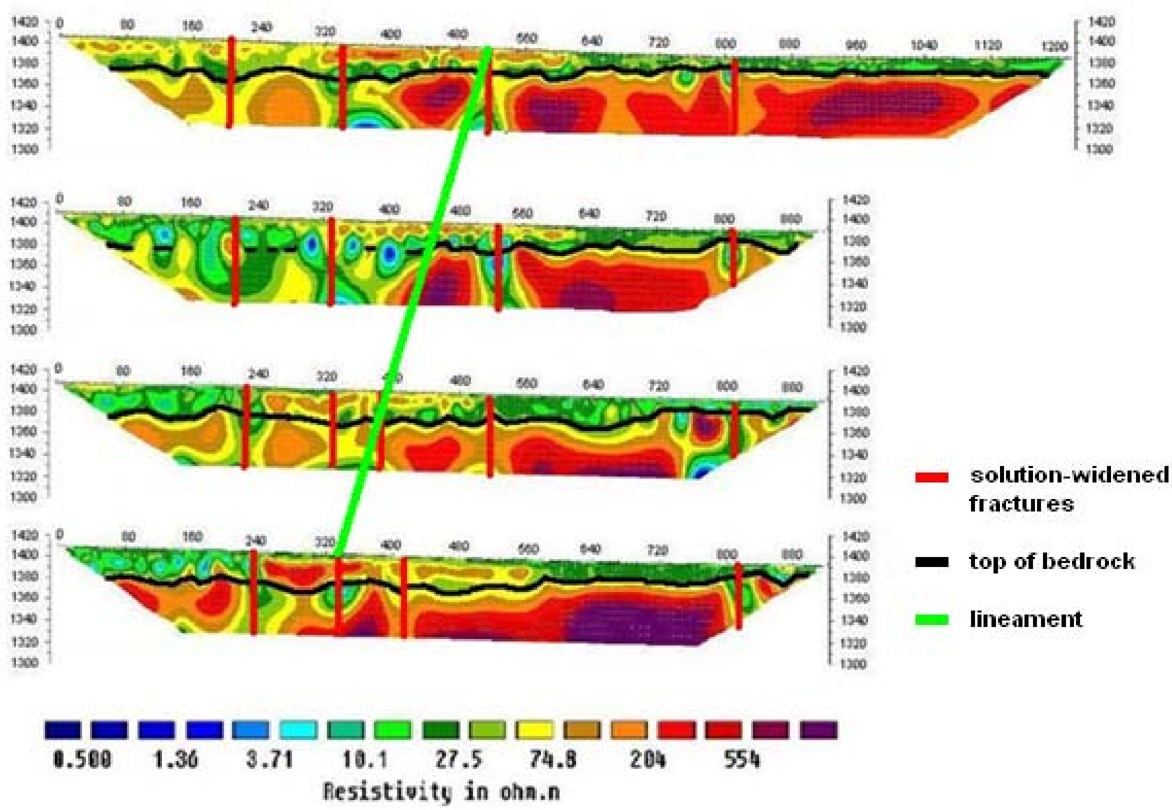

Figure 9: Interpreted ERT profiles (A-D; bottom to top; Figure 1). Several prominent interpreted solution-widened fractures and the projected lineament have been superposed on the ERT profiles. Distances and depths are in feet (the horizontal scale is exaggerated so the northwest-trending lineament does not appear to be properly oriented). The top of rock correlates well with borehole control. Station 270 overlies the center of the mine access tunnel on all profiles.

Bedrock to the north of Station 600 is interpreted to be more intensely dissected by solution-widened fractures, so the top of rock, in many places, does not coincide with the 50 ohm-m contour interval (Figure 9). The identification/mapping of top of rock is further complicated because the resistivities of the shallower soils to the north of Station 600 are greatly in excess of 50 ohm-m in places. These higher soil resistivities north of station 600 are attributed to the presence of thicker and drier embankment fill along this elevated section of roadway (the embankment to the north of Station 600 becomes increasingly elevated with respect to the waters ponded in eastern right of way).

In Figure 9, the northwest lineament along which roof failure occurred has also been superposed. (This lineament does not appear to be oriented northwest because the horizontal and vertical axes use different scales.) We note that the projected lineament correlates reasonably well with the locations of interpreted solution-widened fractures and conclude that roof rock failure in the mine access tunnel (and elsewhere) probably occurred along a prominent northwest-trending solution-widened fracture.

Several other prominent interpreted solution-widened fractures have been highlighted on Figure 9. These solution-widened fractures are characterized are characterized on the ERT profiles as near-vertical zones of low electrical resistivity (relative to adjacent more intact limestone). The lowered relative resistivity of the fractured rock is attributed to some combination of enhanced porosity and permeability, increased water saturation, and increased clay content. Our inclination is to correlate these features as shown in Figure 10. This interpretation appears to be reasonable based on the ERT images and the observation that waters flowed primarily from east-northeast trending fractures on the ceiling of the access tunnel where failure occurred. This interpretation is also supported by the literature. As shown in Figure 6, the dominant near-orthogonal faults and lineaments in Greene County trend approximately north-northwest and east-northeast, respectively.

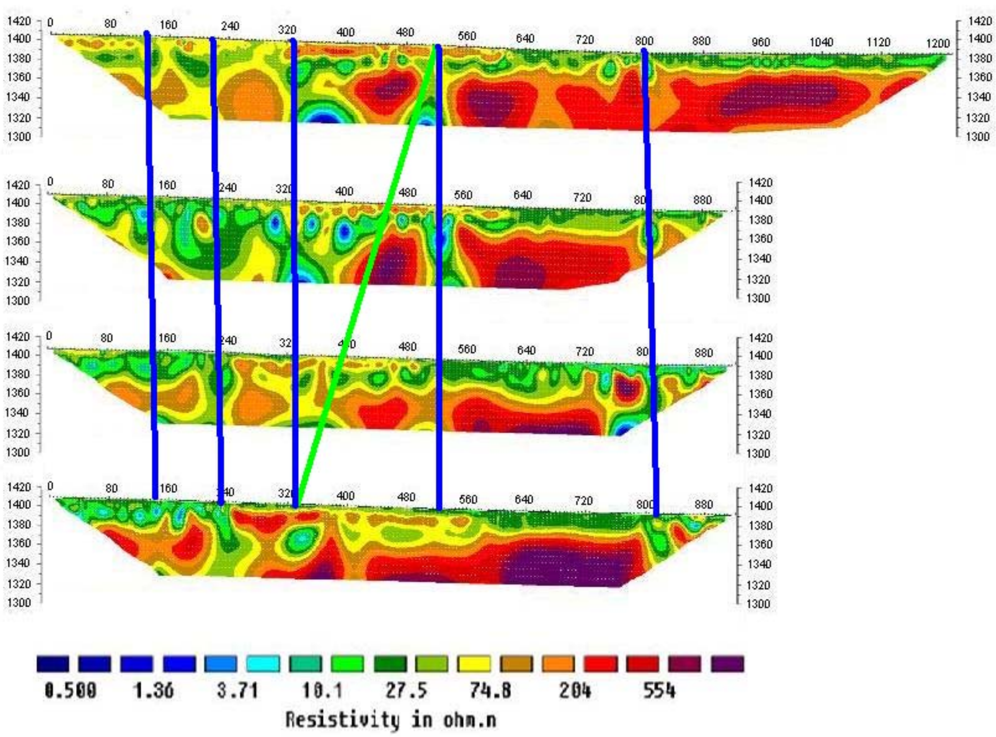

Figure 10: Interpreted ERT profiles (A-D; bottom to top; Figure 1). Several prominent interpreted solution-widened fractures (blue) and the projected lineament (green) have been superposed on the ERT profiles. Station 270 overlies the center of the mine access tunnel on all profiles.

It is interesting to note that roof rock failure in the mine access tunnel occurred at the intersection of projected lineament and one of the more prominent interpreted solution-widened fractures (Figure 11), and speculate this zone was especially susceptible to failure. Similar observations have been reported by Robison and Anderson (2008).

It is also interesting to note that the resistivity anomalies associated with both interpreted fractures diminishes with depth on ERT profile A. This may indicate why the postulated fractured zone is not readily identified on the ceiling of the access tunnel or on the GPR data. Unfortunately, the ERT data do not image the top of the tunnel, so more specific conclusions cannot be drawn.

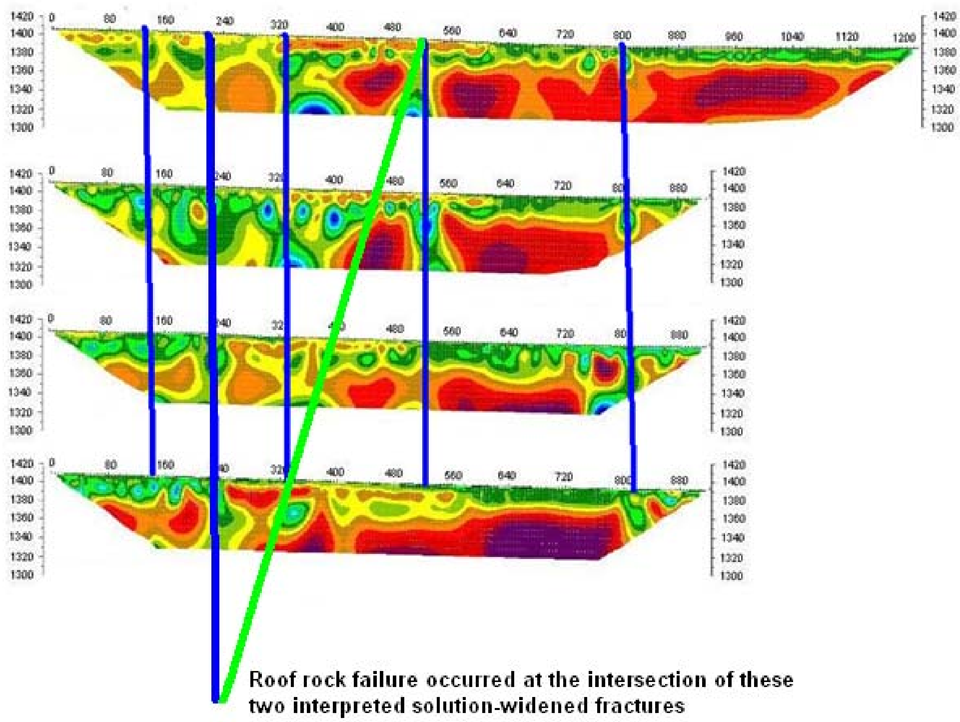

Figure 11: Interpreted ERT profiles (A-D; bottom to top; Figure 1). Station 270 overlies the center of the mine access tunnel on all profiles. Roof rock failure in the mine access tunnel occurred at the intersection of the projected lineament (green) and one of the more prominent interpreted solution-widened fractures (blue).

Conclusion

Bedrock in proximity to the mine access tunnel is interpreted to be dissected by a suite of near-orthogonal near-vertical solution-widened fractures, trending predominantly northwest or east-northeast. The solution-widened fractures are characterized on the ERT profiles as near-vertical zones of low electrical resistivity (relative to adjacent more intact limestone). The lowered relative resistivity of the fractured rock is attributed to some combination of enhanced porosity and permeability, increased water saturation, and increased clay content.

Roof rock failure on the ceiling of the mine access tunnel appears to have occurred at the intersection of a two prominent solution-widened fractures: one trending northwest; one trending east-northeast. This intersection zone was probably most susceptible to failure.

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