

Use of Geophysical Methods, Investigation by Drilling, and Remediation of Highway T Subsidence, Macon County, Missouri

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Abstract

A portion of Highway T in Macon County, Missouri about 10 miles south of the City of Macon is located above the Kansas and Texas Coal Company Mine No. 57, west of Ardmore community. The asphalt pavement on this segment of highway has had variable levels of subsidence for many years since construction, and has consumed an inordinate proportion of maintenance funds available to the Missouri Department of Transportation's Macon District (District 2). The Kansas and Texas Coal Company Mine No. 57 was abandoned in 1903. It is a shallow underground coal mine developed by the double entry room and pillar mining method, mining the Bevier-Wheeler coal seam. A surveyed underground mine map showing the extent and internal features of this mine is not available.

Three rounds of investigative drilling, totaling 42 holes, and two geophysical surveys were completed on this problematic stretch of pavement during 2003. MoDOT crews and geologists from both MoDOT and the Missouri Geological Survey and Resource Assessment Division completed the drill holes, while a crew from Geotechnology, Inc. completed resistivity and ground-penetrating radar surveys. Glen Young and Brenna Holt of the Geological Survey and Resource Assessment Division of the Missouri Department of Natural Resources performed two additional resistivity surveys.

Limits of the mine as determined by drilling and the geophysical surveys were determined with some degree of correspondence. The presence of upward-migrating voids, areas of subsidence on and adjacent to the highway, and the presence of visible "swallow holes" in the right-of-way adjacent to pavement surfaces indicated the potential for further collapse and subsidence on Highway T. Upward-migrating voids present a serious threat to traffic safety on this portion of Hwy T. High-speed (50 to 60 mph) car, suburban utility vehicle, and light truck traffic by local residents commuting to and from work was routinely observed during three weeks of drilling. In addition, cattle, trash, and aggregate haulers commonly use Highways C and T as a connector between U. S. Highway 24 at Huntsville and U. S. Highway 63 at Excello. High-speed commuter traffic mixed with tractor-trailer units over unstable asphalt pavement may be a prescription for serious property damage and personal injury. Commuters and truckers may ignore posted speed and load limits. The Geological Survey and Resource Assessment Division of DNR therefore recommended that underground voids, both at the horizon of the Bevier-Wheeler Coal Bed and those migrating upward from that horizon, be stabilized by grout as soon as possible. A geological map was constructed which is an estimate of the shape of the top of the Ardmore Limestone Member of the Verdigris Formation along Highway T in the affected areas, shown by structural contours.

Underclay and the Bevier-Wheeler Coal Bed overlie the Ardmore. Contractors used this map to estimate the flow direction of grout at the Bevier-Wheeler coal horizon at various points along Highway T.

Regional Geology and Stratigraphic Setting

The College Mound 7 ½' quadrangle of north-central Missouri is part of what was known by miners as the "Ardmore Mining District", where coal was mined from the Bevier-Wheeler coal seam until the late 1960's. Both surface and underground mining methods were used. Surface methods were largely confined to areas where overburden thicknesses were less than 40'. This area today contains numerous sinuous small lakes, some highly acidic in content, which wind between mounds of coal spoils accumulated during the mining process.

Stratigraphically, the Bevier-Wheeler seam represents the convergence of Pennsylvanian Desmoinesian) coal seams further west in Missouri, the Bevier and Wheeler seam. All of the formations present are from the Cherokee Group's Cabaniss Subgroup, from (in ascending stratigraphic order) the Verdigris Formation, which includes at its top the Wheeler coal bed, the Bevier Formation that is inclusive of the Bevier coal seam, and the Lagonda Formation. A simplified stratigraphic column is shown as Figure 1. As can be seen from this figure, the three formations have a fair amount of diversity in lithology. Each of the formations represented contains a coal-bearing cyclic succession, or cyclothem. Though the coal unit that lies atop the Lagonda Formation is not shown, this is because it consists of a coal smut or featheredged bed in Macon County. In addition, note the underclay, shale, and sandstone in the Bevier Formation also. These are absent in Macon County, so that the Bevier and Wheeler coal seams merge.

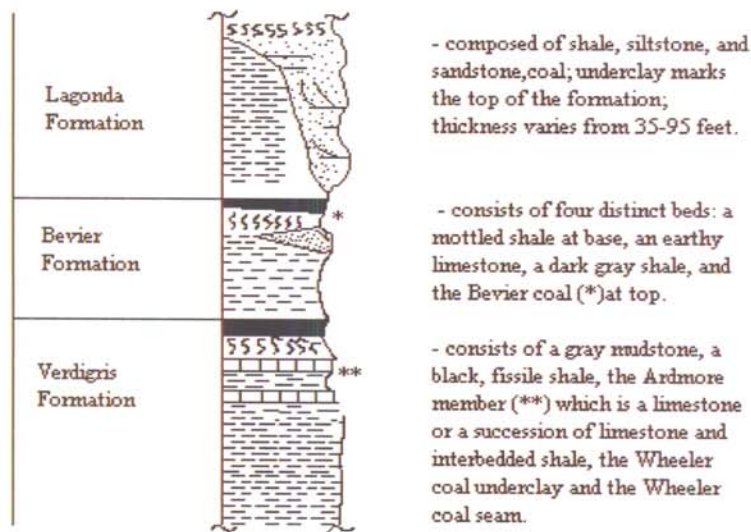


Figure 1. Stratigraphic succession represented at Macon County Route T site of geophysical Investigation, investigation by drilling, and subsequent grouting. Adapted for use from Howe (1961)

These absent beds are also absent in Boone and Randolph Counties to the south, where the Bevier-Wheeler was mined extensively until Federal regulations requiring the use of low-sulfur coal caused most of the open mines to be abandoned and reclaimed. Large tracts of formerly mined ground still exist on the surface that are easily identified. Subsurface workings are largely undocumented, though some maps exist. No known map exists for the No. 57 mine.

Drilling program

Route T has been a maintenance headache since the late 1970's, and several areas on or adjacent to the road have subsided. Luckily, no injuries or fatalities have been reported. Comparisons with other areas of potential and actual subsidence in north-central Missouri yield the following ideas:

- 1) The double-entry room-and-pillar method, most often used by miners from the 1800s to the early 1900s, left voids with higher collapse potential due to the practice of the miners to mine whatever remaining coal they could from mine pillars remaining in the mine.
- 2) A high potential for collapse is expected for those areas which have been undermined where overlying beds are normally shale and underclay. In areas that has limestone as the overlying bed, good compressive strength means a likely high degree of surficial stability, with substantially lessened chance of gradual or catastrophic collapse. Sandstones overlying the undermined areas may or may not have sufficient strength to support overlying materials.
- 3) Prediction of the extent and timing of collapse that will occur is speculative at best. Surficial clues to upcoming collapse in the past have included pavement separation and faulting, "swallow holes" adjacent to the roadway surface, and areas within and off the right-of-way that exhibit depressional landscape features.
- 4) Dewatering events that take place in water-filled underground workings increase the likelihood of immediate and future collapse.

With these ideas in mind, Route T was surveyed to establish centerline of the road. Subsidence features on and adjacent to the road were located in relation to the centerline. A number of features that pertained directly to the location of the old Mine No. 57 were also located in relation to the road and a topographic map. The map that was created as a result of this investigation is shown as Figure 2. This map, also known as "Map No. 11" was part of a series of maps created by The Department of Natural Resources Geological Survey and Resource Assessment Division in Rolla, Missouri. Their participation in this investigation was vital to a clear understanding of the potential magnitude and possible costs of future grouting and remediation.

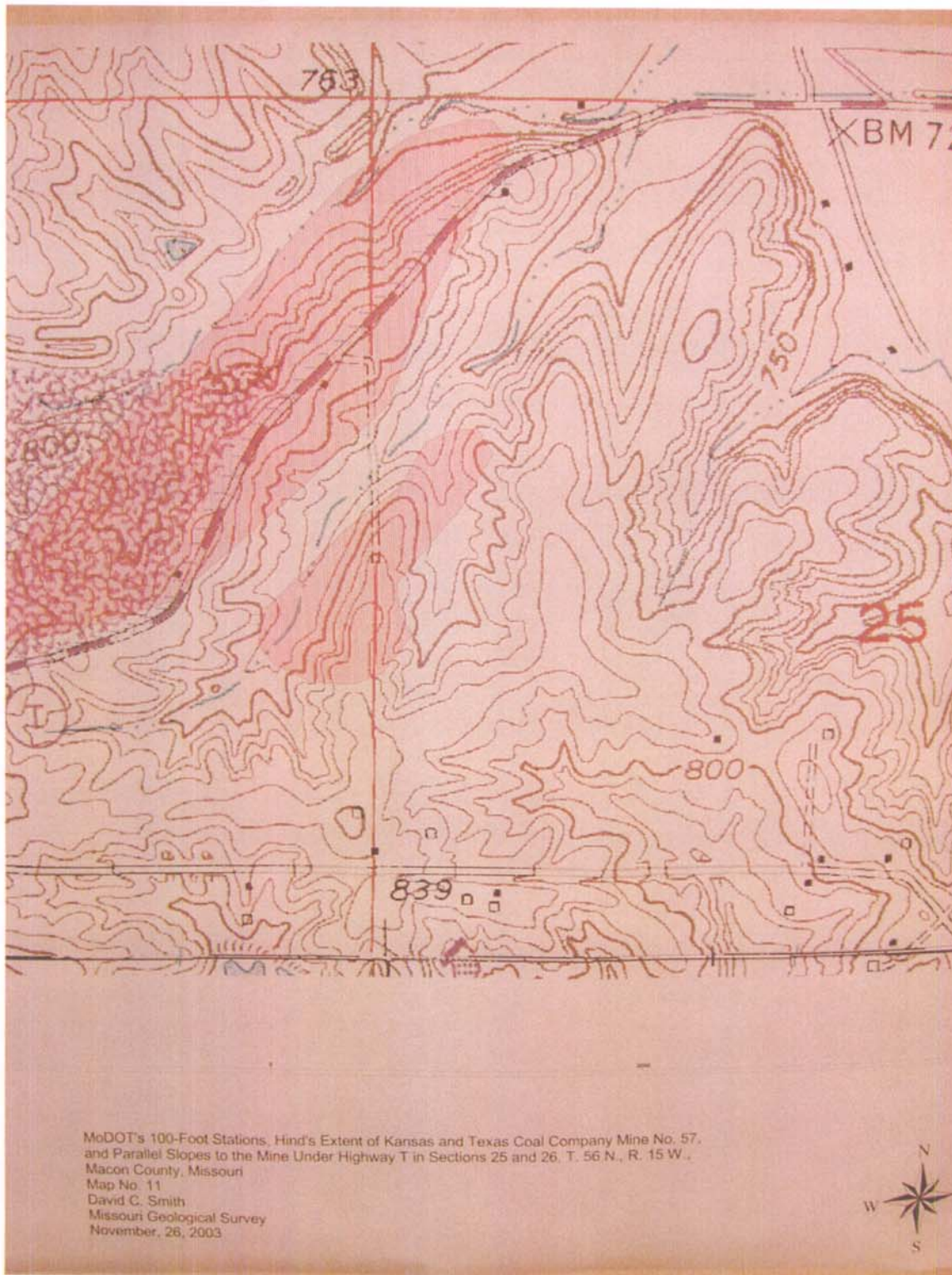


Figure 2. Missouri Department of Transportation (MoDOT) 100- foot stationing versus extent of Kansas and Texas Coal Company Mine No. 57 Between US Highway 63 and College Mound, Missouri. Part of Ardmore Mining District. Stationing from direct survey of road.

reflections and reduce background noise. The limited depth of the investigation was due to the presence of increased moisture in both the clay and shale at depth. Sandstones encountered during drilling were also saturated with water. Water increases the rate of radar attenuation with depth, which reduces the ability for the radar energy to propagate through the subsurface. An example of the GPR lines that were completed is shown as Figure 4.

Geotechnology and GSRAD each completed dipole-dipole resistivity surveying of the affected area also. Resistivity is a geophysical technique in which the apparent resistivity of the subsurface is determined by measuring conductivity of earth materials between two sets of electrodes. By placing the electrodes at successive locations along a survey line, a profile of subsurface resistivity is determined, which represents a cross-section of electrical conductivity conditions beneath the survey line. Subsurface voids (or clay filled features) may be detected due to the relatively low resistivity (high conductivity) of features with the surrounding materials, or by measurements of high resistivity (low conductivity) of surrounding materials.

Geotechnology's dipole-dipole resistivity surveys were conducted using an Iris Syscal R1 earth resistivity meter with a 72-electrode switching system. The resistivity data were collected with a nominal electrode spacing of 15 feet, with a maximum dipole separation of 120 feet, in an attempt to image subsurface anomalies (features) up to 50 feet in depth. The actual depth of penetration of the resistivity measurements for Geotechnology, Inc. was on the order of 35 feet. GSRAD's resistivity measurements penetrated deeper than those of Geotechnology, with better anomaly resolution and discrimination. Maximum dipole separations of up to 250 feet were used, with nominal electrode spacing of 25 feet. GSRAD's measurements were those that were used to determine siting of core drills for the third and final round of drilling in September and October 2003. An example of Geotechnology's generated resistivity profiles is shown as Figure 5.

Grouting

Grouting operations from emergency funding supplied from the U.S. Department of Interior's Office of Surface Mining was initiated during the week of Feb. 23, 2004. Currently, the Missouri Department of Natural Resources Abandoned Mine Lands Program is being disbanded due to loss of state funding. It is anticipated that the Missouri DNR's AML program may cease operation on or about July 1, 2004. Additional grouting may have to be paid for directly from MoDOT funds should Highway T become endangered from abandoned mine voids.

Under normal circumstances, one of two types of grout is used. The first is a combination of Class F fly ash and concrete, with the fly ash being used as a pozzolan to increase the speed of concrete curing. The second potential grout mixture is a combination of slaked lime (calcium oxide) and concrete, which is a normal mixture that is used also in mudjacking and pavement repairs. The first type is probably what will be used, since surrounding shales are still moist to saturated and MoDOT will not be using any dewatering technique for fear of initiating a sequence, which will lead to collapse.

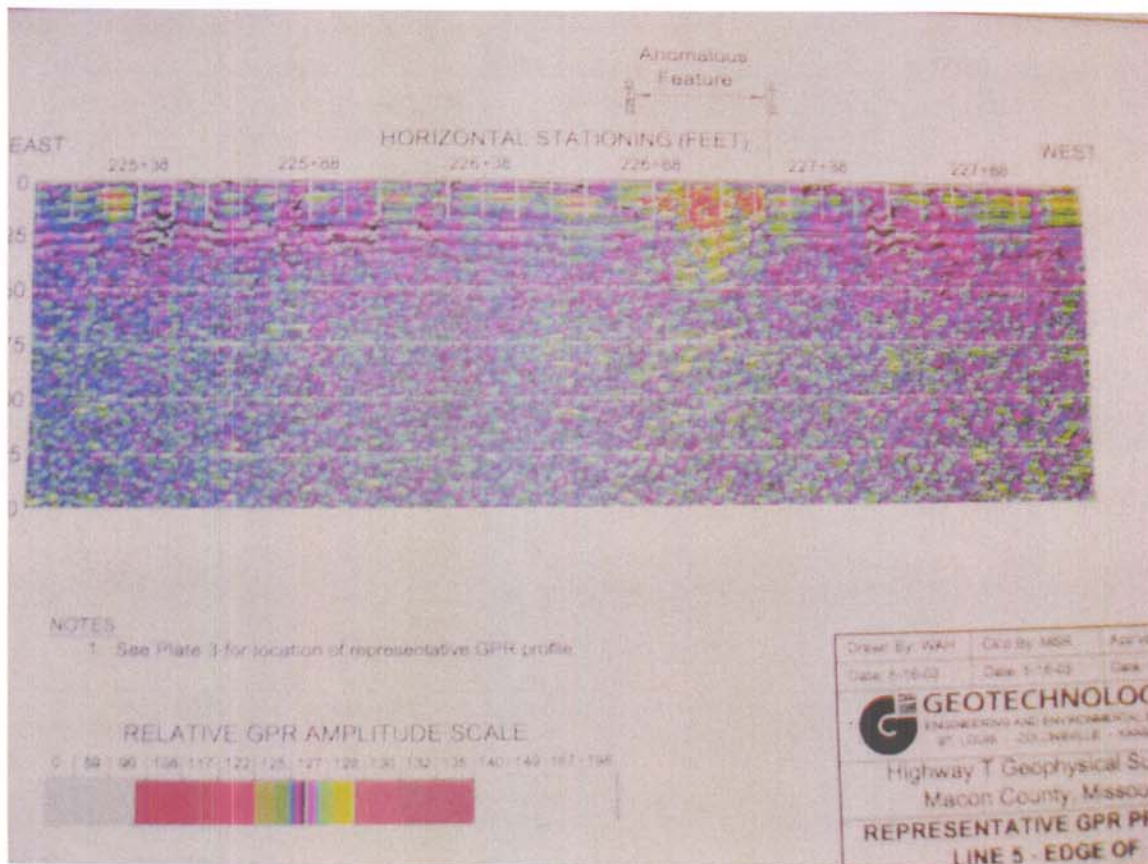


Figure 4. GPR profile showing anomalous feature, Route T, Macon County, Missouri.

Conclusions

The investigation of Route T subsidence leading to its remediation could be considered a case study in Federal agency, State agency, and consultant cooperation. All of the parties involved were willing and able to share information without exception. Public safety overrode any need for preeminence among state agencies in this cooperative effort. GSRAD personnel were highly complimentary of MoDOT personnel and vice versa. Close in-field cooperation to solve everyday problems of drill hole and geophysical line location insured that each location was placed fortuitously to obtain the maximum amount of information available for the effort expended. Frequent in-field discussions generated copious quantities of information that aided in both investigation of, and solution for the problem.

This effort provides both guidance and a "blueprint" for future cooperative efforts between MoDOT and GSRAD in other highway areas which are undermined by abandoned underground coal mine voids. U.S. Highway 24 near Huntsville, Missouri in Randolph County has voids as little as 18 feet under the traveling lane. This is also from mining of the Bevier-Wheeler coal bed. U.S. Highway 63 also has voids approximately

60 feet under the pavement in Macon County near the City of Macon airport, also associated with the Bevier-Wheeler coal seam. U.S. Highway 65 has underground voids associated with abandoned large underground coal mining operations in the Lexington coal seam, near Lexington, Missouri. State Route B in Columbia, Missouri is also affected by underground coal mining. These locations offer potential for future cooperative effort which we hope will protect the public from the potential danger that abandoned underground coal mining operations have created.

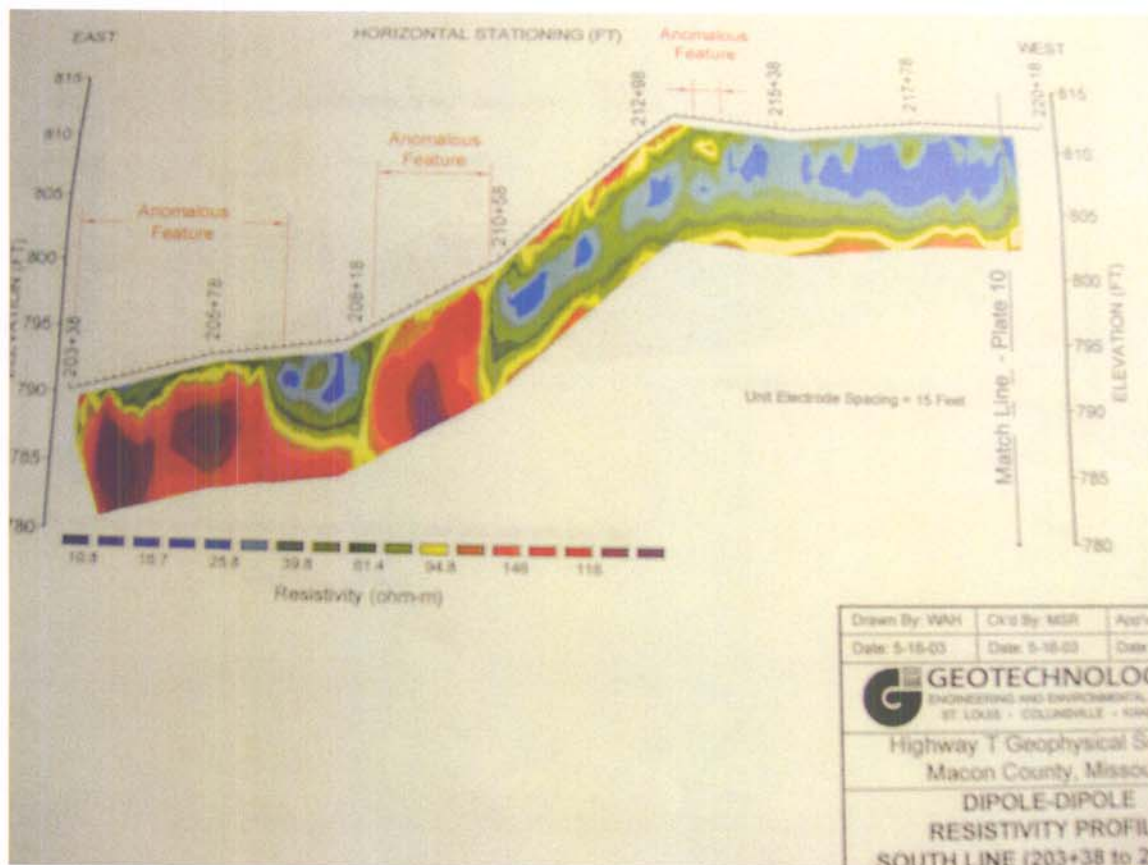


Figure 5. Example of processed data from resistivity line performed by Geotechnology, Inc. of St. Louis, Missouri. Note high resistivity measurements in areas marked “anomalous features”. Drilling later confirmed that these locations contained mine voids.

Acknowledgments

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