GEOLOGICAL ENGINEERING FIELD CAMP EXERCISES

Geological Society of America 2002 Rocky Mountain Section Annual Meeting,
Cedar City, Utah
May 10, 2002

Home threatened by a small landslide that has formed on the headwall scarp of the much larger Green Hollow landslide near Cedar City, Utah.

Field Exercise Leaders

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ABSTRACT

Over the past 29 years, the University of Missouri-Rolla (UMR) has conducted a geological engineering field camp near Cedar City, Utah, taken by undergraduate majors in geology and geological engineering. Part of the field camp is conducted as a traditional geology field camp, focusing on stratigraphy and rock identification, structural interpretation, and field mapping. Forty percent of the field camp focuses on field trips and exercises to give geological engineers practice in applying geological concepts to solve typical engineering problems. The exercises they complete require them to use geologic maps and field observations to identify geologic hazards, to estimate strength and other engineering properties of soil and rock, and to design structure layouts and hazard mitigation programs.

Field exercises in geological engineering provide students with a chance to use their geologic knowledge to identify and address a variety of engineering problems. By scheduling a variety of both short and long projects, students are exposed to a wide breadth of problems. They focus on individual hazards in projects of limited scope before they are expected to address these hazards on a large project, and the variety helps maintain their interest and enthusiasm levels. The students rely heavily on published geologic maps, just as they will in their careers, and they learn to discern the accuracy, precision, and reliability of maps prepared by others.

PURPOSE AND INTRODUCTION

Over the past 29 years, the University of Missouri-Rolla (UMR) has conducted a geology field camp in the vicinity of Cedar City, Utah. The field camp has always included a geological engineering component, taken by undergraduate majors in geological engineering. The purpose of the geological engineering component is to give geological engineers practice in applying the geologic concepts and mapping techniques they have been learning towards solving typical engineering problems. The exercises they complete require them to use geologic maps and field observations to identify geologic hazards, to estimate strength and other engineering properties of soil and rock, and to design structure layouts and hazard mitigation programs.

The Geological Engineering Field Camp Exercises short course for which this road log has been prepared has three goals. The first is to detail the pedagogical issues that a geological engineering field camp is intended to address. The second is to provide a set of example exercises for educators interested in conducting either short-term or long-term applied geology problems for their students. The third goal is to provide short course attendees with a broad overview of the complex geology and numerous geologic hazards in the Cedar City area.

FIELD CAMP STRUCTURE

The UMR field camp is typically five weeks in length. The first three weeks follow similar schedules, and are conducted like many other university field camps: students learn the stratigraphic column for the area, hear an overview of the geology of a particular location, and then develop geologic maps and cross-sections. During this time, they are expected to develop skills in rock and mineral identification, formation recognition, mapping techniques, and geologic drafting and presentation. At this point, the geology majors and the geological engineering majors generally split into two groups for focused instruction and problem solving in their respective areas during weeks four and five.

For the geological engineers, the fourth week of field camp has traditionally incorporated a trip to the Salt Lake City area for an overview of local engineering geology issues. Activities vary from year to year, but have included tours of urban geologic hazards, tours of the Bingham Canyon open pit mine and environmental reclamation areas, visits to various underground coal mines, a visit to the Wasatch Drain Tunnel that supplies water to the Snowbird resort, and visits to the Thistle landslide complex and the nearby Schurtz Lake landslide and Joe's Canyon debris flow. The week is concluded with trips to Bryce Canyon and Grand Canyon National Parks for overviews of the geology.

The goal of the fourth week trip is to expose students to a wide variety of engineering problems that are affected or created by geology. The trip gives them a chance to contemplate how the same geologic units they have studied in detail for several weeks have influenced settlement, mining, and water supply, and have created hazards for transportation routes, businesses, and residential structures.

During the fifth week of the field camp, the students apply what they have learned to predict locations and severity of hazards, to suggest hazard mitigation methods, to prepare engineering geologic and engineering soils maps, and to interpret geologic maps for engineering use. The students rely heavily on published geologic maps during this week, just as they will in their careers, and they learn to discern the accuracy, precision, and reliability of maps prepared by others.

An overview of the regional geology in the vicinity of Cedar City is provided below, so that the reader may better understand the fifth-week exercises detailed afterwards in the road log.

REGIONAL GEOLOGY

Cedar City, Utah is an ideal location for a field camp for both geologists and geological engineers. It is located on two major geologic boundary lines, which gives access to varied types of geology. The Hurricane fault, which passes through the east side of Cedar City, is a major NNE-SSW trending, down-to-the-west, normal fault with a vertical displacement of at least 5,000 feet and possibly as much as 8,000 feet occurring over the past ten million years. The Hurricane fault is the structural boundary line between the Basin and Range geologic province to the west and the high Colorado Plateau to the east. Cedar City, located on the downthrown side, is at an elevation of 5,800 feet. Immediately across the fault to the east, Cedar Breaks National Monument is at over 10,000 feet and Brian Head Peak is just over 11,000 feet. Because of this topographic difference, deep erosional valleys have been cut into the upthrown side of the fault and large alluvial fans are deposited on the downthrown side. Also, because of the large topographic difference across the fault, unstable slope conditions have resulted in large landslides at several locations along the fault.

Regionally, the Hurricane fault is part of a much larger system. To the north it is equivalent to the Wasatch fault in Salt Lake City, and to the south, the fault continues to the Grand Canyon where associated basalt flows create Lava Falls, the largest cataract in the canyon. Also associated with the Hurricane fault are a series of basalt flows that flowed across the fault at various stages of its development. These basalt flows have been displaced, and are used to date and positively identify movement on the fault.

The Hurricane fault in the Cedar City area roughly coincides with the eastern (leading) edge of the western overthrust belt of North America (second major geologic boundary line). Valleys cutting the upthrown side of the fault expose spectacular cross section views of a number of different compressional structures. In one canyon, students develop a geologic map of a leading edge recumbant anticline, the single-most important structural trap for hydrocarbons in overthrust belts throughout the world. As students move up the valley they observe the progression of bedding plane attitudes from flat-lying, through increasing east dips, to overturned, then back through decreasing east dips, and finally back to flat lying, over a horizontal distance of about a mile and a half. This is an important exercise not only for developing their mapping skills, but also for the opportunity to observe firsthand the magnitude and complexities of such an important geologic structure. This is a structure that geological engineers in the petroleum industry are likely to be drilling, and there is no substitute for actually seeing such a structure in the field.

Table 1 shows a highly generalized summary of rocks units and tectonic events for the Cedar City area. The majority of rocks in the area consist either of valley-fill alluvium on the downthrown side of the Hurricane fault or Triassic and Jurassic (red colored) and Cretaceous (brown colored) rocks that crop out immediately across the Hurricane fault to the east. Paleozoic rocks are not exposed near Cedar City, but wells drilled in the area indicate thicknesses of 6,000 to 7,000 feet of Paleozoic rocks. The closest well-exposed thick section of Paleozoic rocks are in the Virgin River Gorge to the southwest of St. George (along I-15 to Las Vegas) and in the Grand Canyon.

The area is characterized by a series of major tectonic and erosional/depositional events. During Precambrian time (1.2-1.5 billion years ago) southern Utah and northern Arizona were probably the core of a major east-west trending mountain range. This range was topographically high and experienced erosion over the next 700 million years (this period is noted as "The Great Unconformity").

During early Paleozoic time (Cambrian through Mississippian), the western U.S. was relatively quiet and marine sediments were periodically deposited. During Pennsylvanian and Permian time, local uplifts throughout the western U.S. created a complex mosaic of highlands and basins resulting in highly varied geology for those two periods. At the end of Paleozoic time, the continents were linked together as Pangaea, and during Triassic and Jurassic time, redbeds and evaporites associated with the breakup of Pangaea were deposited. During Jurassic time the coastal plain where redbeds were being deposited dried up and a great desert was formed, which resulted in the spectacular eolian Navajo Sandstone so well exposed at Zion National Park. Immediately following deposition of the Navajo Sandstone, a small, north-south rift valley opened in central Utah and significant thicknesses of evaporites were deposited, resulting in the Carmel Formation exposed near Cedar City and Salina.

Early Cretaceous rocks are missing across all of Utah and Late Cretaceous time is marked by the climax of Sevier deformation. Sevier deformation is synonymous with thrusting in the western overthrust belt, and although thrusting is considered to have initiated during Jurassic time in Nevada, the effects in Utah are not seen until Late Cretaceous time. During the Late Cretaceous a major mountain range occupied all of western Utah, and it shed large volumes of sediment eastward into the Cretaceous interior seaway. The coals of Utah and Wyoming were deposited in coastal plain sediments associated with this seaway.

During early Tertiary time (Paleocene and Eocene), compression continued in the Laramide orogeny, but the structural style was much different. Laramide deformation is marked by Precambrian, granite-cored uplifts (such as the Uinta Mountains, the Black Hills, and the San Rafael Swell) which pushed up through overlying rocks creating typically asymmetrical uplifts with thrust faults along one flank. Between these uplifts, downdropped basins were developed and significant lacustrine sediments (such as the Green River, Flagstaff and Claron Formations) were deposited.

Table 1. Generalized stratigraphic column and tectonic events for the Cedar City area. Modified liberally from Hintze (1988).

System or Series	Tectonics	Formation	Thickness (feet)	Brief description and comments
Quaternary	Basin & Range tension faulting		0-300	Alluvium and basalt flows
Pliocene			0-6000	Valley fill, alluvial fans and basalt flows
Miocene		Intrusion		Quartz monzonite in Iron Springs area, 20 mya
Oligocene		Ash flow tuffs	300-4700	Numerous ash flow tuffs from west, 21-30 mya
Eocene Paleocene	Laramide Compression	Claron	700-1800	Lake deposits of Cedar Breaks and Bryce Canyon Laramide uplifts and lakes between uplifts
Cretaceous	Sevier Deformation (thrusting in Western Over-thrust belt)	Kaiparowits Iron Springs "Tropic" "Dakota"	1600-2500	Transition to Tertiary lacustrine deposits Sandstone and shale with some coal at the western edge of the Cretaceous interior seaway. Various names including Tropic, Dakota, Wahweap, and Straight Cliffs have been used with confusion
Jurassic		Carmel	1100-1250	Limestone, mudstone & evaporates (marine incursion)
		Navajo	1700	Eolian sandstone of Zion National Park
		Kayenta	700-1600	Redbeds, sandstones, and shales
		Moenave	350-550	Redbeds, sandstones, and shales
Triassic		Chinle	240-500	Shinarump Sandstone and Petrified Forest redbeds
		Moenkopi	1900	Redbeds, shales, siltstones, and evaporates
Permian		Kaibab	400	Limestone, very little seen in the Cedar City area
Paleozoic rocks below the Kaibab Formation are not exposed at the surface in the Cedar City area.				

During Oligocene time, approximately 20-30 million years ago, major volcanic activity occurred throughout the western U.S. and Mexico, resulting in the deposition of spectacular ash flow tuffs mainly to the west of Cedar City. At about 20 million years ago, quartz monzonite intrusions thought to be laccoliths were intruded in the Iron Springs area about ten miles west of Cedar City. Surrounding these intrusions significant iron ores were emplaced as veins and as replacement deposits in the Jurassic Carmel Formation. These iron ores have been mined discontinuously since 1851, and one of the abandoned mines now serves as a landfill. During the Oligocene, the tectonic regime in the western U.S. changed from compressive to tensional, initiating Basin and Range normal faulting, which continues to the present.

TYPES OF EXERCISES

Because the students have spent several weeks in the field before starting their geological engineering exercises, and have waning motivation and enthusiasm, the authors' philosophy during the fifth week of the camp has been to challenge the students with a wide variety of exercises, both in terms of length and topic. The longer exercises allow them to spend parts of several days studying a site in detail, and the shorter problems allow them to think through a single engineering geology issue at one time. By careful scheduling, the short problems are sequenced to give the students some technical background for the aspect of the long project that they will tackle later that same day. Students start the day with a short quiz on several technical readings that cover the stops for that day. An excellent overview of the engineering geology of southwestern Utah is presented in Mulvey (1992).

The short problems are considered "Hour Problems," and usually three of them are assigned each morning. Each problem deals with a different geologic hazard or issue, such as "debris flows," or "ground-water contamination." The students are taken to the problem site and use a geologic map and their knowledge of engineering geology, hydrogeology, and geomorphology to answer a series of questions regarding the engineering geology of the site. The Hour Problems are included below at Stops 1 through 9. They rely on the geologic map of the Cedar City quadrangle (Averitt and Threet, 1973), and several technical articles cited in the road log below.

The long problems are "Multi-Day Projects," and involve identification and mapping of geologic hazards, analysis and recommendation of mitigation methods, optimal siting of a number of facilities, and estimation of properties for foundation design. In all cases, four days are allotted for the Multi-Day Projects. Some years the students were required to prepare a typewritten report after they returned from field camp, and other years they prepared a more succinct report due on the last day of field camp. Four examples of Multi-Day Projects are included below at Stops 3, 7, 10, and 11. They rely on geologic maps of the Cedar City, Cedar City NW, and Three Peaks Quadrangles (Averitt and Threet, 1973; Mackin and others, 1976; and Mackin and Rowley, 1976; respectively). A technical library is provided for the students covering engineering geology, southern Utah geology, rock engineering, and natural hazards mitigation.

"Single-Day Projects" help keep the students' attention levels and enthusiasm high by providing a break from the Hour Problems and Multi-Day Project work, while requiring them to maintain their focus on technical engineering geology topics. An example of a Single-Day Project is included below in Stop 12.

By mixing project length and topic, students typically are exposed to nine Hour Problems, a Multi-Day Project, and a Single-Day Project in a week. They receive instruction in a broad range of engineering geology topics, and the frequent transition of both topic and location helps maintain their interest.

ROAD LOG

The route progresses from Cedar City southward to Green Mountain, over Green Mountain to State Highway 14 (SR-14) in Cedar Canyon, down Cedar Canyon returning to Cedar City. Following several stops in Cedar City, the route heads westward for two stops in the Iron Springs area, and then northward for a final stop in the Parawon Gap area. Each stop illustrates a different geological engineering problem covered in the field camp. Stops near Cedar City are shown on figure 1 and stops away from the city are shown on figure 2.

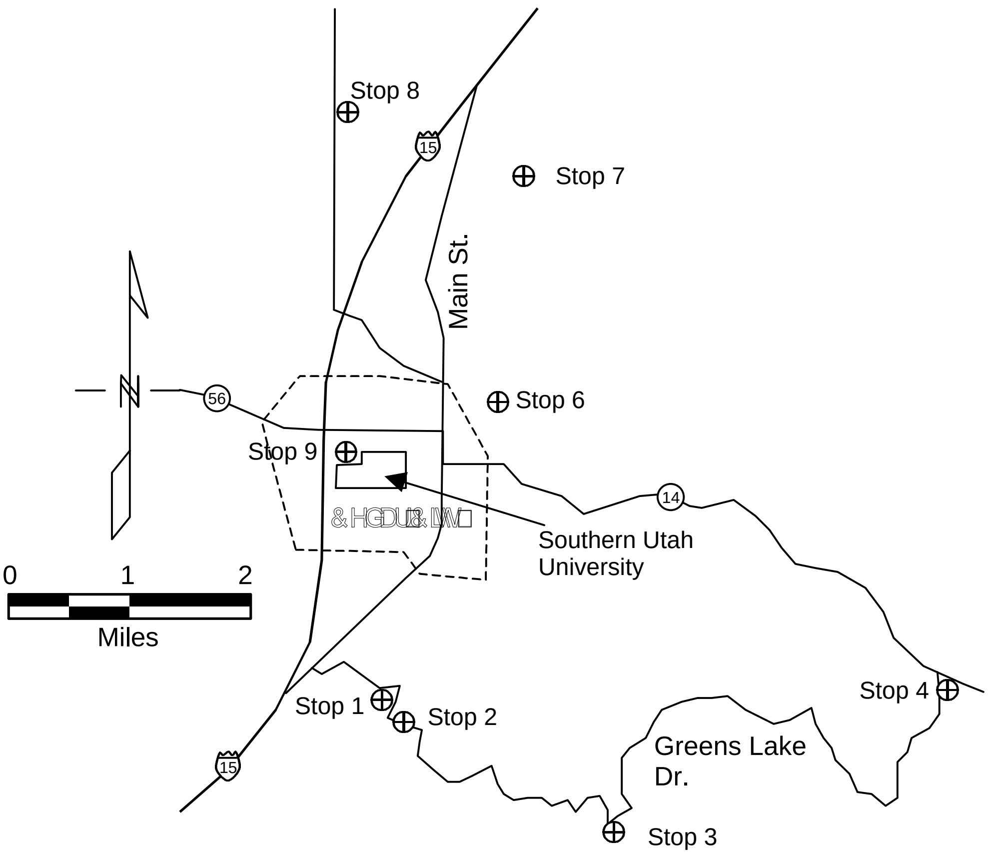

Figure 1. Local map of Cedar City showing road log stops.

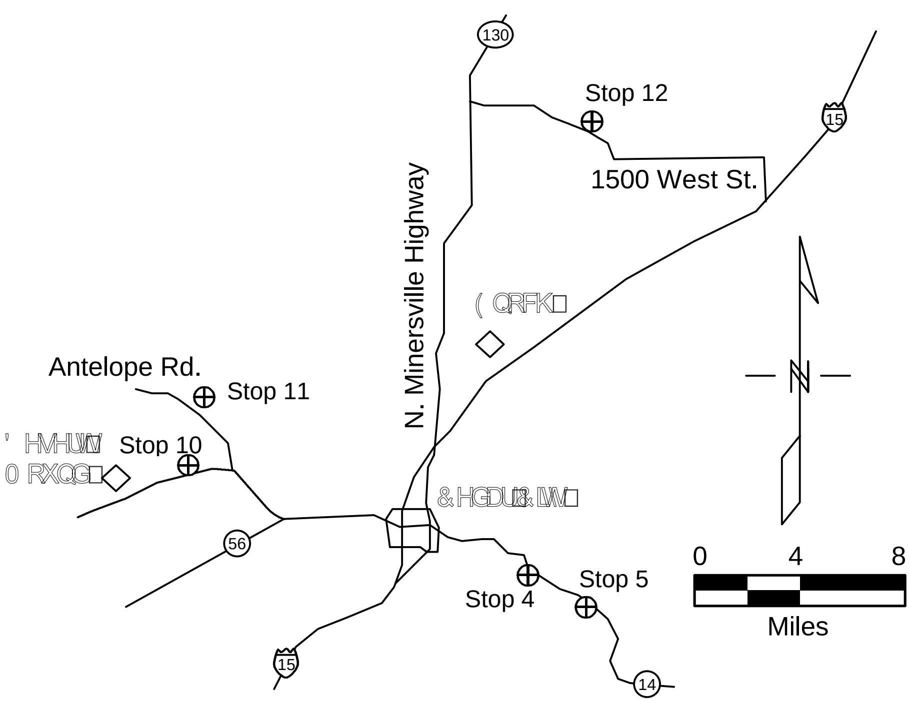

Figure 2. Regional map of the area surrounding Cedar City showing road log stops.

0.0 0.0 **START**. Begin at Southern Utah University, intersection of 200 S. Street and 1150 W. Street. Proceed East on Center Street.

0.9 0.9 Turn right (S) on Main Street.

1.7 2.6 Turn left (E) on Kolob Road.

0.2 2.8 Turn left on Greens Lake Drive.

1.0 3.8 Follow Greens Lake Drive up Green Mountain and park at the water tank.

STOP 1 – HOUR PROBLEM: LANDSLIDE. The purpose of this stop is to allow the students to consider construction on or near a large paleolandslide. They should learn how to recognize these features and how to evaluate the likelihood of renewed movement. The slide is referred to as the Green Hollow landslide, and it is a complex slide morphology mostly in the Cretaceous Tropic and Triassic Moenkopi Formations. The slide is estimated at 222 million cubic meters and is over 4 kilometers in length (Harty, 1992). Students are presented with the following questions:

1. Is the Green Hollow Landslide composed of material that traveled a short distance or a long distance? How do you know?
2. What is the most likely triggering event and why?
3. How can you tell?
4. Is it OK to build on it?
5. Beyond the toe of the landslide?
6. How would you decide?
7. Describe the sequence of materials you would expect in a drill hole placed near one of the vans.
8. Why do we not typically see landslides in the rock record?

Continue uphill (E) on Greens Lake Drive.

0.2 4.0 Park on the second dirt road to the left.

STOP 2 – HOUR PROBLEM: VOLCANIC / GEOMORPHOLOGY. At this stop, students use simple volcanic stratigraphy to judge relative ages and sequences of landscape-shaping events. The site of interest is the Cross Hollow Hills directly west of the stop, which are composed of Tertiary fanglomerates capped in places by Quaternary basalts. Basalt flow remnants can also be seen to the south, comprising the nearest ridge at the edge of Green Hollow. Background reading for this site is Bugden (1992). Students are presented with the following questions:

1. Where is the source of the basalt?
2. The fanglomerate?
3. What geologic hazards do these units present?
4. Outline a chronology of events leading to what you see across the valley.

Continue up Greens Lake Drive.

2.9 6.9 Park at a broad meadow on a flat topographic bench, with a white picket fence on the right.

STOP 3 – HOUR PROBLEM: HYDROGEOLOGY. At this location, students are introduced to geologic controls on spring location, and possible engineering modifications to spring flow. Green Lake and the surrounding marsh developed on the flat and back-tilted head of the Green Hollow landslide (figure 3). The spring, which appears to have been tapped to feed the water tank, issues from above a confining bed in the Tropic Formation. Students are presented with the following questions:

1. Why do the spring and Green Lake appear where they do?
2. What kind of water inflow would you expect in a horizontal adit above or below the spring?
3. What would happen if you stopped up the spring?
4. How would you keep a mine dry in the vicinity of the spring?
5. What sorts of depositional environments would favor development of springs millions of years later?

Figure 3. View from the top of Green Mountain across Green Lake (center) and the Green Hollow landslide (treeless area in center of photo, representing the down-dropped head of the landslide).

MULTI-DAY PROJECT: SUU RADIO TELESCOPE FACILITY. Students were asked to complete the following project in the vicinity:

Southern Utah University has recently received a large endowment from a grateful UMR field camp alum in order to construct a radio telescope array. The telescope will consist of the following structures:

1. A set of four 25-foot diameter dish antennas. The antennas will be installed in a line trending magnetic north, 2000 feet apart, and at the exact same elevation. You are to site the array somewhere between the elevations of 8000 and 9000 feet. Each antenna will require a 30x30 foot pad that should be able to support 2000 pounds per square foot.
2. A high-tension power line serving the array. The power line will extend from the center of section 22 to one end of the array. The line will be supported from towers 100 feet high and spaced every 1000 feet. Towers should be placed so that the aesthetic disruption will be minimal for Cedar Highlands residents. Each tower will require a 20x20 foot pad to support 4000 psf dead loads and 6000 psf transient (wind) loads.
3. A cooling water system for electrical equipment and transformers. The system requires a water supply and storage of 500,000 gallons.
4. A building to house a supercomputer and related electronic equipment. The equipment is very sensitive to movement and the building should be very stable. The building will be constructed in the southeast quarter of section 22, it will have a floor area of 1200 square feet, and impose loads of 2000 psf.

Here is what you are expected to do for this project:

Monday – Select locations for the antenna array, evaluate foundation materials and conditions, and evaluate the activity and impacts of the large landslide.

Tuesday – Develop a cooling water supply and storage plan (where will it come from and where will it be held). You need to decide if you can use Green Lake for this or if you need an alternate plan. Begin working your way down the hill to site power line towers. Pay particular attention to foundation materials, soil conditions, and geologic hazards.

Wednesday – Finish siting lower line towers. Select a site for the supercomputer building.

Thursday – Complete any remaining field work.

Due Thursday noon – Preliminary map showing locations of antennas, power line towers, cooling water storage, and supercomputer building. For each structure, include a list of geologic hazards and a short description of how you will address each hazard. For each structure list the expected foundation materials and comment on treatment needed.

You will work in groups on the project, but each student is expected to complete his or her own project report. Target length is about 10 to 15 pages of text, not including figures, tables, and appendices.

The goals of this project, as for the other Multi-Day Projects are to teach the students to interpret geologic maps and general technical references for engineering construction properties and geologic hazards, and to site various facilities. The general geologic issues impacting the project include the potential for reactivation of the Green Hollow Landslide, the thickness and foundation properties of landslide deposits, the impacts of increasing surface water storage (and infiltration) at the head of the landslide, and the practicality of large cuts and fills for the antenna sites.

Continue uphill to the end of Greens Lake Drive.

0.5 7.4 Turn left on Right Hand Creek Road and follow it around the north side of Green Mountain, and downhill to the intersection with Utah SR 14.

4.5 11.9 Park at the southeast corner of the intersection.

STOP 4 – HOUR PROBLEM: FLOODING. The two goals of this stop are to help the students to recognize the effects of long-term climate changes on river morphology and to help them identify proper uses of various features within a river basin. The students should recognize that the stream valley was cut much deeper than the current grade, that the terraces were deposited in a different post-glacial climatic period, and that the current stream is downcutting into the terraces. Background reading for the stop is Lund (1992). Students are presented with the following questions:

1. Is the stream channel here the size you would expect for this size floodplain? If not, why not?
2. Where would you build a structure to avoid the flooding hazard?
3. How could you protect the structure from flooding?
4. What are three constructive uses for the floodplain area?
5. Was this a depositional or erosional environment 10,000 years ago?
6. What will the current stream do to the floodplain in the next 10,000 years?

Turn right (E) and proceed on SR 14.

2.7 14.6 Park on the broad shoulder on the north side of the road.

STOP 5 – HOUR PROBLEM: LANDSLIDE. This site is the 1989 Cedar Canyon landslide, with a volume of approximately 1.5 million cubic meters (Harty, 1989). The slide is located in the Cretaceous Tropic / Dakota Formations, and the vertical cliffs above are the Cretaceous Straight Cliffs Formation (Harty, 1989). The goal of this stop is to help students identify and judge the effectiveness of various landslide remediation methods. Students are presented with the following questions:

1. List four remediation options to address the landslide hazard. Rank them from most desirable to least.
2. Explain why you felt the most desirable option was the most desirable.
3. Find two other geologic hazards in the vicinity and explain how they have been remediated (or how they could be).
4. How would this site be different if the climate suddenly had three times the current rainfall?

Proceed West on SR 14 back to Cedar City.

7.2 21.9 Upon entering town, turn right (N) on Highland Drive.

0.6 22.4 Follow Highland Drive to its dead end.

Park in driveway of demolished house on left.

STOP 6 – HOUR PROBLEM: COLLAPSIBLE SOILS. At this location, the extent of damage caused by collapsible soils may be seen in the basement and foundation cracks in the demolished house. Background reading is from Rollins and others (1992). Students are presented with the following questions:

1. Looking at the crack patterns in this basement, describe the mode of settlement of the structure.
2. Describe briefly why some soils are collapsible.
3. If you were called in by the homeowner to diagnose the problem here, how would you distinguish the damage here from damage caused by expansive soils?
4. What would you do in order to rebuild at this location?
5. What other depositional environments and parent materials would produce similar problems?
6. What would happen to these materials if you buried and lithified them?

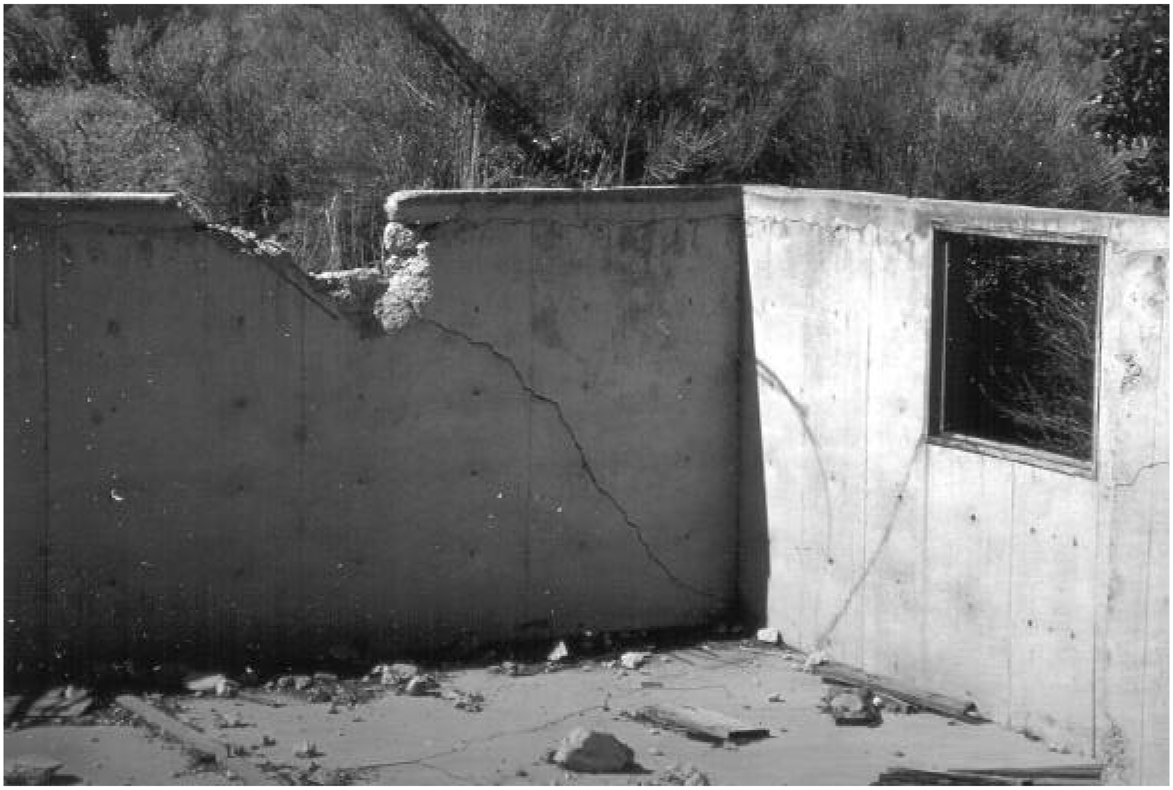

Figure 4. Basement of demolished house severely damaged by collapsible soils. Note the cracked walls and floor slab.

Return to SR 14 (Center Street).

0.6 23.0 Turn right (W) on Center Street.

0.5 23.5 Turn right (N) on Main Street. On the left, note the berm protecting the high school from debris flows and flooding from Fiddlers Canyon.

2.4 25.9 Turn right (E) on Fiddlers Canyon Road.

0.6 26.4 Pass a school on the left and turn right on the dirt road leading across an open field to a debris basin.

STOP 7 – HOUR PROBLEM: DEBRIS FLOW. At this location, a large debris basin has been constructed to protect the structures downhill. Debris flow deposits are clearly exposed in the channel walls feeding into the basin. One of the goals of this stop is to help students distinguish between in-place residual soils (clast-supported, single rock type, exposed on the low ridge to the south) and debris flow deposits (matrix supported, multiple rock type). Additional goals are to introduce them to the ideas of debris flow morphology and debris flow hazard mapping and zonation. They are presented with the following tasks:

1. Draw a rough sketch of the geomorphology within ¼mile of here.
2. Delineate different lobes of the debris fan and their sources.
3. Select a location for a building that minimizes debris flow hazards.
4. Explain how you selected this site.
5. Describe three ways to mitigate the debris flow hazard in this area.

6. Discuss three similarities between a debris flow fan and a delta.
7. Why does a delta have a better chance of becoming an oil reservoir?

MULTI-DAY PROJECT: CEDAR CITY MASTER PLAN. Students were asked to complete the following project in the vicinity:

In anticipation of northward expansion, Cedar City has hired you to delineate geologic hazards in an area north and northeast of town. For the region flanking the canyon mouths from Stephens Canyon to the canyon immediately north of Fiddlers Canyon, you are requested to do the following:

1. Prepare a GLQ map of the region.
2. Prepare a geologic hazards map of the region (anticipated hazards include the following, at a minimum: landslide breccia, landslide, rockfall, flooding, debris flow, collapsible soils, expansive soils, liquefaction, erosion, surface fault rupture, seismic amplification, aggregate resources, environmental contamination).
3. Zone hazards into low, medium, or high risk or other appropriate categorization. Provide descriptions of the characteristics of each category and cutoff values between categories.
4. Create five engineering geologic cross-sections (Dry, Stevens, Fiddlers, Fiddlers South and Fiddlers North Canyons).
5. Select the three best 1/16-section areas for your professors to buy.

You should map all undeveloped areas that are not fenced.

Here is your schedule for this project:

Monday – Map Dry Canyon (called Stephens on the topographic map).
Tuesday – Map Stephens (unnamed on the topographic map) and Fiddlers South.
Wednesday – Map Fiddlers Canyon and Fiddlers North Canyon.
Thursday – Complete any remaining field work.
Due Thursday noon – Drafts of maps and cross-sections.

You will work in groups on this project, but each student is expected to complete his or her own project report. Target length is about 10 to 15 pages of text, not including figures, tables, and appendices.

While the project at Green Hollow focused on engineering properties and facility siting, this project focuses on engineering geologic mapping and hazard mapping and zonation. The Genesis-Lithology-Qualifier (GLQ) mapping method used for the project is described in Keaton (1984).

Return to Main Street.

0.6 27.0 Turn left (S).

1.8 28.8 Turn right (W) on Coal Creek Road. Cross over I-15 (the road is now called Bulldog Field Road). Cross a bridge over an intermittent stream that is part of the distributary network from Coal Creek. Pass several gravel pits.

2.7 31.5 Turn right onto dirt road parking just south of one of the pits.

STOP 8 – HOUR PROBLEM: GROUND-WATER CONTAMINATION. This site is on the broad outwash fan of Coal Creek. As one travels north from the I-15 crossing, the depth to ground water increases: Bulldog Field Road crosses an ephemeral stream, then a gravel pit with water in the bottom, then a pit containing trees but no standing water, then the current dry pit. The students should be able to use these observations to deduce that Coal Creek and its distributaries are losing streams, which explains the increasing depth to ground water as one moves away from the stream. They are presented with the following questions:

1. What is a reasonable estimate of the depth to ground water at this site?
2. What direction does ground water flow?
3. How well does this material transmit water?
4. Why is there no water in this gravel pit and there is water in the gravel pits to the south?
5. Where would you put 4 ground-water monitoring wells to detect contamination from the garbage left at the north end of this landfill?
6. If the canyon mouth of Coal Creek has boulders 1-2 feet in diameter, how far away from the mouth would you expect to run out of sand-sized particles (2mm)?

Proceed South on Bulldog Field Road.

1.5 33.0 Turn right (W) on Kittyhawk Drive.

0.5 33.4 Turn left (S) on Airport Road, cross over SR 56 (the road is now called College Way).

1.3 34.8 Turn left (E) on Center Street, cross over I-15.

0.4 35.2 Turn right into parking lot on the northeast end of the football stadium (at 1050 W. Street)

STOP 9 – HOUR PROBLEM: FAULT RUPTURE. At this location, the concealed North Hills fault shown on the geologic map (Averitt and Threet, 1973) abruptly ends. It provides an excellent opportunity to query the students on how they might try to locate the fault in an urban setting. The background reading for the site is Christenson and Nava (1992). Students are presented with the following problem:

> The "State Harm" Insurance Company has decided to begin selling earthquake insurance in the Cedar City area. They will charge two premiums: a higher one for houses within 150 feet of an active (Holocene movement) fault, and a lower one for houses more than 150 feet away. For the area bounded by Center Street and 200 North, develop an investigation plan to determine the location and activity of the North Hills fault. Draw a rough map to show your proposed work. What other factors should "State Harm" consider besides proximity and fault activity?
>
> Will the nearby surface expression of this fault (in the Qal) be preserved in the rock record? Why or why not?

Proceed back (E) on Center St. to College Way.

0.4 35.5 Turn right on College Way.

0.4 35.9 Turn left (W) on SR 56.

4.0 39.9 Turn right onto Antelope Road (SR 253).

2.9 42.8 Follow Antelope Road to left (toward Desert Mound) when it forks.

1.9 44.7 Park on right (northwest) side of road, near mine tailings piles to north.

STOP 10 – MULTI-DAY PROJECT: EIGHTMILE HILLS RETIREMENT COMMUNITY. Students were asked to complete the following project in the vicinity:

> You have been contracted by Gordo y Flaco Developers to assist them in laying out the Eightmile Hills Retirement Community development. In their tradition of riding down each successive wave of industry, Gordo y Flaco, Inc. have purchased approximately 2500 acres of useless land and intend to create yet another retirement community in southwest Utah. Having once been burned by geological problems in their "Thistle Canyon Emu Farm," they want you to pay particular attention to potential geologic hazards and help them design around such hazards.
>
> The housing development will consist of the following structures:
>
> 1. 1000 single family dwellings. Prices will range from $100,000 to $400,000, and lot size will vary from 10,000 to 60,000 square feet,
> 2. 4 multi-unit apartment buildings, similar to the ones you are staying in,
> 3. an 18 hole golf course,
> 4. a swimming / recreation center,
> 5. green space with hiking and mountain bike trails, and
> 6. road and utility infrastructure.
>
> Here is what you are expected to do for this project (specific deliverables are underlined):
>
> Monday – Begin preparing <u>GLQ engineering geologic map</u> for site (based on geologic map and your field observations).
>
> Tuesday – Finish GLQ map, prepare <u>engineering soils map</u> (based on soil survey of area) and <u>geologic resource map</u> (potential aggregate, future mining areas, etc. that construction should work around).
>
> Wednesday – Prepare <u>geologic hazards map</u> (include earthquake hazard zones based on soil amplification and proximity to active faults), provide <u>recommendations for hazard mitigation</u>, <u>site zoning map</u> for potential construction (where each structure would best be located), and <u>map of water supply well locations and water storage facility location(s)</u>.
>
> Thursday – Complete any remaining field work.
>
> Due Thursday noon – Drafts of the 6 maps, including legends, and a one-page outline of your recommendations for hazard mitigation.

You will work in groups on this project, but each student is expected to complete his or her own project report. Target length is about 10 to 15 pages of text, not including figures, tables, and appendices.

This site offers three excellent conditions for an in-depth project. First, the students will find that although the geology is complicated, many of the rock units offer similar engineering properties and present similar hazards, so they may be conveniently grouped. Second, the students will find that subtleties in the topography of the valley area closely reflect geomorphic features such as alluvial fans, terrace deposits, and residual bedrock ridges. Third, the inactive mine and the mine tailings piles create substantial land-use problems for the students to plan around. The geologic map for the site is Mackin and others (1976).

Return to fork in road.

1.9 46.6 Turn left to proceed up other branch of road.

2.7 49.2 Turn right to cross railroad tracks and enter the Three Peaks area.

1.1 50.4 Park at a point where the Three Peaks are visible to the east and the outwash fans are visible to the west.

STOP 11 – MULTI-DAY PROJECT: THREE PEAKS ELECTRONICS RESEARCH AND DEVELOPMENT COMMUNITY. Students were asked to complete the following project in the vicinity:

A consortium of eight electronics industry companies has hired you to assist them in laying out the "Three Peaks Electronics Research and Development Community." The development is intended to provide living and working quarters, and infrastructure for approximately 2000 people who really want T3 internet access from their homes. The development area is outlined on the attached map and will consist of the following structures:

1. 1000 single family dwellings. Prices will range from $100,000 to $4,000,000, and lot size will vary from 10,000 to 100,000 square feet,
2. 8 multi-unit apartment buildings, similar to the ones you are staying in,
3. an 18 hole golf course,
4. a swimming / recreation center,
5. green space with hiking and mountain bike trails,
6. road and utility infrastructure,
7. a set of three 25-foot diameter geosynchronous satellite antennas. The antennas will be installed in a line trending magnetic north, 2000 feet apart, and at the exact same elevation. You are to site the array somewhere between elevations 5500 and 6000 feet. Each antenna will require a 20x20 foot pad which should be able to support 2000 pounds per square foot.
8. Four lab and research buildings with footprints of 300x1000 feet. The equipment in the buildings is very sensitive to movement and the buildings should be very stable. They will impose loads of 1000 psf.

Here is what you are expected to do for this project (specific deliverables are underlined):

Monday – Begin preparing GLQ engineering geologic map for site (based on geologic map and your field observations).

Tuesday – Finish GLQ map, prepare engineering soils map (based on soil survey of area) and geologic resource map (potential aggregate, future mining areas, etc. that construction should work around).

Wednesday – Field trip to Parowan Gap for Single-Day Project.

Thursday – Prepare geologic hazards map (include earthquake hazard zones based on soil amplification and proximity to active faults), provide recommendations for hazard mitigation, site zoning map for potential construction (where each structure would best be located), and map of water supply well locations and water storage facility location(s).

Friday – Complete any remaining field work.

Due Friday 3pm – Drafts of the 6 maps, including legends, and a three-page summary of your criteria for siting various facilities and your recommendations for hazard mitigation.

This project site is similar to the Eightmile Hills area to the south, except that the bedrock geology is more varied and the resulting engineering properties of the rock depend strongly on the specific underlying rock unit.

Return to the paved road.

1.1	51.5	Turn left and return to Cedar City.
10.0	61.5	Enter I-15 North.
3.0	64.5	Take exit 62 turn left under I-15, and proceed North on N. Minersville Highway (SR 130) towards Parawon.
13.1	77.6	Turn right (E) on paved road to Parawon Gap. Follow the road through the gap.
4.1	81.7	Park at the first sharp turn in the road.

STOP 12 – SINGLE-DAY PROJECT: PARAWON COAL MINE SLURRY POND. Students were asked to complete the following project in the vicinity:

> Because of severe energy needs throughout the country, the Southern Utah Energy (SUE) Corporation is investigating the feasibility of renewing underground coal mining in the Parowan Gap area. You have been asked to assess the geology and site a dam to create a slurry pond for settlement of waste fines from initial coal washing. The dam and abutment foundation should be strong, impermeable, and resistant to dissolution. The reservoir should readily hold water or require only minor treatment to hold water.
>
> The mining engineer and company economist have selected 4 sites for you to consider, based on piping and power optimization. These sites are as follows:
>
> Proposed Site A – Lower Coal Canyon
> Dam 100 feet high Crest at 5900’ elevation
> Proposed Site B – Upper Coal Canyon
> Dam 100 feet high Crest at 6100’ elevation
> Proposed Site C – Section 26 Canyon
> Dam 75 feet high Crest at 6175’ elevation
> Proposed Site D – Section 27 Canyon
> Dam 100 feet high Crest at 6000’ elevation
>
> At the end of the day, you should turn in a matrix table comparing the four sites and indicating your first choice. Items you may want to include in your table are geology and engineering stability of dam foundation and abutments, geology of reservoir pool, potential for leakage to ground water, topographic issues, proximity to borrow material, and geologic hazards and how they may be addressed.
>
> You are encouraged to survey the site and discuss options in groups, but each person will be responsible for producing their own assignment.

The complex structure of this area has produced faulting, dipping beds, and variable fracture density and weathering. The predominant geology consists of Cretaceous Iron Springs Formation sandstone at lower elevations (approximately 6000 feet) and Eocene Claron Formation conglomerates and siltstones at higher elevations. The authors’ analysis concluded that Site D is the least desirable because of large, deep, open fractures in the vertically dipping Iron Springs Formation. Site C shows similar problems in the Claron Formation, but to a lesser degree. Site A has better rock conditions, but is very broad topographically. Site B was both narrow and flanked by thick, intact rock units and was considered the most ideal of the four sites.

SUMMARY

Field exercises in geological engineering provide students with a chance to use their geologic knowledge to identify and address a variety of engineering problems. By scheduling a variety of both short and long projects, students are exposed to a wide breadth of problems, they focus on individual hazards in projects of limited scope before they are expected to address these hazards on a large project, and the variety helps maintain their interest and enthusiasm levels. The students rely heavily on published geologic maps, just as they will in their careers, and they learn to discern the accuracy, precision, and reliability of maps prepared by others.

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Home destroyed by a rock fall on October 18, 2001 in Rockville, Utah near Zion National Park